Learning from the Land

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Grand Staircase-Escalante National Monument
Science Symposium Proceedings 2006

U.S. Department of the Interior
Bureau of Land Management

The mission of the National Landscape Conservation System (NLCS) is to conserve, protect, and restore nationally significant landscapes recognized for their outstanding cultural, ecological, and scientific values.

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Grand Staircase-Escalante National Monument Science Symposium Proceedings

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Grand Staircase-Escalante Partners

Acknowledgments

The Bureau of Land Management would like to express its appreciation to all who participated in the second *Learning From the Land* science symposium. Many thanks to all who took the time to prepare and make presentations, as well as to those who attended sessions. The symposium would not have been a success without the involvement and support of various organizations, including Southern Utah University (Hunter Conference Center). Many people provided valuable assistance as committee members and field trip hosts, and with conference registration and other activities. Marietta Eaton orchestrated the event as Program Chair, Cara Mollenkopf served as Symposium Coordinator, and CZ Shelton acted as Publication Coordinator. Our sincere appreciation and thanks go to each one of you for your hard work. Thank you to Dr. David Willey for supplying the spotted owl photograph for the Biology and Wildlife section, and to Donald Rommes for allowing his photograph "Amber Waves Over Granary" to be used for the Archaeology section. And finally, thanks to Daisy Johnson for all of her hard work making this volume a reality – for compiling the papers, and designing and formatting this volume.

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Introduction

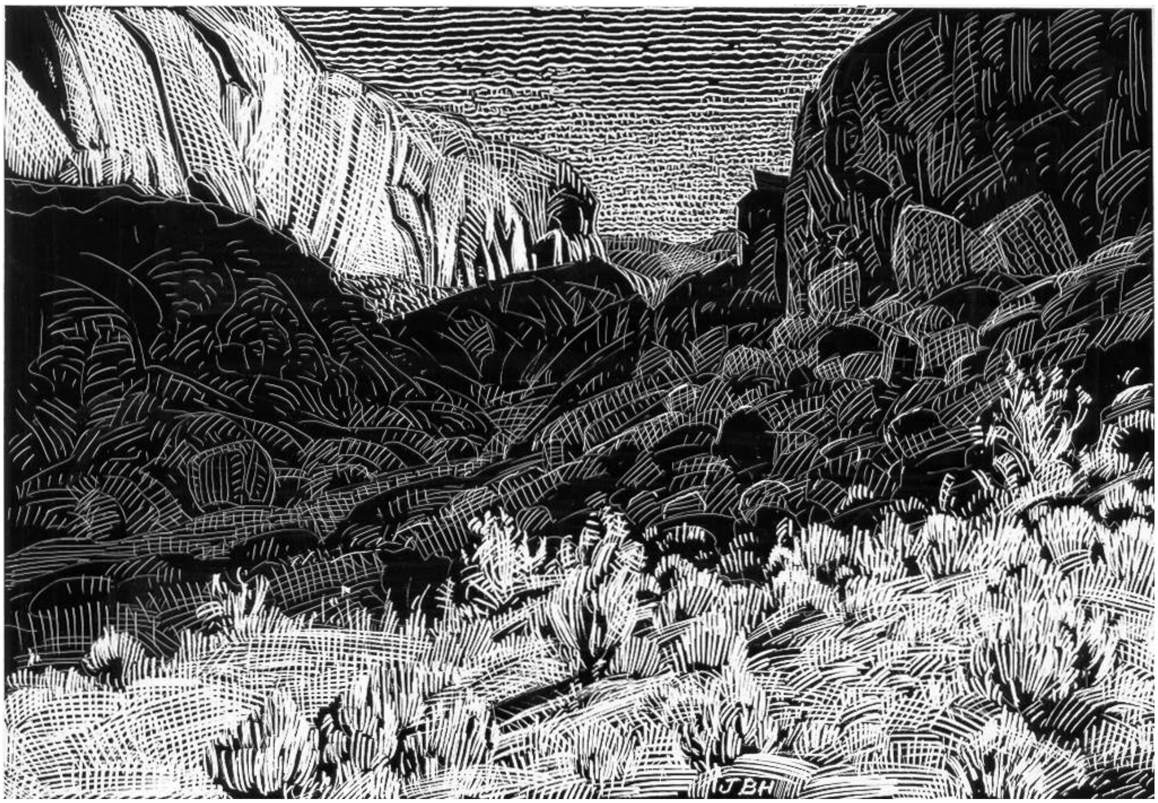
The Grand Staircase-Escalante National Monument's vast and austere landscape embraces a spectacular array of scientific and historic resources. This high, rugged, and remote region, where bold plateaus and multi-hued cliffs run for distances that defy human perspective, was the last place in the continental United States to be mapped. Even today, this unspoiled natural area remains a frontier, a quality that greatly enhances the monument's value for scientific study. The monument has a long and dignified human history: it is a place where one can see how nature shapes human endeavors in the American West, where distance and aridity have been pitted against our dreams and courage. The monument presents exemplary opportunities for geologists, paleontologists, archeologists, historians, and biologists.

President Bill Clinton, September 18, 1996

Established by presidential proclamation in 1996, Grand Staircase-Escalante National Monument in southern Utah was created through a dusty cloud of controversy. As the first national monument to be managed by the Bureau of Land Management (BLM) it came with new mandates to manage for scientific and historic values, a change in the traditional paradigm of BLM. At the time of designation, Grand Staircase-Escalante National Monument was not a well-known or well-traveled region of the United States. In fact, it had remained an unknown area. Maps of the region created by the scientific Powell Expedition in 1871-1872, presented the first documentation of this bastion of untamed landscape. The epic Mormon expedition that created the Hole-in-the-Rock trail memorialized harsh realities of the Utah desert. Isolation and solitude of this expansive country was memorialized in the evocative work of Everett Ruess who venerated its wild and rugged nature. The Monument's mysteries were explored by scientists working in this vast, virtually forsaken place. In 1997 the first *Learning from the Land* Science Symposium was convened at Southern Utah University with scientists invited to share what they knew about this extreme province and the secrets it had barely begun to reveal.

In 2006, a decade after designation, a second *Learning from the Land* Science Symposium convened to celebrate the discoveries of a decade and to validate purposes of the Monument. Controversy about the designation still lingered, but after the three day event, few could deny that the array of research, the profound discovery, and the coming together of diverse participants was anything but a resounding success, as can be seen from this eclectic collection of papers. From the inventories that revealed 648 species of bees in an extremely arid environment (46 of them totally new to science and 22 only known from GSENM), to the window opened into the late Cretaceous world of 100 million years ago and its newly discovered (and now extinct) inhabitants, to the use of the Monument as an analogue to understand Martian geology, to understanding human interactions with this landscape from 1500 years ago to the recent past, it is undeniable that this is a unique landscape with its own story to tell. We still only remain a small part of that story, and still only a small part of that story has been told. Within these pages is a glimpse of discoveries that await us and future generations.

Welcome



"Things are only impossible until they're not."

– Jean-Luc Picard –

Marietta Eaton
Science Program Administrator
Grand Staircase-Escalante National Monument

Welcome guests, dignitaries, colleagues, partners, and friends. Many thanks to the SUU conference center and to Vickey Myers' crew, as well as all the folks on the Monument who have been working hard to pull all of this together. So welcome, really welcome, I am so excited to be here. Ten years ago, more or less, we were doing something similar, so it's really fabulous to be standing up here and welcoming you. I am Marietta Eaton, the Grand Staircase-Escalante National Monument Science Program Administrator and the acting monument manager until next Monday!

I want to mention that we are really proud; we have partnered with Grand Staircase-Escalante Partners and have offered scholarships to students in the area and some of those students will be attending some of our sessions. If any of you are here yet please stand up; Megan McManus from Page High School, and students from Kanab High School - Leah Neumann, Sara Chapman, Ty Bunting, Morgan Livingston, Justin Powell, and Kelsey Barber. These students participated in an essay that was looked at by a number of people who decided on the best essay. They couldn't decide on just one so we thought it would be appropriate to have them all come, thanks to Grand Staircase-Escalante Partners.

Grand Staircase-Escalante National Monument, in partnership with the United States Geological Survey, Glen Canyon Natural History Association, and Grand Staircase-Escalante Partners, is proud to co-host the second Learning from the Land symposium, here at the Hunter Conference Center at Southern Utah University. This symposium celebrates a decade of science and discovery since the Monument's designation. Over the next three days, we are pleased to offer an array of papers and posters that will cover a broad range of past and ongoing research and social sciences at the Monument.

It has been a fascinating and out of the ordinary experience, from every perspective, for anyone who is interested in this landscape. Not just for the Bureau of Land Management, but for those who live, work, play, or even dream of wild places. So thank you very much for joining us in what will, hopefully, be a bridge for scientists, the public, and managers. This is an opportunity to better understand the treasures of Grand Staircase-Escalante National Monument and to attest to the values for which it was set aside.

Now that we have a better sense of the scientific potential, we must find the best ways to adapt our management based on what we've learned and to help us focus on what we still need to know. We have a couple of special events: this evening Grand Staircase-Escalante Partners are hosting an open house at Cherished Memories Bed and Breakfast at 400 W 175 N. Everyone is invited to come.Of course, our keynote speaker, Jayne Belnap, will be speaking at the end of this morning's session. And then Wednesday night we have a plenary session open to the public. Dr. Patricia Limerick and Craig Childs will be joining us at 7 o'clock. So without further ado I would like to introduce our associate state director, Gene Terland.

Gene Terland

Associate State Director, BLM, Utah

I believe in your agenda it indicates that Henry Bisson, our current acting State Director for Utah, is supposed to be here but something came up late Friday and so you're stuck with me. Otherwise, he sends his greetings and apologies.

I'd like to welcome everyone on behalf of Utah BLM to the second *Learning from the Land* Science Symposium. I thank each of you for attending. I'd also like to welcome our slate of dignitaries. We have Dave Hunsaker, past monument manager and currently deputy director for the bureau's National Landscape Conservation System. Seated next to him is Brad Exton who will, on Monday, become the current monument manager. Seated next to him is Jerry Meredith, former monument manager and former associate state director for BLM Montana.

Representing Utah's congressional delegation: Miss Marreen Casper, Director of Senator Hatch's southern offices; Mr. Bryan Thiriot, representing Senator Bennett; Michael Empey, representing Congressman Matheson. Seated next to him, state of Utah science advisor, Dr. Gregory Jones. Representing Kane County, Commissioner Mark Habbeshaw. And representing Garfield County, Brian Bremner. Down at the end, Jayne Belnap is going to be our keynote speaker from USGS. I thank each of you for taking time from your busy schedule to join us.

I'm proud to be here to celebrate the 10th anniversary of Grand Staircase-Escalante National Monument, BLM's first national monument. We'd like to consider it the flagship of BLM's National Landscape Conservation System. It's managed for multiple uses like grazing, fuelwood cutting, recreation, including OHV use on nearly 600 miles of open routes, and world class hiking opportunities, as well as scientific research.

You will hear over the next couple of days about the myriad of science efforts at the Monument. I think you'll be impressed with the world class science taking place. Now, however, in the words of Paul Harvey, I'd like to tell you the rest of the story.

The staff at Grand Staircase works closely with communities surrounding the Monument in planning for trails, beautification efforts, and rangeland restoration projects to improve the health of the land. This cooperation not only helps us in our efforts, but it helps support economic development in these gateway communities. The Monument counts among its many local partners: Kane and Garfield Counties, State of Utah Division of Wildlife Resources, Division of Water Resources, Division of State History, Department of Environmental Quality, and Utah Geologic Survey. Dozens of universities including: Utah State, Brigham Young, and Southern Utah University. Sportsman's groups like Federation for North American Wild Sheep and Mule Deer Foundation. Volunteer organizations include Glen Canyon Natural History Association and Grand Staircase-Escalante Partners - more than 80 different organizations.

In addition, we have partnerships with the Museum of Northern Arizona, Northern Arizona University, Yale University, Montana State University, Hopi and Paiute tribes, National Weather Service, NASA, and the United States Department of Agriculture - just to name a few. Projects range from developing better predictive models for flash floods to looking for tamarisk and invasive species on digital satellite images, and from ethnographic studies to pinion-juniper ecosystem work.

Education and outreach is another important part of our efforts at the Monument. A curriculum-based environmental education program was developed for school children based on national kindergarten through grade 12 education standards. These programs have been field tested with elementary schools from surrounding communities at Monument visitor centers and with high schools nationwide. A paid intern program for local high schools has provided opportunities for many students to be exposed to programs and projects in archeology, paleontology, wildlife, botany, and visitor services. Our Monument staff judges local science fairs.

Volunteers play a big role on the Monument. Volunteers help staff our visitor centers. They help prepare paleontological specimens for exhibits. They help build and maintain trails, document rock art sites, and participate in National Public Lands Day and Earth Day events.

Another group important to the Monument is the hundreds of thousands of guests who visit the Monument each year. To help serve them, four visitor centers were built, each focusing on a different scientific discipline. And that brings us back to science - the reason you all came here, our second *Learning from the Land* Science Symposium. Again, welcome, and I hope you enjoy the symposium.

Thank you.

Dave Hunsaker
Deputy Director
National Landscape Conservation System
BLM, Wahington D. C.

It's a distinct pleasure to be here. I have met many of you today, some of you for the first time, but many old friends are out there in the audience. I'll be around all week and I'll be in Kanab the next weekend as well. In fact, Friday I think, we have something going on in the community so I'll be there.

I'm pleased and honored today to be here with you. Having been gone from the manager's position for nearly six months now, it does my soul good to return to this place. I came to the Monument more than five years ago and was immediately struck by the realization that Grand Staircase-Escalante National Monument means many different things to many different people. A common thread is that all of us have an abiding love for the land and that we all continue to learn from that land every single day. Now that I'm in DC I see what a critical place the Monument has in the National Landscape Conservation System of BLM.

It's been ten years since the last symposium; ten years since we've stepped back from what we were doing, to see what we've accomplished and discuss what myriad challenges lay before us. The pace of new discoveries and scientific study in the intervening ten years has been nothing short of frenetic.

Gene went through a number of the things that we've been doing over the last ten years, and indeed it didn't start ten years ago. Science has been ongoing in this area, including the Monument area, for a very long time. But I'll go through a few of the really major milestones:

- Completion of an order three soils survey.
- Discovering the Mars connection to iron concretions found on the Monument and throughout the region.
- Inventories and strategies for dealing with invasive plant species.
- Human waste studies and impacts of human use in this environment.
- Establishment of a comprehensive, integrated real time system of weather stations and stream gauges.
- The most comprehensive data in BLM today on rangeland health.
- Completion of a three year comprehensive study on visitor characteristics, expectations, perceptions, and economic impacts to local economies and the region — you'll hear more about that this week from Dr. Burr.
- Completion of the four visitor and interpretive centers located in communities around the Monument to support economic development in those areas. That was nothing short of phenomenal — four visitor centers in five years. Ten million dollars of construction money on the ground.
- The visitor center in Escalante, both that community and BLM can be proud, receiving a Gold Leed rating. This is a rating for environmentally friendly constuction and operations of a building and is the highest rating in the government and the first one in the BLM's system. So you talk about progress, we've got it.

The Monument is an integral part of the National Landscape Conservation System and is acknowledged as a national leader in science. So I want to talk a little science with you. Not as a scientist, obviously, but as a public lands manager. I want to talk about the National Landscape Conservation System, science priorities, and strategies in the future. The conservation system itself is composed of nine types of designations, of which this national monument is one. The system is comprised of some 866 units nationwide. There are national monuments; national conservation areas; national recreation areas; wilderness study areas; national, wild, and scenic rivers; national scenic and historic trails; cooperative management and protection areas; a forest reserve; and outstanding natural areas. All make up what we refer to as the NLCS, America's newest conservation system.

All NLCS units were established by either presidential proclamation, or by legislation. The mission of the NLCS is to conserve, protect, and restore these nationally significant resources. Units of the system are found in states where BLM has a management presence. Ten states have a national monument or an NCA (National Conservation Area), or both. All states have a segment of a National Scenic or National Historic Trail, and wilderness and wilderness study areas are found in most field offices. NLCS is an integral part of the BLM, and science and research is alive and well within the NLCS. Scientific importance is a basic tenant for the proclamations and legislation establishing the units. BLM remains committed to science for applied and basic research, and for inventory and monitoring.

In canvassing NCA and monument managers, and other BLM conservation areas, we found that out of the 32 reporting units, 29 of those units reported over 300 science projects. The total on all BLM lands is much higher than that. Projects cover subjects including wildlife, ecology, archaeology, recreation, botany, geology, hydrology, and every other science subject under the sun. The highest number of projects obviously is within the wildlife, ecology, archaeology, and recreation arenas.

One unit alone, this unit right here that we're talking about today, at any given time has over 40 researchers and some 25 institutions involved. Science plays a pivotal role in helping us understand, plan, monitor, and manage the nation's natural resources. Benefits from a vibrant science program flow to the agency, to our partners, to the public. Increased knowledge, effective networks, information availability, and application to management actions are critical to maintaining and managing our public lands. Reliable, repeatable, peer reviewed, and defendable information is also critical to our efforts.

Combining the scientific and research communities enhances partnership opportunities with the private sector and with academia, and builds strong bridges. Increased trust from working together helps lessen perceived biases on sensitive issues and, frankly, raises our credibility. It builds public support for the agency, the units, and the system itself. It also raises awareness and increases knowledge about these very special places that lie on public lands.

So, what's happening within BLM's conservation units? Curricula have been developed — not only here, but in many other units of the NLCS. Programs range from elementary through high school levels at Red Rock Canyon National Conservation Area in Nevada, Santa Rosa and San Jacinto Mountains National Monument in California, Canyons of the Ancients National Monument in Colorado, and at the National Historic Oregon Trail Interpretive Center at Flagstaff Hill in Eastern Oregon.

BLM employees and volunteers at NLCS units have been judges at science fairs at local schools. Research on the unique grassland ecosystem and the high concentration of sensitive plant and animal species is occurring at Carrizo Plain in California. Raptor research has been occurring for more than 30 years at the Snake River Birds of Prey National Conservation Area in Idaho.

Grand Staircase-Escalante National Monument here in Utah has a permanent full time science program administrator on staff, coordinating an active science and research program. Of particular interest is the discovery of dinosaurs new to science.

The Forest Service's Aldo Leopold Wilderness Research Institute is the primary provider of wilderness-related research within the NLCS. Scores of other science projects are occurring throughout the system. We have scratched the surface, and I will say just barely. We have recently identified our science priorities in NLCS for 2006 and 2007. These national priorities are in four emphasis areas:

- Studies on resources referred to in each unit's enabling language.
- Studies that relate to BLM's management needs, especially monitoring and research, and assessing the effectiveness of restoration and mitigation efforts.
- Multi-disciplinary synthesis of research and data has application for use in all stages of the planning process, especially plan implementation.

- Efforts that link to other regional or national science initiatives.

Some examples of these priorities:

- Agua Fria National Monument in Arizona for archeological resources, primarily restoration and stabilization of pueblos.
- Cascade-Siskiyou National Monument in Oregon for reintroduction of fire in the ecosystem, weed abatement, and documentation of past ranching practices.
- Grand Canyon-Parashant National Monument in Arizona where there is restoration of native plant species in pinion-juniper woodlands to pre-1870 conditions, and erosion reduction.
- Upper Missouri River Breaks National Monument in Montana where we are assessing long-term effects of the vehicular road system on big game species, especially on winter range, and beginning restoration of native vegetation Monument-wide.
- Wild and scenic rivers where research is needed to support protection and enhancement of the values for designation including recreation, fish and wildlife, cultural resources, and water quality and quantity.
- National trails where research is needed including modeling of storage spring and intermittent stream resource capacity, and quantity and quality on the old Spanish Trail; identifying risks to linear trail resources under fluctuating rainfall regimes on the El Camino Real de Tierra Adentro; and studying vegetation and landscape using repeat photography and satellite imagery.

So what are we going to do about these opportunities? We continue to support field-based and coordinated efforts in our field offices. We are developing a long term science strategy that we will release this year. It sets our objectives for promoting natural and social science on NLCS units, for implementing a standardized process for conducting scientific research on our national conservation units, and for developing a process for sharing the knowledge gained from scientific inquiry.

In addition, we're working with the National Park Service who will host a science portal for BLM on the web to share research with scientists, local communities, the BLM and other agencies. This system will make it easier for us to accommodate and track research activities within the National Landscape Conservation System.

Finally, there is no way we can do this alone. That's where you and our other partners come in. Without you, we cannot hope to accomplish all of our goals. This is especially important in what we are currently doing in the field. It's absolutely critical. There are many roads to the future but there's only one route. And that's the route of partnership and cooperation. BLM's National Landscape Conservation System is America's newest collection of incredible places and these lands truly are landscapes of the American spirit. Thank you very much for inviting me to attend.

Brad Exton
Monument Manager
Grand Staircase-Escalante National Monument

Well, I am in awe already. I should probably sit down and listen to everyone else speak because I would learn a lot more about the Monument than by standing up here. As most of you know, I'm new; both to the Monument and to the agency.

I would like to welcome all of you to *Learning from the Land* 2006, the second science symposium since designation of the Monument. I wish I had had the opportunity to go to the first one. But this is very special for me to be able to come into this new position at the 10th anniversary.

I'd like to thank the co-hosts of the symposium: Grand Staircase-Escalante National Monument, USGS, Glen Canyon Natural History Association, and Grand Staircase Escalante Partners. I'd like to give a special thanks to employees on the Monument staff that worked hard at putting this together.

When Marietta asked me to speak, I was on my house hunting trip a few weeks ago. She said, "I have a slot there for you." My first reaction was "…Why? I'm not even a part of the Monument yet. In fact, I'm not even a BLM employee yet." So then I thought "hmm, okay" because I realized what we all have in common is love for that special, extraordinary piece of ground out there.

I remember back to my first trip to the southwest, back in the 70's, when I went on a backpacking trip in the Grand Canyon. That trip and the desert and canyon country imprinted on me. I continued to come back, year after year, to various places on the Colorado Plateau. Even when I was living in the Northwest and the Midwest I kept coming back. It got to a point that was addictive. I needed my red rock fix every year, so I would find an excuse to get back there.

And now, to be able to live and work in this, it's kind of a dream come true as far as my career. I can't even express in words, it's that important to me, and I'm excited about being here working with people on the Monument, and building relationships with local communities. I talked to Mark this morning and told him that he was going to see a lot of me. I hope we'll have a great relationship. But as I mentioned earlier, it's one of those things you dream about, you hope that will happen one time in your career, and it did, so I'm very excited about this opportunity.

I'm not going to stand up here and talk about science because I'm here to learn. I was amazed as I was reading some of the information in our report describing what has happened since designation of the Monument ten years ago. We've had over 150 funded projects. That just blows my mind. I come from the Forest Service and spent about 29 years with them and a little bit with the Park Service before that, and I have never heard of that many funded research projects.

The opportunity to do science as a basis for science, as opposed to support other resources is just fantastic. To see resource people and scientists working together, doing things that we can learn from in the future is very exciting.

I'm looking forward to the three days here. I think it's going to be very special and I hope I get the chance to meet all of you. Again, I'm honored to be selected for this position.

Gene, I appreciate your confidence in me. I'm looking forward to working with the folks on the Monument, the people that visit the Monument, and the communities around here.

Thank you.

Jerry Meredith

First Monument Manager
Grand Staircase-Escalante National Monument

I'm very excited to be here, I really am. Most of you are probably not aware, but I retired from BLM about a year ago so when they called, it kind of shocked me. I wasn't sure if they were after a token old guy or just wanted a perspective from someone who was here on day one. After all, since I'm retired, they don't have to be nice to me anymore. But I decided that I wasn't going to delve into the motivation. Maybe I didn't want to know. I was just going to accept the opportunity to be here and enjoy the experience.

It's a pleasure to see many of you that I've known for a long time and to be here in Southern Utah. It's a wonderful place. Those of you who, like me, have moved around a lot will recognize that. Those of you who live here and always have may not fully appreciate how spectacular Southern Utah is. Anyway, I want to thank the monument staff for inviting me. This is a wonderful event.

As you all know, this is the second *Learning from the Land* Symposium that Marietta Eaton has organized. More importantly, a lot of what Grand Staircase-Escalante National Monument's science program has become is a result of her work. And, I appreciate her very much.

I was in Escalante on the day after Grand Staircase-Escalante was designated a National Monument. I don't know how, but the Washington Office ran me down. Cell phone coverage wasn't great in those days but somehow they found me! I was summoned back to the Potomac and starting the next Monday spent an entire week in Washington meeting with more people than I can name. The whole thing is kind of a blur to me as I think back about it now.

A lot of people were surprised, and that included me. When I first heard the area was going to become a national monument and rumors started leaking out I began to wonder, since I was district manager at the time, if I was going to lose half of my district to somebody else or what?

I love that area and I had lot of personal attachment. When I was summoned back to Washington there were a lot of things they tried to clarify, but most of that is now fuzzy in my mind. But one thing was made very clear. That one point was not fuzzy, and has never been fuzzy. It was very clear to my mind and in the minds of most everyone that has served in the Monument. That point is that one of the primary responsibilities at Grand Staircase-Escalante is to foster a strong science program. And I think the monument has done a great job with that responsibility. The reports that you have heard from Gene and from Dave, spoke of not only what Grand Staircase has done, but also about the impact the monuments program is having throughout the National Landscape Conservation System.

I think it's critical to know that without designation of Grand Staircase, the NLCS system would have never had a chance to come together. Certainly, Grand Staircase is the cornerstone for that entire system.

I had an opportunity to talk to some people in senior leadership positions in the bureau as well as the Secretary and some of his staff when this system was being contemplated. I know the progress that the staff at Grand Staircase made in the first few years of its existence were essential for the rest of that system to come into place.

During my first visit back to DC after designation of the monument, it was made crystal clear there was to be a major emphasis on science. I was given a number of contacts of people who could help us implement that program, people in many fields from both state and federal agencies. Some of those people are here today, including Jayne Belnap. Another individual, who is not here today, was also critical to our program. That person is Tom Cassidovol who is currently the director of USGS. He and I were told in no uncertain terms that these two agencies needed to get our act together and become friends. Back in those days, as many of you know, USGS had a great relationship with the national park service, particularly after the park service science program was absorbed by USGS. The Fish and Wildlife Service and even the Forest Service were more closely tied to USGS than BLM. Frankly, there wasn't a lot of joint work going on between BLM and USGS. Tom and I were told that we were to change that.

So we got together and talked. We agreed that we needed to bring him and some of his staff up to speed on what resources were located within Grand Staircase-Escalante National Monument, what was going on, and what the place looked like. So we set up a field trip.

And this field trip, I have to tell you, turned out to be the best field trip I have ever been on in a 35 year career with the federal government. I had a ball. When you combine a group of USGS scientists with my senior staff and spend a week bumming around Grand Staircase-Escalante, it's like taking a group of kindergarteners to the park. They want to look at every stick and every rock and play with every bug!

It was just a great time for me. I had worked in Southern Utah before my assignment as District Manager. In fact, I started my career back in the 70's here in Southern Utah and worked for eight years as Public Affairs Officer for the Cedar City District. I had been back as District Manager for about a year and a half. But it brought a whole new insight to spend this week out in the field with these scientists. It opened a whole new view of what was out there and the potential. Then, shortly after that, the first *Learning from the Land* Symposium took place, right here in this room and the adjoining conference rooms. I spent a week listening to people report on research done in and around the monument. Talk about opportunities! If that first field trip opened the door to my appreciation for the opportunities; the first symposium turned the lights on behind that door.

That is why I am delighted to be here and see that there is a second *Learning from the Land* Symposium where you can report on much of what has been learned since then, and have an opportunity to share those results with each other.

There was so much enthusiasm on that first field trip. I referred to it like taking a bunch of kindergarteners to the park, and it really did feel that way. That's a good thing in my opinion. I love enthusiastic responses to any assignment. Enthusiasm wanes from time to time, but it can be rekindled. I hope that each of you will take the opportunity to rekindle your excitement during this symposium.

I'd like to talk about one aspect of the monument's designation, and its science program, that I think is even more important than the monument itself – even more important than the creation of the NLCS program within BLM.

In my opinion the creation of Grand Staircase-Escalante National Monument and the science program that it started created a renewed interest and reinvigorated the BLM's interest in science throughout the agency. Not just in NLCS units and certainly not in just Grand Staircase. I don't know how many of you are aware that shortly after Grand Staircase was created the Bureau started looking at the science program in many areas. In 2000, the old National Applied Resource Center, which almost nobody in BLM knew even existed at the Denver Service Center, was abolished and instead what is know today as BLM's Science Center was created.

It has grown to the point where there are now a hundred permanent employees dedicated to the sciences within BLM. They are not just working to gain scientific knowledge but they also focus on transferring that information to field units throughout the BLM.

Scientific knowledge is wonderful. But one of the things many scientists, if you'll forgive me, have not conquered, is how to get back to other people and how to share information. How to make sure that as many people as possible know about that information and understand the implications. I'm proud to say that is one of the purposes of BLM's science program.

Before I retired I was serving in the Montana/Dakota's BLM State Office. I was also chair of the BLM's National Field Committee. The Field Committee is an organization made up of all the state office Associate State Directors, and all the Washington Deputy Assistant Directors. These are the people responsible for day to day operations within BLM, and with making sure that the Bureau gets its business done.

Anyway, I bring that up to point out that the director of the Science Center also meets with BLM's Field Committee. During those meetings, the Field Committee receives regular reports on what the Science Center is up to so that they can filter that information throughout BLM. Perhaps just as important they talk about how BLM is going to integrate work at the Science Center into dealing with day to day problems. The Science Center director and staff are available to participate in management decisions recommended to the BLM Executive Committee.

I think these are critical changes. They change the entire complexion of how BLM does business and influences day to day operations throughout the entire agency. I'm also happy to report that over the ten years since Grand Staircase Escalante was designated, USGS and BLM have continued to improve the relationship between those agencies.

A few years ago, BLM and USGS started holding joint executive sessions about once every two years. The most recent one was hosted by Tom Cassidovol in Denver, Colorado. Senior executives from USGS and BLM get together and spend time talking about how to continue to improve the relationship between those two agencies and how to continue to emphasize the need for scientific information in the day to day operation of business by BLM.

In addition, the central region of USGS meets with one BLM state within its region each year and spends time in the field talking about critical scientific needs and research opportunities for partnerships not only between BLM and USGS, but many other partners that both agencies have in academia: universities and special organizations. It's a wonderful thing that takes place.

Just three years ago, that meeting took place in Colorado where they toured the west slope and then talked about the oil and gas boom in that area. They focused on how research could help. Then two years ago the BLM state office in Wyoming met with the regional office of USGS and toured some of their oil and gas development areas along with some coal mining areas of the state. During these trips they discussed the need for scientific information to improve decision making.

I am happy to report that one of the last official duties I performed with BLM was to set up a field trip in the Upper Missouri River Breaks National Monument for Tom and his senior staff to meet with BLM Montana/Dakota senior staff to talk about work going on there. I think BLM has made critical strides forward. They're incremental certainly and not any one can be considered a landmark, but it's important progress – progress started by Grand Staircase-Escalante National Monument and by the science program developed here at this Monument.

There's so much going on in each of your areas of expertise that enthusiasm is pretty high right now. But kindergarten students at the park eventually get tired. They eventually want their blanket, milk and cookies, and nap time. No matter what we undertake, or how high the enthusiasm, everyone needs an opportunity to rest, step back, and restart the enthusiasm before we can go on again.

I think it's critical that you're here today at the second *Learning from the Land* symposium so you can reinitiate that enthusiasm here in this monument. You are not just here as leaders locally, you're looked at as leaders in the NLCS system, as leaders throughout BLM. In fact, I believe the science program here at Grand Staircase is looked at throughout federal land management agencies.

What we don't know can hurt us. You all know that. Not everybody does, but you do. You're here in this room today to reinvigorate yourselves, to share information and to get going again on learning what we need to know. On reducing that gap between what we should know, and what we don't know. And to figure out ways to apply what we do know on the ground, in day to day management. I hope that you'll take this opportunity to rekindle your enthusiasm and rededicate yourselves to being leaders in the science program, not only in the Bureau of Land Management but in the realm of public land management in general. And I hope that you enjoy this week as much as I'm sure I will. Thank you very much for inviting me.

Marreen Casper
Director
Southern Utah Offices, Senator Hatch

I'm excited to be here today to see old friends. It's good to see Dave again. We've been able to work together on a couple of things and I'm looking forward to working with you. I did let the senator know that I was going to be here today and asked him what he would like me to say. He emailed me a little letter and I would like to read it to you:

"Dear participants, I am very pleased to know that you are holding this *Learning from the Land* symposium. Congress spends hundreds of millions of dollars each year towards university research on agriculture and natural resource issues which, for all intents and purposes, is a very expensive effort to learn from the land.

Usually the money is well directed and it provides us with a better understanding of our natural world.

In my heart though, I've always considered the true experts in this field to be the generation of farmers, ranchers, miners and citizens who have carved out a basic existence on the land. When your life depends on your natural world, you don't need an outside influence to teach you to respect and understand it.

Over the last decade, I have become troubled by a trend among public land managers who too often feel that they must make excuses for allowing rural economic activity to continue. Managers have so much to protect - watershed, wildlife habitat, special soils, viewsheds. Sometimes they attempt to protect natural quiet and even the air space. That's a lot for land managers to have to deal with.

But I want to reiterate to you that the most important thing that you are managing or that you are helping to manage is the future of our rural way of life. It is in your hands."

And then he closes with "I plead with you, our public land managers, to consider the rural way of life a value that must be protected as well. I congratulate the organizers of this symposium and I hope that the land managers and the resource users can learn from each other as they learn from the land. Thank you and best wishes for today."

Bryan Thiriot
Field Representative
Office of Senator Bennett

Bryan Thiriot spoke on Senator Robert F. Bennet's behalf at the *Learning from the Land:* Grand Staircase-Escalante National Monument Science Symposium 2006. His comments are not included here per Senator Bennet's request.

Michael Empey
Field Representative
Representative Jim Matheson

I'm here representing Representative Matheson. He sends his greetings. He very much appreciates that fact that people are getting together to talk about science on the monument. He would like to be here but Congress is in session, which means the boss is doing what we've elected him to do. He is on the house floor this morning dealing with issues.

Congressman Matheson is particularly interested in the science symposium because he serves on the House Science Committee. He asked me to cover some of the things that the science committee has jurisdiction over. They actually have 13 areas, all related to non-defense federal scientific development - scientific research development, demonstration projects, science scholarships, National Weather Service, and National Science Foundation, which I know is important to many of us. Also science research related to environmental research and development, and then all energy research and development projects related to non-military energy development.

So he's very involved in science policy. He sits in committees and committee hearings related to science issues all the time. He is not a scientist and my background is in social science and that may even be a step down from political science. The congressman shares your interest in the sciences and the ground-breaking discoveries that happened during the time of the Monument.

Looking back over the history of the Monument and history of the land, we should first recognize native peoples who made discoveries that allowed them to survive there. Scientific investigation of the land to become the Monument probably began in the modern era when John Wesley Powell, during his second expedition down the Colorado River, made the decision to exit the river at Lee's Ferry, Arizona, and began mapping and exploration of the area north of the Colorado River, north of the Grand Canyon, the first real intent to scientifically document what was there.

Most of you know and are familiar with a famous geologist by the name of Clarence Dutton. He described the Grand Staircase as a huge stairway ascending out of the bottom of the Grand Canyon northward with a cliff ledge of each layer forming giant steps. I suppose if we had a test, many of you would be able to name those steps from the limestone of the Kaibab Plateau to the Claron Formation of Bryce Canyon. We are here to discuss and learn about the magnificent scenery and the discoveries and exciting things to be found in between. Those discoveries are of interest to this group and of interest to the congressman.

Grand Staircase-Escalante is of special interest in the areas of geology and paleontology. I know that those of you particularly interested in paleontology are recognizing that school textbooks are actually being rewritten because of discoveries happening on the Monument and by scientists working those areas in the monument. Other areas of scientific inquiry include archeology, history, botany, wildlife - I remember seeing the visitor center video out at Escalante with the excited person talking about a new bee species discovered and how significant that is in terms of both botany and wildlife on the Monument.

Of current interest is the story of how modern people interact with the land, the hydrology, climate, soil, and also social science - that is how we as people interact with the land. As the news people like to say, this is a developing story. That is part of the excitement of this conference. The congressman congratulates you for being here and for your participation in educational opportunities the Monument is providing. The ongoing developing story in science really is exciting and I appreciate the chance to be a part of it and to hear some of the discoveries and things that are happening.

Thank you.

Dr. Gregory Jones
Science Advisor
Office of Governor Jon M. Huntsman, State of Utah

To start out let me tell you that I'm from New Mexico. I spent my undergraduate and doctoral years in New Mexico, and I was born there - and no one called me and told me I could wear my bolo and boots. I'm a little disappointed I didn't get to come fashion appropriate. It is horrible as a scientist, wearing the suit and tie nonsense all the time, especially when I could have sported a bolo.

First, thank you so much for letting me share a few thoughts at this symposium. I did something when I said "yes" to giving a two or three minute, or twenty minute talk here. I did something really uncharacteristic for myself. I decided to dive in and find out what I was actually addressing, what I was speaking about - which is novel for me.

In doing this research, one morning I spent a couple hours on my laptop in the dining room looking up the work that has been done at Grand Staircase-Escalante National Monument, through the program and the talks coming up. I was there for about two or three hours, because there's really a lot of work out here. My son came into the dining room - he's about 10 years old just started playing football. He picked his helmet up while I was on the computer, and put it on backwards and said, "Hey dad, look." I looked over and thought, "boy what a knucklehead." And then it dawned on me - what do you expect from a 10 year old? Right? He hasn't been around long. He hasn't been in school long. He doesn't know much. Then it dawned on me that your effort here at the Monument is about 10 years old.

Now, if you scope the work that you've done, and the community you've built in those 10 years, it's really, really significant. Of course you know, science is collaborative and competitive. So I have to remind myself, my University of Utah lab was about 30,000 square feet, and you guys have two million acres, right? So if I normalize on space and lab furnishings, I think you guys could do some more work.

But more seriously, during my career, I have had the opportunity to work at some scientific powerhouses, both national and large foundation laboratories. And there's great lab equipment at these places, great buildings. I was in Japan a couple years ago and was introduced to a several million-dollar electron microscope that was just beautiful. And I asked the director of that microscope, which was about a year and a half old, "How many publications have come out of this microscope?" And he said, "Two." And that was probably eight million dollars worth of equipment and a beautiful lab. Two publications. And I thought "What does this lab have or not have, relative to other places I have been?" like Scripps and Los Alamos laboratories; and they certainly have great equipment. But more importantly they had community. So these scientific hot spots were all about community.

So, to look at value and work and what has been accomplished and the information produced; it's all about community. It is not about buildings, it is not even about the land. It is about community, and in ten years you have built a community that is extremely significant. So as I appreciate the land and the Monument and the Antiquities Act and all that goes into the research here, it really has been the foundation that is most notable. And what I think you should remember to celebrate during these three days is the community you have built.

There is over one hundred, maybe a couple hundred people here, all focused on science discovery at this national monument. And discovery happens in communities. That is the essence of science - the community you put around research. So mostly what I wanted to offer today is congratulations for the community you have built. Congratulations to that, and celebrate heartily for this ten-year anniversary.

Thank you.

Mark W. Habbeshaw

Kane County Commision, Chair

The GSENM and Kane County: An Evolving Relationship

(PowerPoint Presentation)

Good morning. I want to thank Marietta for including a local perspective in this seminar. I think that's important and I appreciate that. And I appreciate your suggestion to not be afraid to talk about issues too. And I want to welcome Brad, and what I'm going to say to Brad this morning is a pledge of cooperation as we move forward. I want to welcome you to Kane County if you're able to participate in field trips on the Grand Staircase. You'll be going through Kane County. I'm obviously not going to talk about science, but I would suggest that you consider your science in the context of both history and politics.

What I want to talk about is an evolving relationship. A little bit of the demographics of Kane County: we're a small county, and the important thing is that the Grand Staircase takes up about one half of Kane County. We're left to deal with 4.4% of private property to eke out an economy.

That graphically illustrates the impact of Grand Staircase. Kane County is the lowest box, and Garfield is right above it. I think its 68% of the Grand Staircase that's within Kane County. To understand some of our economic issues, historically local residents relied on natural resources, mining, timber, and grazing. We have abundant coal and gas reserves. Most importantly are these significant coal reserves now locked up in what's called the Kaiparowits Coal Reserve.

We have no interstate, we have no natural gas, we have no scheduled air service, and we're in a remote location. Developing a sustainable economy is difficult. We want to rely on a diversified economy rather than tourism alone. There's an ugly picture of coal. I think that's the reason Grand Staircase was designated.

It was designated in '96 with a great deal of controversy. It withdrew almost 2 million acres from Southern Utah. The Utah delegation that's been mentioned wasn't included. And that process of designation, it was an event designated at the Grand Canyon in Arizona, not in Utah. And there was a congressional report titled "Behind Closed Doors: The Abuse in Trust in the Establishment of the GSENM."

There were subsequent legal challenges to the Monument by the Mountain States Legal Foundation and the Utah Association of Counties. After the Tenth Circuit decision against those two groups, Judge D. Benson, the newest district court judge, summarized the position best that presidents had virtually unlimited discretion to designate Monuments. There was no purpose in proceeding forward legally; we accept the designation of the Monument today.

When the Monument plan came out, it further created some local controversy beyond the designation. The primary areas in controversy are roads, grazing, water, and the primitive zone which is over half of the Monument and is managed very close to wilderness. This sign demonstrates a great deal of local attitude about some of the management, "The road may be impassable due to BLM and wilderness group's restrictions." That's not an official sign.

Regarding roads: management and historic uses of a road are all important. The Tenth Circuit recognized the road issue is one of the contentious land issues in the west. It's not just an issue between Kane County, Garfield County, and GSENM. The Monument's position, and I took the liberty of bringing this from the Monument plan, was basically that routes not considered necessary or desirable for resource protection purposes would be closed.

The county's position on the other hand was a reliance upon FLPMA and the proclamation itself which spoke of recognition of valid existing rights and that our county plan bases our county transportation system upon grants under Revised Statute 2477. There's current litigation to consider. SUWA v. BLM was recently dismissed. It ran from 1996 to 2006. It resulted in a Tenth Circuit decision that was very well reasoned and balanced use with protection needs and provides a great deal of guidance. Secretary Norton developed a policy based on this decision and it now applies nationally. The Wilderness Society filed a suit against Kane County; that case is pending. Kane County filed a lawsuit against Grand Staircase along with Garfield and Kane County Water Conservancy Districts. That case is pending. If we had not filed the case, we would have lost the ability to do so through statute of limitations. We filed it right at the end of the six year period.

We're currently in road negotiations with the Department of the Interior and BLM, Kane and Garfield counties. The county's goal is to resolve the controversy and develop a process recognizing existing rights, and of course road rights. Negotiations involve complicated legal issues. The main stumbling block is whether or not BLM can restrict traditional uses of roads established prior to revocation of RS2477 in 1976. We may require further legal resolution before we solve the roads issue.

The main issue is, "Can environmental organizations close allotments created under the Taylor Grazing Act through a mechanism of buy-outs, relinquishments and plan amendment action to retire the grazing allotment from grazing use?" This case is in court right now, and the ultimate decision will determine whether this practice of retiring allotments will continue or not.

Water appropriations, that's also subject to a lawsuit against the Monument plan by the Kane County Water Conservancy District. The general plan contends that diversions of water off the Monument will not be permitted and new developments have to provide some beneficial effect to the Monument. Of course that conflicts with state law beneficial use previsions.

The main evidence of why I'm here today is this right here: cooperation. And I want to thank Larry Crutchfield for his efforts in working towards cooperation. He kind of broke the ice and said let's quit fighting with each other and let's start talking. I want to thank him.

These are some of the areas where we have developed cooperation that the public is not aware of. The Commission's goal is to obtain economic and life quality benefits and I appreciate comments by the staff of the senators because it's right on the money with this goal. Benefiting from allowing multiple use of the Monument's resources is consistent with the proclamation. And our approach here is to cooperate fully regarding Monument management but we also have a judiciary responsibility to protect the county's property rights and interests under the law.

We respect the great discretion the congress delegated to land management agencies. They are our public lands managers. We are not. We do review planning actions for their compliance with federal authority and other lawful requirements. Commissioner Spencer sits on the Monument's Resource Advisory Committee and I'm the county's public land liaison representative.

The sheriff's department offers general law enforcement service, search and rescue responsibility, and assistance at anytime to both public land law enforcement and managers. And right now BLM and the sheriff are talking about a possible law enforcement cooperative agreement. The county travel council has a good working relationship with the Monument and we need to rely on destination tourism. Multiple day visits leave money in Kane County, whereas windshield tourists are in another part of Utah or in another state the next day. We also need diversified tourism and recreation for a stable economy.

The road department obviously performs road maintenance and repair within the Monument but most importantly, we've provided non-road project assistance. Just two examples: there was a seeding project and the forest service had to pull its equipment. We sent our road crew out and pulled the seeding equipment around for two or three days to finish the seeding project. The Paria movie set was just burned down, either by arson or by accident we don't know. We got a call from the Monument asking if our road crew could assist with clean up and we didn't hesitate to send them out. We also coordinate and support the Great Western Trail along county roads.

There's optimism for the future and I want to touch on that regarding road planning. Nonbinding determination, they're called NBDs, are basically recognitions of claims for land use planning. That's really all we need. We can't afford to go to court to resolve every road throughout the west. But the agency can look at our rights of way claims. If they administratively agree there's an established right of way, it's in effect for all land use planning. That would resolve the issue as a brand new policy; no roads have been recognized today. Several have been submitted, in fact several from Kane County, about eight, I believe. Another example is Hole-in-the Rock road. It's a two million dollar federal highways project the engineer from Garfield County got for us. It's been delayed for a couple of years now over the right of way issue. I think we could resolve that and move forward with an NBD solution.

Regarding grazing, the Grazing Rangeland EIS is about to come out any day. We don't know what the conditions are going to be. I understand you don't either. It's back in DC being reviewed; we're optimistic that it's going to sustain reasonable levels of grazing in the Grand Staircase.

Rangeland improvement projects: an example is the Five Mile Sagebrush Restoration EA and there are others. It's a proactive effort to restore failed seedings and decadent sage and I applaud BLM and I want to thank Karen Weiss for leading that. The concept of community-based ecosystem management is important. Two quick examples are cooperative agency status, primarily within the Grand Staircase Grazing EIS, and our Kane County Resource Development Committee which represents multiple interests throughout the community from geologists to environmentalists, which meets often with federal agencies.

Some principals: these are the lessons I've personally learned, and it is that we need to rely on early communications. If we have a problem, we need to talk to each other up front, and not let it fester and get involved in eleventh hour controversies. We need to develop interpersonal relationships and trust. If you have trust, then the issues you disagree on don't become controversial. We need to avoid creating media conflicts. And Brad, a little insight to you, be careful what you say to Mark Havnes. You'll read about it in the Tribune.

We also need to consider the other's needs. Often we come to the table to argue for our own position. We very seldom say, "What does the BLM," or conversely, "What does the county really need? How can I satisfy the other's needs in finding the solution?"

I enjoy field trips. We just did one with Karen, and I think they're absolutely magical. I can't tell you how many field trips I've gone on where we've argued up front, gone in the field and ended up agreeing. Again, THE TRUST, I've got it in yelling, capitalized, because it's that important to me. If we could trust each other, we won't have issues.

We need to first negotiate if we have differences, we need to second, litigate, but we need to avoid conflict and public controversy and I can speak to both of those two from personal experience. Again, we need to look at the other's needs and focus on what we agree on. We've talked a lot about, in this presentation and today, we disagree in areas, we agree in other areas, like the seeding program. Let's focus on that. Karen's made an effort not to focus on the roads rights of way issue and I think that's all beneficial. Tenth Circuit says we all need to be responsible for the common good. That's another really important point to me.

And last, the future, I don't know for sure. But this is probably my strongest message for today: We may strongly disagree on specific issues, but that does not mean we can't develop effective relationships. Effective relationships will depend on how hard we work at building cooperation; you have to work at building cooperation. It doesn't come by itself. And finally, the public deserves it for the common good. And I would submit that that common good is that special place called the Grand Staircase.

Thank you.

Brian Bremner
Garfield County Engineer

Marietta's never going to ask me to do anything ever again. First of all, I got the date wrong. Then I got the time wrong. And it looks like I got the attire wrong. It's interesting that I follow Mark because Mark is generally the calmer, wiser, and more timid of us.

With that said, I hope to lay a great burden on all of you in this room. First of all, I'm surprised at the number of faces I recognize. And as I lay that burden on, I hope you take it willingly. It is interesting to me the kinds of different tones you have heard from different people. Interestingly enough in my mind, you are the people that solve the conflicts. I believe in several things. I believe science and truth are inseparably connected. Either one you can define as the knowledge of things as they are, and as they were, and as they are to come. It is truth. It is also science.

I said to my boy as he asked something about science today, "Well you know, for a thousand years all the scientists thought the world was flat. You know, things change. We learn more. We don't know everything." Undoubtedly, with designation of the Monument, a change came. Rather than an extraction-based area, or a place where natural resources were taken off the land and used for the benefit of man and for the benefit of others, that changed. A lot of that was politically and not scientifically done.

The overwhelming thing I see as I attend RMP meetings and planning meetings is the lack of truth or science or knowledge that is available to make resource-based decisions. They just don't have it - don't have the time, don't have the money, don't have the data. You people in this room carry the burden of providing for the future, whether you want it or not. If we don't have good data, if we don't have good science, if we don't have the truth about what happens, we are subject to political whims. We are subject to plans that are poorly done. And we are subject to guessing. So I lay the burden upon you.

Number one: Make sure we have good science. Make sure we have the data we need so that as the land managers make their decisions, they are good decisions. Those of you that are my acquaintances, and I would like to believe my friends, have heard me say over and over, "95% of the time, what's good for the land is good for the road." I'm a county engineer, I deal with roads and 95% of the time, what's good for one is good for both. Not just roads and land, but one side of an issue, the other side of an issue, the nature, the people, the growth, the preservation.

And those few times that they're not compatible, we have the technology and the ability - if we can step beyond the politics, and actually use science and truth and cooperation - to find an answer. We don't do that all too often.

I have another burden I want to lay upon you. Personally, I want to thank the Monument staff, especially Marietta Eaton. Three days a year, Marietta Eaton is my wife's favorite person in the world because my wife helps organize a science fair. My wife cannot always find judges, and Marietta always comes through to help. To those judges, I'm going to lay a little burden on you. You're not there just to look at science projects. And you're not there just to support the community. You are there to take the spark that's in those kids and turn it into a flame.

If you have walked away from that experience without at least one kid changing sparks into a flame, you have missed your opportunity. They have little interest in science at that point. It is your job at that point to fan their interest.

I've got a story that I want to relate real quickly. Every time I come in this room, I'm irritated because they just have the pictures (motioning to the pictures around the room). They don't tell what they did to get there. It drives me nuts! I look at this gal in the red coat, and I thought, "I bet she was raised in Beaver or Cedar or Parowan and she was a cheerleader and she played on the volleyball team, and in the summer she changed sprinklers for her dad on their farm. And you don't want to wrestle with her because she's gonna win."

But that isn't why she's up there. Someone took that rural gal, and I'm making this up, but I know somewhere up there, these are people and somebody gave them an opportunity. The extraction industry we now have on the Monument is science. You're not going to get coal, you're not going to get oil, unless there are some major changes; we're not going to go back to those old days. It's science.

The best scientists in the world should be the people that live in Garfield and Kane County. I was amazed, and our reporter over there can remember it, weren't you amazed at what those Escalante kids knew when they announced the Hagryphus giganteus! They knew more about dinosaurs than I did! They knew it backwards and forwards!

My commissioners walked out of the first meeting and I said, "What did you think?" And they said, "Amazing, amazing, fantastic!" They were thrilled! The people in those counties need to be the best scientists in the world. You carry that burden, which means you don't take your data and run back to your lab or publish it in a magazine that we've never heard of, couldn't get, or couldn't understand even if we wanted to.

It means you've got to somehow communicate that information and data to the people that live here. And Senator Hatch said to consider those. I've kind of looked and as far as I can tell, there's five slots left on these walls. There are three over there and two there. I think those belong to Garfield and Kane County kids.

And as you deal with adults, parents, kids, schools, science, roads, conflicts, politicians, and everything, I hope you look at them and say, "Is that the kid that goes on the wall?" That's the burden we have.

It is amazing to me how much the political process makes poor decisions. I can tell you what will happen if we change administrations. Now, I'm not going to judge whether that's right or wrong. But I can tell you what will happen. And when we change back. I say there's a pendulum and when a Republican administration is in, it is on the right. And when a Democrat administration is in it is on the left. And the best decision is somewhere in the middle. Unfortunately it's the voting public that moves the pendulum across the top, and it never even swings through the good judgment in the middle.

And those of you who think about it and experience some of those things will recognize that's right. It is the science that we have to have, that we can go to those politicians and say no, this is the way it works. This is the science. This is the truth, and that's why we've got to cooperate. That's why we've got to work together. That's why we have to take it out of a voting situation and put it into a real live science situation.

That's a huge burden. Do you know what? You guys are capable. You can do it. Don't get discouraged. You're going to run into some obstacles that will make you think it will never be done. And if you give up your right, it won't be. You need to step forward and do what it takes to provide those opportunities for these counties and for the world to show how cooperation and science can make things right. I have confidence in you.

I won't read the story about Philo Farnsworth. Do you know who he was? He invented the TV, a farm boy of about 14 driving down, plowing the field. He must have been bored at the time. And he thought, "Gee whiz, I wonder if you can't communicate light as waves?" Born and raised in Beaver, he sold his patent to RCA in 1939. And that's why you guys have T.V.s.

That's the kind of people we have in these counties. You can help them; you can enlighten them; you can strengthen them. And I pray with all my soul that you and I do it.

Thank you.

Dr. Jayne Belnap

Keynote Speaker
Research Ecologist
United States Geological Survey

The Interplay of Science and Management

Dr. Jayne Belnap has been a scientist with the Department of Interior since 1987, and is currently with the US Geological Survey, Biological Resources Division in Moab, UT. She received two undergraduate degrees (Biology and Natural History) from the University of California, Santa Cruz in 1980; a Masters of Science (Ecology) from Stanford University in 1983, and a PhD (Botany and Range) from Brigham Young University in 1991.

Since then, she has worked for the US Geological Survey, focusing on how different land uses (such as hiking, biking, military training, livestock grazing, and energy exploration) affects the fertility and stability of desert soils and how these lands can be maintained in a sustainable fashion. She has also been researching linkages between soil organisms, soil nutrients and the composition of desert vegetative communities. This has led to the study of what factors make some desert communities susceptible to invasion by exotic plants, while others remain uninvaded. Dr. Belnap's studies have taken her around the world, including South and East Africa, central Asia, Siberia, Australia, and Iceland, advising scientists and managers on how to maintain soil fertility and stability in their regions while maintaining traditional land uses.

She also travels extensively throughout the United States, interacting with and training federal, state, and private land managers on best management practices for dryland ecosystems. She is the past Chair for the Soil Ecology section of the Ecological Society of America, President of the international Soil Ecology Society, is on the governing board of the Ecological Society of America, is a subject editor for the journals Ecological Applications and Ecohydrology, and participates in many other professional functions as well.

The two previous talks have me really thinking about roots and what they mean to me. My entire family spent all of their lives in Springdale, Hurricane, Rockville, and Cedar City. My great-great-grandfather founded Springdale, Utah, and my grandmother gave it the name Springdale because of all the springs there. My grandfather owned the general store, the movie theater, and the switchboard in Cedar City. So, when a National Monument was created in this area, it really tugged at these roots of mine, and I wanted to become involved because the area called so strongly to me. I was really surprised as I didn't even know the pull to this region was in my heart.

Before I delve into the science reasons for which the monument was created, I wanted to take this opportunity to talk about that pull of the landscape and how much it means to all of us. I have talked to many people here already, and as divergent as their backgrounds might be, there is a bond based on the love of this landscape. This gives us commonality that can allow us to work together. Certainly, everyone has different ideas about how to use this landscape and how it should be managed. But, I believe if we keep rallying around our common purpose, we will, in fact, find ways to move forward, despite conflicts over particular issues. Even the conflict, I think, is good. As long as we don't take the conflict personally, it gives us a huge opportunity to begin to understand other positions and grow and develop through that understanding. Thus, I encourage us all to keep the idea of this common bond in the back of our minds throughout this conference and to keep asking ourselves how we can use it to move forward.

I used to be a resource manager and am now a scientist, and thus I have a view of the issues that face both parties. When asked to give this talk, I was asked to discuss how to bring managers and scientists together. But, I think it is important to first back up a bit and discuss the mission of the BLM, the National Landscape Conservation System, and the Monument itself, including what the purpose of this resource is, how we are to manage it, what science we are supposed to be doing here, and what changes are needed so that scientists and managers can really communicate and work together effectively. One thing I want to point out immediately is that not all things that we call science fit under the missions of the BLM, National Landscape Conservation System, or the Monument.

BLM's mission is to sustain the health, diversity, and productivity of the resource. That sounds pretty straightforward, but you can fit many things under that mission. For instance, diversity is not just the number of species and subspecies one finds in a place, but also includes the genetic diversity found there. We need genetic diversity in populations because that confers species resistance and resilience to different types of disturbance. Diversity also encompasses diversity of ecosystem processes, such as nitrogen cycling, carbon cycling, fire cycles, speciation processes, and many other types of processes. Diversity can also occur at the landscape level. Landscapes, obviously, are a mix of different components but there's a diversity of smaller landscapes nested within the larger landscape, and those nested within even larger landscapes.

So what is "productivity?" Productivity is a very difficult term to define, and agreement on the definition is often difficult as it depends on one's point of view. To define productivity, we need to answer the question "Productive for what?" If you're a rabbit, you're going to see productivity in a very different way than if you're an eagle, a mouse, a cow, or a rancher. Thus, to consider and integrate all these points of view is a very hard job. What we do know is that productivity is not just how much grass is growing; it also includes the health and productivity of the conditions and processes critical for that grass to grow. This means concerning ourselves with the rates of the processes and the interaction among different processes. Part of productivity is also landscapes—their size, their shape, and how they connect with, and influence, each other. Productivity, therefore, is not just the amount of something but is a product of diversity and health that results in amounts of things. Also, having a high biomass of one or many species is not necessarily the most productive landscape. We need to consider the productivity of the entire system. Thus, productivity includes all the pieces of a system, including species mixtures, habitats and food for animals, and those processes that sustain those habitats and animals. It also includes the resilience of ecosystems to disturbance. For example, carbon storage, which is an important issue these days, depends on all sorts of processes. Examples include plant production, which depends on water and nutrient availability, which depends on climate, soil structure, stability, and fertility; decomposition of plant material, which depends on soil water, nutrients, temperature, and microbial and faunal community abundance, richness, and activity rates; and fire, which depends on ignition sources, the amount of fuel present, and climate.

Now we need to consider the National Landscape Conservation System Strategy. It says we need to know about resource condition, resource dynamics, and the mechanisms underlying those dynamics. This gets us to the meat of things, for to satisfy this strategy we need to know more than whether the ecosystems are productive and diverse: we need to understand why and how. This is a big mission, as there are many different ecosystems and landscapes out there. This is where science comes in, because you have got to have the science in order to understand the whys and hows of ecosystems. There's no way to do it without science.

And lastly, we get to the level of the Monument mission. The Monument is unique in that it has a proclamation that spells out in great detail what the Monument is about and lists the protected objects and foci for study. So let's talk about what science is needed in order to understand and protect these various objects. First are listed geological and paleontological resources. There is much we don't understand about these resources. For instance, weathering rates: what influences them and how do we conserve that process? Are there activities that alter the natural rates? The need to study the paleontological resources is obvious: what species existed here, what environments were present at the time they were living, what did they eat, etc. Then there are human prehistoric and historic sites; there is much to learn there about how those people lived and how we protect those resources.

The proclamation then goes on to list biological resources, in which there is a long list of objects identified. For example, the Monument has stunning elevational gradients that span five life zones. This is the perfect place to answer questions such as what controls plant distributions, soils or climate or an interaction between the two? If they are controlled by the soils, what's going to happen with climate change? Are the plants going to be able to move or are they stuck on that substrate? They may really be stuck there and that will have large implications for land management decisions. How will nitrogen deposition affect these distributions? Will ecotones shift with climate change? Which species will be able to shift with climate change? Will the pollinators be able to follow the plants or vice versa? Understanding these questions is going to be very important for protecting these elevational life zones. The presence of these gradients also results in a very high number of different plants and animals. This high diversity is really exciting for ecologists to study, and there are myriads of questions to answer. For instance, what is going to happen to the dynamics among communities and among the plants in a given community? We talked about sustaining productivity and health, and here is where we need to understand how one goes about that task. To do that, we need to understand the mechanisms underlying how the community functions in order to understand why future changes may occur. Did the changes happen because we did something? Did it change because of added nitrogen from power plants or cars? As it gets warmer and the cool system components begin to die out, we will especially need to know if the species are dying out because of management decisions or air temperatures.

Another topic discussed in the Proclamation is speciation. There are a huge number of endemic plant species in the Monument and the surrounding area due to what I call the Goldilocks effect. For speciation, you need a landscape that's not too big and not too small, as populations need to be able to be separated from each other by some, but not too much, distance. This balance allows for speciation. We need to understand what controls this process so our land management decisions do not interrupt this process, and we can follow the monument mandate to protect the process of speciation. We also need to address the question of whether these species are bound to the substrate where they occur. If they are, how will they be protected if the climate shifts or some disturbance, such as fire, increases and changes the suitability of the habitat?

Another wonderful science opportunity in the Monument are relict areas, where natural processes have been dominant throughout time. These areas are our best opportunity to show everyone what a given community looks like without an overriding influence of human activities. Thus, they can help us distinguish the difference between human-caused and natural change. These areas also enable us to see the potential for similar areas and provide a pathway for restoration efforts. We need to know what is possible before we try to accomplish it. That does not mean you necessarily manage for what is possible, but at least you know the envelope of possibilities. We also need these relict areas for monitoring future climate change. There are also relict areas in other areas on the Colorado Plateau, which allow for comparisons that will further understanding of natural areas.

The Proclamation also points out the importance of conserving unique, isolated communities like tinajas, dunes, and hanging gardens. To do this, we need to understand how they got where they are, what processes are important in keeping their integrity, and how future changes will affect them. These communities are a big challenge because they are very small and isolated and easily extirpated. Pollinators are also a big issue. We are losing many pollinators due to pesticides and herbicides, habitat destruction, climate change, and other factors. Many endemic plants are dependent on pollinators, even though they may be some tiny little bee or inconspicuous wasp. We don't understand much about them, and we know almost nothing about who pollinates what plants. Many of the pollinators in this region are new to science, so we don't even know the names of the species we are extirpating. Another huge question is whether or not pollinators and plants will be able to move together as climates get warmer. This is in terms of both flowering times and actual spatial shifts. If the soil is warmer sooner, many plants will flower earlier. However, that doesn't mean the pollinators will be able to come out sooner. If the plants move to another climate zone, that area may or may not be habitable by the pollinators.

Biological soil crusts also occur throughout the Monument. As with the other species we have talked about, we don't know what will happen to them as soils get warmer. We know these organisms are critical for soil stability and fertility, and we also know they are easily crushed by people, livestock, and vehicles. So another big question science needs to answer is where is the balance between using the land and preserving the important functions that these organisms provide? How does this balance vary with soil type or climate? Frankly, we just don't know. We need to understand this balance and how can we plan for it.

The study of packrat middens has been a key to past climates, helping us understand what plants used to inhabit these landscapes and what plant communities we might expect to see in the future. Therefore, we also need to conserve the ability of packrats to continue forming this record for future scientists by not overly disrupting their lifestyles with our land use decisions.

Then there are the raptors, large mammals, and predators such as hawks, eagles, desert bighorn sheep, mountain lions, and bears. We know so little about these animals!! We don't know how many there are, their habitat preferences, the status of the populations, or their movement patterns. We don't know how artificial water sources or roads affect the predators or the prey. We know very little about how grazing, recreation, or climate change will affect these animals, nor do we understand how global connectivity will affect disease transmission. We have an enormous amount to learn about large mammals and raptors.

In summary, a list of the big questions we will face in the future includes: What are the ecosystem changes we can expect in the future, which of them will be due to human activities, and which will be due to climate change? How will land use, nitrogen deposition, and climate change interact to affect ecosystems? And lastly, how can management respond so these resources can be used in a sustainable fashion?

So, what will the future bring? Current climate models predict that large changes will occur in this region. During this century, it is predicted that precipitation will decrease by 15–20%, and temperatures will rise by up to 4–6°C, if not higher. By 2050, increasing temperatures alone are predicted to increase evaporation, resulting in average soil moisture conditions in the Southwest being worse than the conditions experienced during any of the mega-droughts of this century (Dust Bowl years, 1953–1956 or 1999–2004 droughts). Increased warming is expected to decrease runoff in streams and rivers by up to 30% through the 21st century. Thus, while demands for water are likely to increase dramatically, the number and severity of droughts, caused by decreasing precipitation and increasing temperatures, will decrease water availability.

The severe and extended droughts that will accompany an increase in temperatures and a decrease in precipitation will affect all aspects of dryland ecosystems. For example, ecosystem processes that keep soil carbon and nutrients available will be slowed. Natural and managed systems will both be impacted. We expect to lose shallow-rooted species (e.g., soil lichens and mosses, grasses, some trees). Such alterations at the base of the food chain will reverberate upwards, reducing populations of animals that depend on the quantity and quality of these plants for food and habitat (e.g., small mammals), which will then impact their predators (snakes, larger mammals, raptors). Animals that depend on free surface water (e.g., amphibians, large mammals) will also be at risk. Domestic cattle operations depend on both grass and surface water being available, and thus will be heavily impacted. Insect outbreaks on drought-stressed plants will be more common and will likely lead to a dramatic increase in wildfires. Recovery after fire generally depends on water availability and thus is expected to be much slower than in the past.

In addition, increased surface disturbance, such as that caused by grazing, energy exploration/development, and recreation, will also reduce or remove the natural components that stabilize desert soils (live and dead plant materials, physical and biological soil crusts, rocks). This will enhance the already-increased soil loss that the loss of grasses and soil lichens will exacerbate. Surface disturbance also enhances the invasion of exotic annual grasses. In wet years, these grasses produce sufficient fuels to carry fire in dry years that follow. Fire consumes the vegetation and leaves post-fire soils exposed to erosion. In drought years, annual grasses do not germinate, leaving soils barren and vulnerable to erosion. A synergistic effect is created when surface disturbance occurs on invaded landscapes during drought years, and large amounts of soil can be lost from an area as a result. Increasing temperatures and decreasing precipitation also decrease soil and ecosystem resilience to land-use impacts, further increasing the frequency and magnitude of erosion events. Soil erosion results in lost soil fertility as nutrients are often attached to dust particles. Dust obscures visibility on highways and thus endangers travelers. The fine particles found in dust can cause respiratory disease if inhaled and can also carry Valley Fever. Dust also affects water storage and delivery. Most of the dust produced from the Colorado Plateau is deposited on the snowpack of mountains that feed the Colorado River. The dark-colored dust on the snow surface absorbs heat, which melts the underlying snowpack up to a month earlier than normal. Water storage in the snowpack is reduced, and thus the amount and quality of the later-season water is reduced. A faster melting rate can also mean an increase in flooding and less opportunity to store water in downstream dams.

Exposed soils are also vulnerable to erosion by water. As with dust, water erosion has both local and regional impacts. Locally, water erosion reduces the fertility of the soil and can alter which plant communities the area can support. Massive soil loss can entirely denude areas. Gullying can drop water tables too low for plants to access. Water erosion also increases sediment loads in streams and, ultimately, large rivers. As these sediments are often heavily laden with salts and heavy metals, they contribute to water quality problems downstream. Thus, both wind- and water-borne sediment is likely to severely exacerbate issues regarding the quality and quantity of the Colorado River water.

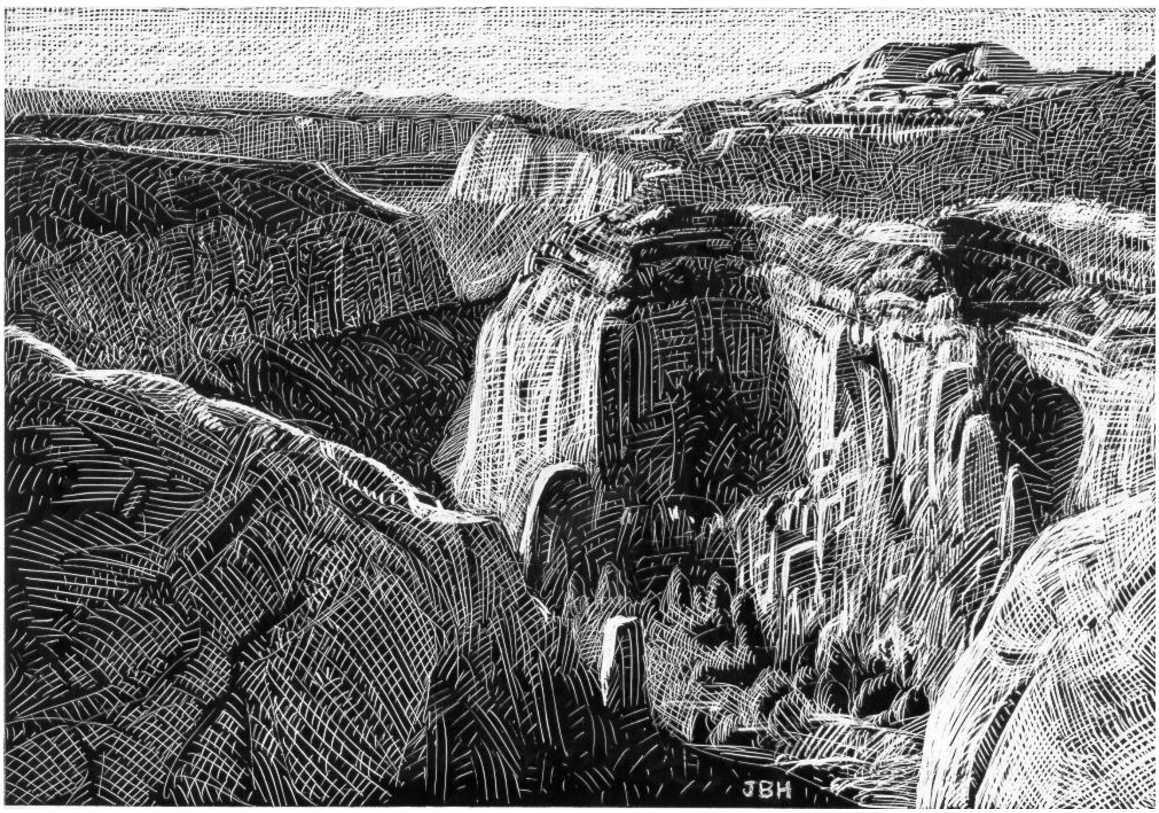
So what tools do Monument managers have to deal with these issues? Luckily, there are excellent geology, hydrology, and soil maps. There is a large network of automated weather stations. An assessment of rangeland condition has been done, providing a tool for deciding where to focus management and restoration efforts. There is also a network of long-term vegetation plots. However, although there are many resources available, other tools are also required. A systematic network of large exclosures, placed in each habitat and soil type, will be essential in distinguishing climate from human-caused change. Continued long-term monitoring of vegetation, soils, animal populations, and ecosystem processes is needed for all the major soil and vegetation types. Experimental manipulations that imitate future conditions can be very helpful in predicting what the future will bring. This will require scientists on staff and engagement of other federal and academic scientists as well.

This raises the question of how to get the science done and how to link the science to management decisions. This is going to require effort on the part of the scientists, managers, and land users. Scientists need to ask what science is needed, rather than assuming they know, and go to the field with the managers and users so everyone can share their perspective. Scientists need to think about how their results, and the implications of their results, can be used to better manage resources. They need to communicate their results more effectively by using language everyone understands. They need to provide interpretive materials and training. Providing training to staff on designing experiments, conducting monitoring, analyzing data, and interpreting results can help build trust and establish local expertise. And lastly, having scientists who work and study one place through time is essential in gaining true insight into that place.

Managers and land users have a responsibility in effective communication as well. First, having needs identified ahead of time can really help scientists understand what the issues are for each group. Managers need to be sensitive to the needs of scientists: most advancement opportunities depend on getting papers published, and this may require finding a different way of working together. Finding ways for the permitting process to be easy, quick, understandable, and reasonable helps immensely. Managers need to let scientists know upfront what they will be required to do, such as submitting a written report. And, of course, managers need to be welcoming of scientists and help them meet their needs if it is possible. Engage them on a personal level, let them know you appreciate their efforts, and invite them to come back.

Teamwork, of course, is the ultimate answer. Trust, respect, and clear communication will enable us to reach our common goal: maintaining the health of this incredible landscape. These things, above all, will determine whether or not the Monument will reach its full potential. We are all here because we hope this will be the outcome; I am here because I truly believe this can be the outcome. Meetings such as this are an essential part of realizing our common vision, so please take the opportunity to greet the person next to you, learn about their history and their dreams, and let us all work together towards the common purpose of loving and taking care of this extraordinary landscape that has been entrusted to us.

Plenary Session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Dr. Patricia Limerick

Plenary Speaker

Democracy and Conservation: The Interests of Posterity and the Clash of Well-Intentioned People

Dr. Patricia Limerick was born and raised in Banning, California and has been observing the West for many years. She received her B.A. in American Studies in 1972 from the University of California, Santa Cruz, and her Ph.D. in American Studies in 1980 from Yale University.

From 1980 to 1984, Limerick taught at Harvard University as an Assistant Professor, before joining the faculty at the University of Colorado at Boulder. At CU she teaches a variety of courses, both undergraduate and graduate, on the American West, as well as the introductory American history survey course.

She is a recipient of numerous awards and honorary appointments – State Humanist of the Year, 1992, from the Colorado Endowment of the Humanities; a recipient of the University of California, Santa Cruz 1990 Alumni Achievement Award; and Official Fool of the University of Colorado from 1987 to 2008. In 1995, she was named a MacArthur fellow.

Limerick has published a wide variety of books, articles, and reviews. Her best known work, *The Legacy of Conquest*, has had a major impact on the field of Western American History. In addition to numerous scholarly articles and book reviews, she writes frequent columns and op-ed pieces for *The New York Times, USA Today, The Denver Post, The Daily Camera,* and *The Rocky Mountain News.* Her recent books include *Something in the Soil* (a collection of essays) and *The Atomic West*, (in progress).

As an advocate for bringing academic knowledge into the community, Limerick has spoken to audiences as diverse as the American Association of Law Schools, the Bureau of Land Management Summit Conference, the Australian and New Zealand American Studies Association, the Mormon History Association, the International High-Level Radioactive Waste Conference, and a National Aeronautics and Space Administration conference on the future of space exploration. She has served on a number of advisory boards and committees; most recently the Board of Advisors for Ken Burn's and Stephen Ives's eight-part PBS series, "The West." In 1996, she served as President of the 5500 member American Studies Association. She currently chairs the Board of the Center of the American West.

Craig Childs

Plenary Speaker

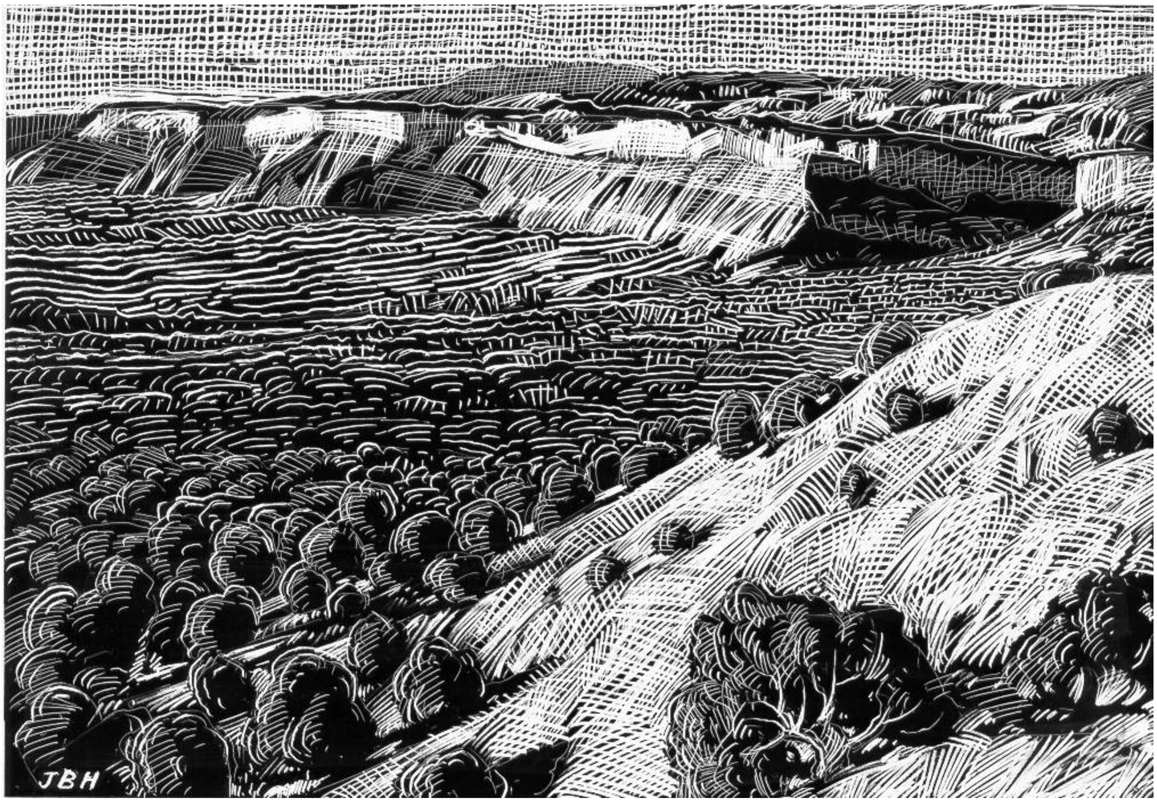
www.houseofrain.com

Craig Childs is a writer who focuses on natural sciences, archaeology, and mind-blowing journeys into the wilderness. He has published more than a dozen critically acclaimed books on nature, science, and adventure. He is a commentator for National Public Radio's Morning Edition, and his work has appeared in *The New York Times, Los Angeles Times, Men's Journal, Outside* and *Orion*. His subjects range from pre-Columbian archaeology to US border issues to the last free-flowing rivers of Tibet.

The expeditions Childs undertake often last weeks or months, informing his writing with a hard-earned sense of landscape and culture. The New York Times says "Childs's feats of asceticism are nothing if not awe inspiring: he's a modern-day desert father." He has been called a born storyteller by the New York Sun, and the LA Times says his writing is like pure oxygen, and "stings like a slap in the face." He has won several key awards including the 2008 Galen Rowell Art of Adventure Award, the 2007 Sigurd Olson Nature Writing Award and the 2003 Spirit of the West Award for his body of work, an honor he shares with Wallace Stegner, Terry Tempest Williams and N. Scott Momaday. Childs is an Arizona native, and grew up back and forth between there and Colorado. With a mother hooked on outdoor adventure, and a father who liked whiskey, guns, and Thoreau, his life was rigged from the start. In his teens, Childs began working as a river guide, and since then has held numerous jobs to support his field time, from gas station attendant to journalist to beer bottler. Now making a living as a writer, Childs lives off the grid with his wife and two young sons at the foot of the West Elk Mountains in Colorado.

Craig gave a personal narrative on the sand dunes of the Gran Desierto in Sonora, Mexico. The talk was based on his extensive foot-treks across the region, an area comprised of approximately 4,000 square miles of sand. The source of the sand is the Colorado River Delta west of the dunes where prevailing winds have carried sand across the desert. His talk focused on both the primacy for water in a parched landscape (both its presence and its absence) and how that landscape is essentially formed by water (the substrate having arrived via the Colorado River and its tributaries). He concluded by offering a bag of sand from the region for participants to feel.

Overviews & Partnerships



"To borrow a term recently coined by mathematicians, the landscape is 'fractal;' no matter how closely you examine or how thoroughly you explore it, its complexity remains infinite. You could spend a lifetime in the Escalante without fully exploring it; yet a single week there can exhaust the mind with its diversity, its fusion of the vast and the intimate."

– Ray Wheeler –

The Cultural Resources Program At Grand Staircase-Escalante National Monument, 1996-2006: An Overview of Accomplishments

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Archaeologists and cultural resource specialists at Grand Staircase-Escalante National Monument are fortunate that the Monument emphasizes its science programs and research to a greater extent than most other federal land management agencies. As a consequence, the Monument has a notable list of scientific accomplishments that BLM can be proud of, and that we should bring to public awareness whenever possible. Some of the program accomplishments, archaeological research, and related products that we would like to highlight include:

Publications and Professional Presentations

In-house Research and Publications

GSENM archaeologist Douglas McFadden worked for BLM for more than twenty years before his retirement in 2005. For the past three decades he and a handful of other southern Utah archaeologists have worked at the forefront of Virgin Anasazi research, and lately more emphasis is being placed on questions concerning Virgin Anasazi/Kayenta Anasazi/Fremont interactions. While many research projects have been oriented towards questions regarding the Anasazi and Fremont, other studies cover other aspects of the archaeological record. Some recent publications and professional presentations from GSENM archaeologists include *Virgin Anasazi Settlement and Adaptation on the Grand Staircase* (McFadden 1996), *Fremont Settlement in the Upper Escalante Drainage* (McFadden 1997), *Formative Chronology and Site Distribution on Grand Staircase-Escalante National Monument* (McFadden 2000), *Who's Who on the Monument? Virgin, Kayenta and Fremont Relationships* (McFadden 2002), *Tank Hollow Burn Inventory: Settlement Patterns and Agricultural Strategies on Fiftymile Mountain* (McFadden 2003), *House Rock Valley Inventory: Pleasant Valley Outlet Tract* (McFadden 2004), and *Who Broke the Glass on the Staircase?: Obsidian on Grand Staircase Escalante National Monument* (Zweifel 2002).

Scientific research by GSENM staff is an ongoing program. Subjects of current studies include the productivity of Anasazi agricultural plots, additional studies regarding distribution of obsidian on GSENM, effects of grazing-related activities on archaeological sites, rock art stabilization, and overall site distributions, to name only five topics.

Research and Publications by Non-BLM Archaeologists

Although the Monument has an active research program of its own, GSENM is a large land mass with unlimited potential for anthropological and archaeological research. This quality is readily recognized by outside researchers, and GSENM staff promote outside research as often as possible. Since designation, several different universities and researchers have taken advantage of the Monument's potential. The result is a significant series of scientific reports and publications. A partial list includes *Human Landscape and Prehistoric Paradigms, A Class I Overview of Cultural Resources in Grand Staircase-Escalante National Monument* (Spangler 2001), *Archaeology of the Dead Raven Site* (Walling and Thompson 2004), *Pithouse Excavations at the Park Wash Site (42Ka4280)* (Ahlstrom 2000), *Kaibabitsinungwu: An Archaeological Survey of the Kaiparowits Plateau* (Geib, Collette, and Spurr 2001), and *Archaeological Excavation at Deer Creek Shelter (42Ga3128)* (Talbot et al 2002).

Beginning in 1999, GSENM worked with archaeologists from Brigham Young University (BYU) and Northern Arizona University (NAU) on a series of excavations and large area surveys in the Escalante River vicinity. These projects resulted in a complete archaeological inventory of the Escalante River canyon within GSENM, as well as inventories covering large portions of the Escalante uplands. These inventories and associated excavations, several of which were run as BYU Archaeological Field Schools, resulted in better understanding of the complex time period when Anasazi and Fremont were coming into contact just prior to abandonment of the region by these agricultural groups. A series of high-quality reports by university staff members and graduate students detailed results of these projects on an annual basis. These reports are a major accomplishment, and stand as basic archaeological texts of the Escalante area for decades to come.

Other Projects and Accomplishments

Other projects and reports of note include *Ethnographic Assessment of Kaibab Paiute Resources in Grand Staircase-Escalante National Monument* (Stoffle et al 2001), and the upcoming *Hopi Ethnographic Overview for Grand Staircase-Escalante National Monument* (Bernardini, in press). Both of these ethnographies were commissioned by GSENM in an effort to facilitate the ongoing Monument Tribal consultation program as well as to gain a better understanding of current and past Native American concerns. Additional ethnographies are planned with other Tribes who have an interest in GSENM.

Public education and interpretation are a major focus of the GSENM cultural resources program, and over the course of the past ten years dozens of presentations and field tours have involved well over 1,000 members of the public. Two GSENM visitor centers focus on subjects of local anthropology and archaeology, using case studies of GSENM history and prehistory to illustrate important concepts. GSENM archaeologists work in conjunction with other agencies as needed and/or as opportunities arise. GSENM archaeologists recently completed burial recovery excavations in conjunction with the Utah State Historic Preservation Office, and have assisted with projects for the Kaibab Paiute Tribe and Kaibab National Forest.

GSENM, in cooperation with the Utah State Division of History, participates in the Utah Oral History Program, designed to capture and preserve the memories and histories of local long-term residents. More than 200 such histories have been documented thus far, recording a vanishing time in early 20th century America. The documentation of GSENM area historic inscriptions ("cowboy glyphs" or "historic signatures") records the presence of individuals based on inscriptions left in rock faces throughout the canyons of the vicinity, and helps document historic trail systems that are, today, largely unrecognizable.

Research by both in-house archaeologists and those working from outside entities are developing new theories and pictures of GSENM area prehistory. For most of the past five decades the world of the Virgin Anasazi was largely unknown, and what little information was available came from a small handful of sites investigated by an even smaller number of professional archaeologists. Under the influence of McFadden and a few other local archaeologists, as well as current GSENM archaeological staff, interest in Virgin Anasazi prehistory is flourishing. The creation of GSENM is facilitating additional research into all aspects of GSENM prehistory and history; this will be one of the Monument's greatest legacies.

From Research to Education: A Case Study of Research on Grand Staircase-Escalante National Monument and Subsequent Interpretive Exhibits and Environmental Education

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Editor's note: Oral transcription

ABSTRACT

Interpretive exhibits developed for four new visitor centers surrounding Grand Staircase-Escalante National Monument (GSENM) provide a foundation for environmental education studies, and are based upon research, studies, and natural, cultural, and historic resources on the Monument. Elementary and high school curriculum developed for students and teachers meet Utah, Arizona, and national standards. Exhibits and educational programming emphasize the diversity of scientific research on GSENM, and how much we still do not know.

Exhibit topics include paleontology at the visitor center in Big Water, geology and archaeology in Kanab, human geography (how the landscape shapes human life, namely Paiute Indians and pioneers at contact) in Cannonville and ecology (flora, fauna, and soils) at the Escalante Interagency Center.

Primary learning objectives include: sharing how and what we currently know about GSENM; encouraging critical thinking and understanding and applying the scientific method – all through the use of scientific examples and studies relevant to GSENM.

Keywords: interpretation, environmental education, exhibits

Shelton

Soon after designation of Grand Staircase-Escalante National Monument (the Monument), congressional appropriation directed construction of four interpretive facilities in gateway communities. This key concept to the National Landscape Conservation System specified that facilities would not be built within boundaries of the Monument, but in surrounding communities. The GSENM Presidential Proclamation set the tone for what those visitor centers would become. The Monument Management Plan (MMP) specifically directed visitor centers to emphasize and interpret scientific research on the Monument.

In 2001 we began exhibit design in earnest. We structured a design-build exhibit contract for four new facilities, scheduled for completion in 2005. Building construction slightly preceded exhibit fabrication. Our exhibit budget was $2 million. We stayed within budget and completed the job on time.

Four of the five facilities are operational; Glendale is slated for completion in 2009. Each visitor center interprets a different story, focusing on the unique resources that helped establish the Monument. At the visitor center in Big Water, we interpret paleontology; in Kanab, geology and archaeology; at Cannonville, human geography, the story of Paiute Indians and pioneers and how they used the same landscape; and in Escalante, ecology, including flora, fauna, and soils. At Glendale, a picnic area and outdoor exhibits will inform visitors about regional recreation opportunities.

Knowing that science and education were key components of our interpretive exhibits, we engaged a unique design team. Typical members were present – exhibit designers, fabricators, and interpretive experts. We also brought on scientists, artists, and educators to provide expertise and perspectives to the interpretive design process.

Reviews by BLM Monument staff scientists throughout the process assured that exhibits were accurate. We wanted our exhibits to provide a foundation for future learning, to be a jumping off point – a means rather than just an end. Rather than being a "brain dump" of facts, we wanted to challenge our visitors and students to realize how much we still do not know about the Monument. This in itself is an ideal opportunity and key motivator for students, as we believe that an inquiring 6th grader could be the future scientist to find a new botanical species or discover a dinosaur yet unknown to science.

In this case study, we focus on one visitor center exhibit in particular. We wanted to interpret real science on the Monument, in particular, an excavation to highlight archaeology. This required selecting a site where the principle investigator, GSENM archaeologist Doug McFadden, would be involved throughout the entire design and review process. He suggested we select the Arroyo Site just east of Kanab, UT.

The site had been excavated; there were thorough reports written, photographs and cross sections available, and good illustrations for exhibit fabricators to develop an accurate, three-dimensional, representational exhibit. Doug had engaged students on field tours, so we knew the site was successful in terms of teaching the methodology and techniques of archaeology.

This resulting exhibit at the visitor center in Kanab is a nearly full-scale model of the Arroyo Site excavation (Figure 1). To depict more complex concepts like dendrochronology (tree ring dating), we included supplemental detailed exhibits. We show how a wooden house beam in the

Figure 1. GSENM archaeologist Doug McFadden inspects the excavation exhibit at the fabricators' workshop, assuring that every detail accurately depicts the actual archaeological site.

excavation – in context – could produce a wood bore, then be scientifically dated to provide valuable information about the place, climate conditions, and people who lived here long ago.

A major difference in our exhibits, particularly in archaeology, is the focus on context. Many museums interpret artifacts themselves. A primary exhibit objective emphasized that where things are found undisturbed, or "in situ," is more important that the object itself merely sitting on a shelf. We include messages to discourage looting and note that it is illegal.

To emphasize the importance of interpreting context and attempting to analyze this place that people lived nearly a thousand years ago, we brought an interpretive artist to the site. Linda Feltner spent several days in the field with McFadden to recreate a three-dimensional mural, to scale, of the location where the excavation took place. For example, in the 8' x 24' mural you might see an Ancestral Puebloan person chipping chert to create arrowhead points (Figure 2). This would correlate to the actual location at the excavation site where archaeologists found a lithic scatter. The artist attempted to be as true to the real place as possible. The mural recreates - based on artifacts

Figure 2. The 24′ mural at the GSENM Visitor Center in Kanab, drawn by an interpretive artist in the field, depicts to scale and in situ how an "average day" may have appeared with Ancestral Puebloan people engaging in activities inferred by archaeological excavation artifacts.

found and structures excavated - the actual setting. It tries to infer what a day in the life of the Anasazi people might have been like in 1100 A.D., at this particular site.

This visualization seems to make more sense to people when you tell "the rest of the story." For example, we have a ceramic pot with a warped lid. This is pretty exciting because I know, as a potter, I would have thrown it away since it would be useless for storage. Finding the remains of a pot like this leads us to deduce it was probably not far from the kiln where fired. From these kind of inferences we learn from archaeology and share knowledge and discoveries with people today.

Throughout our exhibits we examine and apply the scientific method, we look deeply at how one comes to conclusions, how we learn and about the process, rather than just providing facts and information. Scientists were involved throughout design, fabrication, and installation of all of our exhibits. We wanted to ensure they communicated their intent both artistically and scientifically.

We also developed a DVD presentation called Traces in Time. It is shown in our four visitor centers and used in schools for orientation before GSENM curriculum instruction. The film depicts scientists and local experts sharing their expertise about the Monument and includes numerous on-site interviews.

Another prominent exhibit in our visitor centers is a regional three-dimensional map (Figure 3). Made from a Landsat satellite image taken 438 miles above earth, this detailed photograph is laid onto a computer-directed carved closed-cell foam core base. With a magnifying glass people can find their houses - it's amazing.

The key point is that scientific investigation is a journey, not a destination. It's not the end-all answer to everything, but an ongoing process. In particular, we want to engage as many students as possible in this process.

Now I want to introduce Rachel Sowards, our education intern, who will speak briefly about our education program.

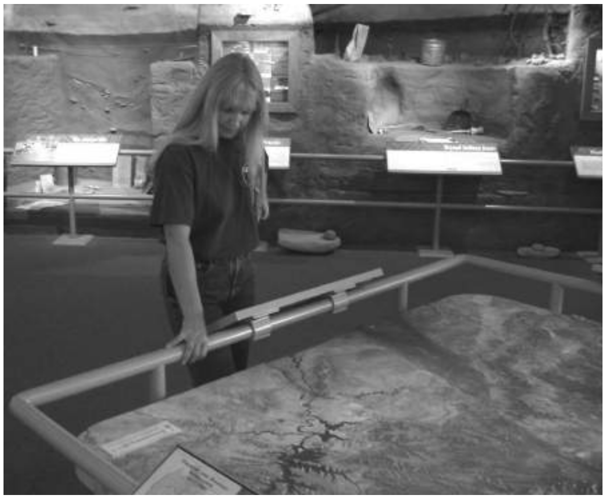

Figure 3. At the GSENM Visitor Center in Kanab, a visitor scans the 3-D topographic map with imagery shot from a Landsat satellite 438 miles above earth; in the background the archaeological excavation exhibit depicts a pithouse structure.

Sowards

Lets start with the management plan. It clearly addresses education and interpretation. It directs the Monument to provide opportunities for research and involve the public. The part I'm going to focus on is "The BLM will encourage researchers to incorporate a public outreach/ education component into projects. Educators and students will have the opportunity to participate in research activities where appropriate. The BLM will involve communities in science and education activities."

"The BLM will play a role in developing educational programs for grades Kindergarten through 12, emphasizing the area's scientific and cultural resources."

"The BLM will cooperate with colleges and universities in undergraduate and graduate programs as resources permit."

I was hired to develop elementary curriculum for the Monument. The educational materials target grades three and four, but can easily be adapted for older grades. At each of the four visitor centers I developed five activity stations where students rotate through different activities. Educational activities correlate with the exhibits, working well because these exhibits were created for educational purposes. There are pre- and post-activities for teachers to engage with their students, all linked to Utah, Arizona, and national educational standards. This is critical, because teachers are more likely to participate when non-traditional activities correlate with students' tests, what is being taught in the classroom, and required standards. At GSENM, we focused on Utah and Arizona standards since local schools would be more likely to come to our visitor centers.

For high school curriculum, we hired a contractor to develop lessons linked to national standards. We established a committee of local teachers and GSENM science staff to advise and test during curriculum development. They provided significant insight and guidance. High school lessons are structured to have two lessons for each theme, the same themes as in our visitor centers: archaeology, ecology, geology, history, and paleontology. There are also supplementary materials like field guides, binoculars, bug magnifiers, and samples. Teachers can check out the materials as needed and use them in the classroom.

To introduce our Monument curriculum, we offered a teacher open house at each visitor center during a week in April 2006. We gave teachers an orientation of the visitor center closest to their school, and described educational materials and resources available to them. In May 2006 we field tested the curriculum with sixteen local teachers, nearly four hundred students, and seven schools in the region surrounding GSENM. When completed, the high school lessons were field tested nationwide; we had thousands of kids involved. We received numerous comments from scientists and teachers.

Field testing revealed that many students and teachers didn't realize so much science and research occurred on the Monument. Teachers checked out the Traces in Time video to show their class, then followed it with a lesson pertaining to the subject they taught. One teacher said "The DVD Traces in Time is a good introduction to scientific research at the Monument. But students need the opportunity to meet with scientists and ask questions or use the interactive 'Ask the Experts' video at the visitor center."

We are working towards having scientists and our staff more involved with local community and schools, and have students visit the Monument on field trips. Right now our major project is translating the high school curriculum into an internet–based interface. Grand Staircase-Escalante Partners hired Daisy Ballard, a local college intern, this summer, and I worked with her on graphic design content for an internet web site. Glen Canyon Natural History Association Executive Director Chris Eaton helped us design the website, and GCNHA hosts it on www.gsenmschool.org.

I've worked with many teachers, and it's been great building relationships – scheduling field trips and speaking to students in nearby schools. The elementary curriculum I developed is for my Master's project at Utah State University which I finished this summer. I also attended conferences to inform teachers that we provide environmental education at the Monument.

So where is this going? We hope to have more training workshops where teachers can get involved, excited, and obtain credit for continuing education requirements. We want to have "kick-off" assemblies at the beginning of each school year and have our scientists share amazing discoveries. Hopefully that would set a tone whereby teachers would bring their students on field trips throughout the year.

With the great outdoor laboratory of the entire Grand Staircase-Escalante National Monument, plus labs in Kanab and Escalante, there exists unlimited opportunities for students and scientists to interact and become inspired. We intend to get students participating in more actual research. Local high school interns have worked with GSENM paleontologist Dr. Alan Titus and GSENM archaeologist Matt Zweifel on field and laboratory research projects, and gone on to college inspired by their work here at GSENM. That's where we see the education program going. Now I'll turn the program back to Carolyn to wrap it up.

Shelton

We developed interpretive exhibits at our four Monument visitor centers that thematically tie to the resources for which GSENM was established – archaeology, paleontology, ecology, geology, and history. We engaged an educator during the design process to assure the exhibits provided a solid foundation for educational curricula and studies. We also involved Monument staff and university scientists to assure accuracy of exhibits that engaged visitors in the wonder of science and authentic research. Our educational intern earned her Master's Degree from Utah State University, using the development of elementary education curriculum as her thesis project.

Our conclusion is that we have built the foundation for a relationship between scientific, interpretive and educational professions. Our goal is to engage countless students, educators, and visitors in actively learning and participating in real science. We also hope that increasing awareness of the nature of Grand Staircase-Escalante National Monument will lead to protecting this unique place in the American West.

Thank you.

A Decade of Science at Grand Staircase-Escalante National Monument

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ABSTRACT

Established in 1996 Grand Staircase-Escalante National Monument had as one of its major mandates a commitment to science. Over the last decade over 175 diverse science projects have been conducted with implications from the most locally specific to nationally, globally and universally significant. The wide-range of topics include: studies in geology with connections to Mars; discoveries of completely new species of dinosaurs and other prehistoric creatures; a complete Level III soils survey; hydrology studies in the Escalante River and Deer Creek; extensive inventories of invertebrates, amphibians, mammals and birds; extensive rangeland science assessments; biological soil crusts; restoration projects; widespread archaeological surveys and rock art documentation; over 200 oral histories; and social science projects related to visitor experiences and impacts.

Looking back over the last ten years this synopsis of the science program will highlight some of the projects and their management implications.

Keywords: science, management

Sustainable Architecture and Energy Pioneering at Grand Staircase-Escalante National Monument

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ABSTRACT

There are many different conceptions of green or sustainable building design due to the large scope of sustainable issues and the novelty of sustainable principles. Green buildings embody a design intent on balancing environmental responsiveness, resource efficiency, and cultural and community sensitivity. Green building design includes all players in the development process from design team (Owner, Architect, Engineer) and construction team (contractors, manufacturers, and waste haulers) to building occupants and maintenance staff. Green measures reduce negative environmental impacts, reduce operating costs, enhance building marketability, increase worker productivity, and improve indoor air quality.

The U.S. Green Building Council developed a consensus-based rating system that assigns values to various green building measures. The Leadership in Energy and Environmental Design (LEED) Green Building Rating System documents the green measures and awards certified, silver, gold and platinum based on performance.

The Escalante Interagency Visitor Center documented 42 approved points which corresponds to the LEED-NC Gold certification level under Version 2. This is BLM's first LEED rated building. GSBS Architects in Salt Lake City, UT designed the 13,000 sq. ft. building which includes science labs, exhibit areas, map and trip planning, a theater, public restrooms, conference room, individual and open office area. Measures taken to achieve the LEED Gold rating include a pervious parking paving system, low VOC paints, adhesives, and sealants, reduced water use and water recycling for toilet flushing, 8.22% recycled content in building materials, 54.8% local/regional building materials, and operable windows. The building uses 48% less energy than a base building through the use of increased insulation, evaporative cooling, and lighting controls. 11% of the building energy is generated by a roof mounted solar Photovoltaic system.

The BLM and Monument demonstrated its commitment to science, environment and community in achieving LEED Gold certification.

Keywords: sustainable design, resource efficiency

Positively Impacting Public Involvement on Federal Land in Southern Utah: A Case Study

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ABSTRACT

Recreational use of off-highway vehicles (OHVs) in the United States has rapidly grown, especially in the western U.S. Case study research was undertaken in southern Utah during 2005 to investigate two processes that dealt with OHV travel planning in 1998-9. These processes took place on the Dixie National Forest and Grand Staircase-Escalante National Monument. Unique to this study are the close proximity of the cases and the inclusion of individual stakeholders that participated in both processes.

This research relied primarily on qualitative analysis of interviews of 27 stakeholders to determine their level of satisfaction with processes and outcomes. Four research propositions were examined to understand what created perceptions of satisfaction (or dissatisfaction) among participants of the two cases. Data analysis showed that all four propositions were supported.

The proposition of authenticity attempts to take a management situation where levels of satisfaction are low, and transform it into something that can be built upon in future public participation. In addition to determining levels of satisfaction, interviewees were asked to suggest improvements to the management of motorized travel, along with suggestions for improving the public participation process in general. Future research could be conducted to address the validity of these findings.

Keywords: OHV, stakeholders, public participation

A Partnership in the Desert: The National Weather Service and Grand Staircase-Escalante National Monument

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ABSTRACT

The National Weather Service (NWS) and Grand Staircase-Escalante National Monument (GSENM) are engaged in an innovative and ongoing partnership. This goal of this relationship is to educate and provide forecasts to GSENM visitors with regard to the ongoing threat of flash flooding. GSENM is one of the most flash flood prone areas in the country, with ongoing threat from early May through late October. With many visitors traveling through the Monument, it is imperative they are informed of the latest flash flood conditions.

The NWS and GSENM teamed up to ensure that each visitor coming into a visitor center and traveling on the Monument understands the nature of flash flooding, and is aware of current flash flood conditions. The two agencies strive to ensure that each visitor has a safe and enjoyable visit, and if threat of flash flooding is present, they be informed in a timely manner. This process is continually evolving with the advent of new forecasting tools and improved understanding of flash flood science.

NWS forecasters regularly tour flash flood prone areas in the Monument to learn about their physical properties by GSENM rangers. This allows forecasters to understand the effects of intense rainfall and resulting runoff to selected areas of the Monument. Additionally, the NWS provides daily forecasts and if threat is present, flash flood watches, warnings, and advisories are advised and posted. To monitor thunderstorm activity and flash flooding in the area, the NWS utilizes data from the network of weather and precipitation stations located strategically throughout GSENM. On any given day, the two agencies share information and provide insight to safeguard against threat of flash flooding and severe weather.

The working relationship of these two federal agencies is a model for government cooperation and resourses sharing for the ultimate benefit of GSENM visitors.

Keywords: weather, forecasting, flash flooding, visitor safety, partnership

Teachers Learning from the Land: Utah's Biodiversity Experiences for Students and Teachers (UBEST)

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ABSTRACT

Biology teachers have been learning from the land and instructing more than 4,200 secondary students over the past two years. Fourteen teachers from Utah and Oregon from eight school districts have designed and conducted small-scale scientific research studies at GSENM to implement with their students. The projects designed for students have included: plant communities, dendrochronology of ponderosa pine, snakefly habitat and insect flight patterns. In addition, an intensive survey of flies from Lick Wash was completed. Findings from these studies provide useful information to enhance scientific research, and understand biodiversity, as well as improve secondary biology education.

Teacher designed plant studies using the natural resources at GSENM included: 1) species richness near roadsides to examine patterns of plant quality as an effect of road development, 2) woody plant spacing along altitudinal gradients from several knolls to compare species richness versus directional slope, and 3) plant habitat preferences of snakeflies. A dendrochronology study was conducted on ponderosa pines in canyons with water sources versus ponderosa pine on canyon ledges. Teachers designed these studies to replicate with their students using campus area resources.

Teachers designed several insect studies that can be replicated with their students in other areas of Utah. One insect study was an examination of grasshopper flight patterns upon disturbance. The other insect study was a comparison of insects captured at a light trap using black light versus white light. A scientific survey was conducted near the parking area at Lick Wash using twelve malaise traps for five consecutive days during two summers documenting species of flies that had not been previously identified at GSENM. Through these studies teachers learned various naturalistic research methods to implement in their classrooms.

Findings from the plant and insect studies conducted by teachers can provide valuable information to many researchers studying GSENM.

Keywords: entomology, dendrochronology, biodiversity, education

Ecosystem Dynamics & Botany

"The tantalizing discomfort of perplexity is what inspires otherwise ordinary men and women to extraordinary feats of ingenuity and creativity; nothing quite focuses the mind like dissonant details awaiting harmonious resolution."

– Brian Greene, The Fabric of the Cosmos –

Characteristics of Pinyon-Juniper Woodlands in Grand Staircase-Escalante National Monument: Changes Since Monument Establishment and Prospects for Future Monitoring

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ABSTRACT

Recent data from the USDA Forest Service Forest Inventory and Analysis (FIA) program have documented spatial and temporal patterns of drought-related mortality across woodlands of the Southwest (Shaw et al. 2005). In the early 1990s, FIA collected data on forested land now included in Grand Staircase-Escalante National Monument (GSENM or the Monument) as part of a comprehensive periodic inventory of Utah (O'Brien 1999). In 2000, FIA implemented an annual inventory system in Utah, measuring 10 percent of the full plot complement each year. These data provide a baseline of conditions just prior to establishment of the Monument and, following establishment, annual measurements spanning the years that vegetation was most affected by drought. Pinyon-juniper woodlands within the Monument have experienced comparable rates of mortality and changes in composition and structure to similar woodlands in the Southwest. The FIA program will continue to collect inventory data in GSENM and provide a framework for monitoring forest vegetation.

Keywords: drought, mortality, stand density, species composition

Introduction

The Forest Inventory and Analysis (FIA) program of the Forest Service, U.S. Department of Agriculture, is responsible for assessing the status and trends of all forested lands in the U.S. (Gillespie 1997), including those within the boundaries of Grand Staircase – Escalante National Monument (GSENM). In the mid 1990s, prior to Monument establishment, the Interior West FIA program (IW-FIA) established permanent inventory plots within the current Monument boundary as part of a statewide periodic inventory of Utah. In 2000, IW-FIA began the process of re-visiting the plots as part of a new annual inventory protocol. In recent years, pinyon-juniper woodlands across the Southwest have experienced elevated rates of mortality due to a complex of drought, insects, and disease (Breshears et al. 2005; Shaw et al. 1995; Shaw 2006b). Because pinyon-juniper woodlands are the dominant forest type on GSENM, we expected that some mortality occurred on the Monument as well. Fortunately, the timing of the two FIA inventory cycles in Utah permits us to assess drought-related changes to pinyon-juniper woodlands, starting shortly after establishment of the Monument.

In this paper we describe the FIA plot history in GSENM, what FIA data reveal with respect to vegetation change, and how changes in GSENM compare to changes observed in the pinyon-juniper forest type as a whole. We also discuss how the FIA inventory protocol may be used to monitor forests in the Monument in the future.

Methods

The national FIA program conducts inventory on all forested lands of the U.S. using a nationally standardized plot design (Figure 1) at an intensity of approximately one field plot per 2,388 hectares (6,000 acres). IW-FIA is responsible for FIA plots in Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. These states encompass over 85 percent of forests in the pinyon-juniper group in the western U.S.

Surveys conducted by IW-FIA prior to 2000 were generally statewide periodic inventories, but in some cases National Forests or tribal lands were inventoried as separate units. Under the periodic system, the entire plot grid in the area of interest was visited over a period of one to several years. As a result, the number of plots visited in any given year varied in number and geographic extent. In 2000, IW-FIA implemented a continuous annual inventory system (Gillespie 1997). Under annual inventory, approximately 10 percent of plots from the full sample set are measured each year. Plots belonging to an annual panel are distributed across each state so as to be free of geographic bias. States have been gradually phased into the annual system (Utah, 2000; Arizona, 2001; Colorado, 2002; Idaho, 2003; Montana, 2003), increasing geographic coverage of the Interior West over the past five years. A pilot inventory of Nevada employed the annual plot system in 2004 and 2005.

About the same time that IW-FIA was implementing the new annual survey, much of the western United States began to enter a period of drought. As the drought continued, managers noted an increase in mortality within pinyon-juniper woodland types. Mortality peaked in 2003, when drought facilitated an explosion of the pinyon ips (*Ips confusus* Laconte) population in many areas (Shaw et al. 2005). The most severely affected areas were located in northern Arizona, northwestern New Mexico, and southwestern Colorado. Analysis of FIA data spanning the peak of mortality – 2000 to 2005 in Utah, 2001 to 2005 in Arizona, and 2002 to 2005 in Colorado – suggested that annual measurements could reveal changes of a relatively small magnitude (Shaw 2006a). The episode of drought-related mortality provided an opportunity to assess the effectiveness of annual inventory in detecting and tracking these types of disturbance events. It also provided an opportunity to explore ways of using periodic data and the new annual data in concert. Because the periodic inventory data were obtained under pre-drought conditions, it could be used to estimate "typical" rates of mortality and pre-drought composition and structure.

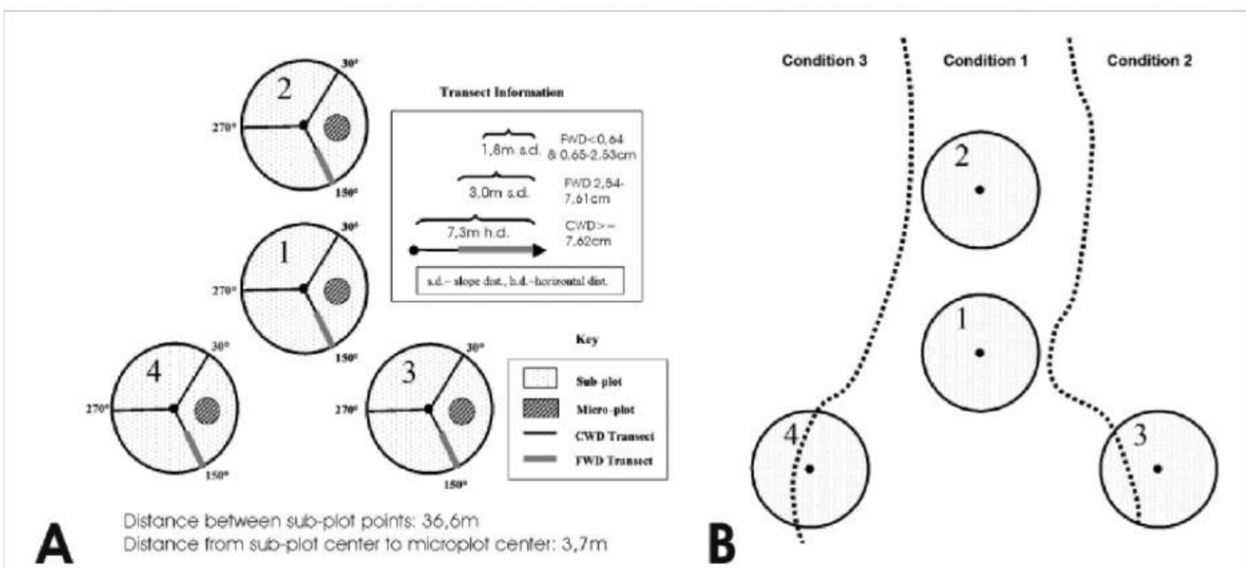

Figure 1. National standard FIA plot design (A). Plots are established systematically, using a pre-determined coordinate for the center of subplot 1. Plots that span multiple conditions – e.g., changes in age, density, or composition – are mapped (B). Tally trees and site variables are assigned to conditions.

In the eight states covered by the IW-FIA program, pinyon or juniper species were found on 14,929 plots, measured between 1981 and 2005. Of the total number of plots, 10,807 were unique plot locations, with the remainder being repeat visits to plots in different inventory cycles. Of the 298,324 trees measured on all plots, 212,142 were pinyon or juniper species. On GSENM, pinyon or juniper species were found on 143 plots. Of these, 50 were part of the Utah periodic inventory and were established and measured in 1994 and 1995, while 93 plots were measured under the annual inventory system. Approximately 218 plots are expected to be visited on the Monument during a 10-year inventory cycle. However, many of these will be classified as non-forest so the final number of field points in the cycle will be less than 218. Because most drought-related mortality occurred in 2003, our analysis of pre- and post-drought conditions necessitates grouping periodic and annual plots to represent pre-drought conditions (95 plots visited between 1994 and 2002). Post-drought conditions are represented entirely by annual inventory plots (48 plots visited from 2003 to 2005).

Up to 140 tree and plot variables are collected on FIA plots. Data on stand and site characteristics can be correlated with mortality rates. FIA sampling protocol includes measurement of live and dead trees. Dead trees are classified as either old dead (snags) or recent mortality and are assigned a mortality code (MORTCD). "Recent" mortality is defined by IW-FIA as trees judged to have died < five years prior to the plot visit. The FIA criteria used to make this distinction, e.g., presence or absence of dead foliage, sloughing bark, or fine twigs, are consistent with the characteristics found to be correlated with stages of deterioration in a pinyon snag longevity study (Kearns et al. 2005).

When a tree is designated as recent mortality, a causal agent code is assigned (AGENTCD). The exact cause of drought-related mortality can be difficult to assess, because trees may be predisposed to insect attack by drought, disease, or a combination of factors (Shaw et al. 2005). We will not attempt to tease apart the relative effects of contributing agents here; rather, we filter out the effects of factors that are not part of the complex (primarily fire) and analyze the remainder.

Shaw (2006b) reported results based on analysis of data spanning the geographic range of the pinyon-juniper type. We examined the data from plots located within GSENM and performed the same analyses as were used on the complete data set. Analysis of forest composition data was done using percent of basal area (BA) by species (one inch or greater diameter at root collar) on a plot. Dead and mortality components were computed as per Shaw (2006b).

percent mortality = mortality BA / (live BA + Mortality BA)
percent dead = dead BA / (live BA + mortality BA + dead BA)

Because of variations in survey type and location over time, it was not practical to scale up to population-level estimates on an annual or multi-year basis. Rather, this study analyzes characteristics and trends found in the sample. Comparability among years is achieved by normalizing the data into proportions of live, dead, and mortality trees.

Results and Discussion

The pinyon mortality event was widespread and detectable, but not as profound as some local reports would suggest. Local reports of near-complete mortality of pinyon appear to be isolated and not reflective of conditions throughout the west. Pre-drought data (1980 to 2002 range-wide and 1994 to 2002 on GSENM) on pinyon trees showed mortality occurring in 0.6 percent of all plots where pinyon was found and on 5.0 percent of the plots containing pinyon in GSENM (Figure 2A). In comparison, post drought data (2003-2005 in all areas) indicate mortality increased to 7.8 percent range-wide and 30 percent in GSENM (Figure 2B). In the Monument, pre-drought mortality affected 0.8 percent of pinyon trees and post-drought mortality was approximately 7.1 percent. This is much lower than the 90-100 percent mortality reported in some stands in the southwest. Given that the data show higher mortality rates in stands where pinyon contributes a large proportion of the basal area (see discussion below), it is likely that these reports refer to areas of high pinyon basal area. Further analysis of plot data in or near these sites could address this idea.

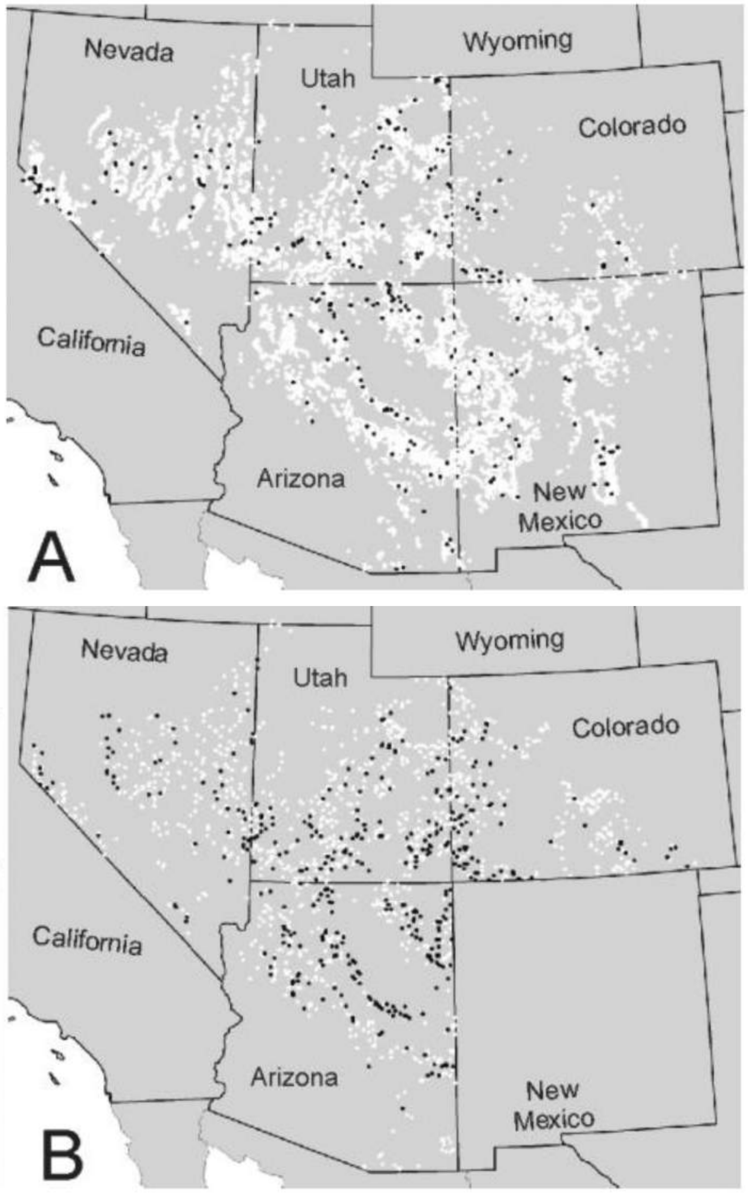

Figure 2. GSENM and surrounding areas, showing plots with mortality during the pre-drought (A) and post-drought (B) periods. Black symbols show plots with no mortality at the time of measurement, and open circled show plots with at least 1 mortality tree present.

Across their range, pinyons account for a minority of stocking (<50 percent of basal area) of most stands in which they occur. The mean proportion of pinyon basal area to total stand basal area is 37 percent, with relatively fewer plots as pinyon percentage increases (Figure 3A). The notable exception is pure stands of pinyon which tend to be more common than stands with >90 percent and <100 percent pinyon. This distribution pattern of composition is common in many other species. Within the boundaries of GSENM, pinyons appear to account for a relatively lower proportion of stocking, with 30 percent of total basal area on average (Figure 3B). Although it is difficult to compare the composition distribution from GSENM with the general population, primarily because of the relatively small number of plots measured on the Monument to date, there appear to be relatively fewer pure stands on the Monument than in the larger population. In general, however, the composition pattern of pinyon stands on GSENM is comparable to the composition of pinyon stands throughout the range of the species.

The data suggest that drought-related mortality altered the composition of pinyon-juniper plots (defined here as any plot having pinyon and/or

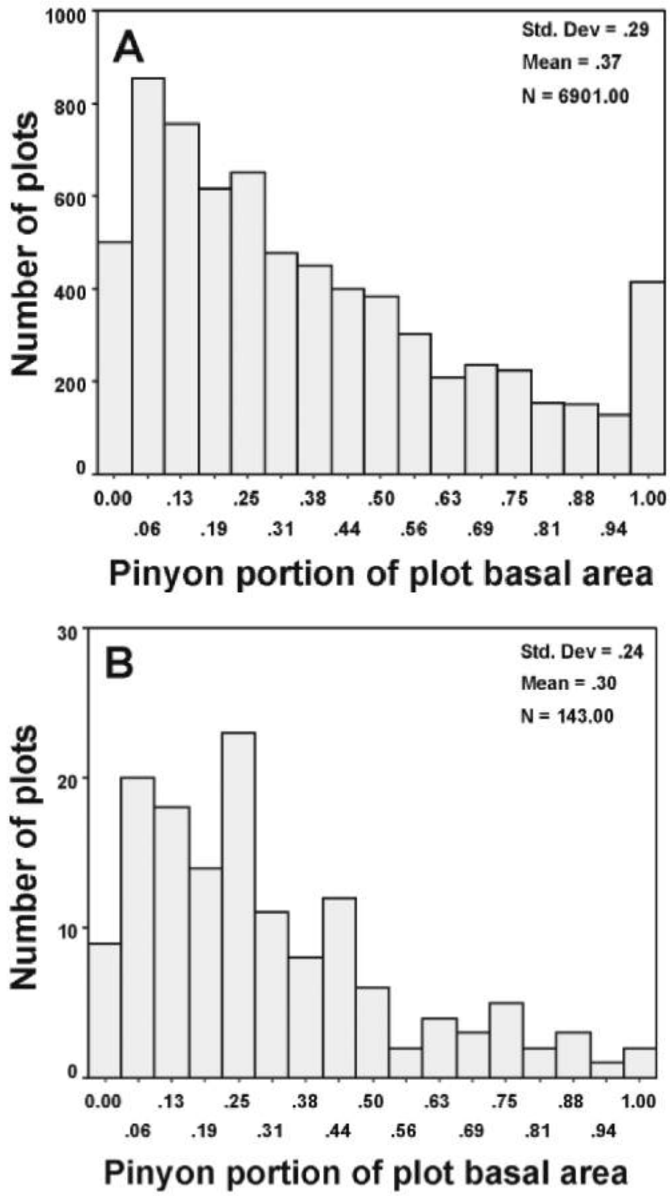

Figure 3. Pinyon species as a component of FIA plots: A) all plots in the IW-FIA states (see text) that include the species *Pinus edulis* Engelm., *P. cembroides* Zucc., or *P. discolor* Bailey & Hawksworth; B) plots that occur on GSENM (all *P. edulis*).

juniper found on it) on GSENM. The composition pattern of plots measured prior to the recent drought (Figure 4A) is similar to the pattern found for pinyon-juniper plots in general (Figure 3A). However, there appear to be relatively fewer plots on which pinyon makes up a small percentage of stocking (<20 percent of basal area) and pure pinyon stands are absent from post-drought plots on the monument (Figure 4B). The resulting effect of "trimming" both ends of the range of composition is that mean composition remained the same, but with less variability in composition. While some reduction in pinyon basal area was detected in most stands, pure or near-pure stands of pinyon appear to have suffered complete mortality of the pinyon component within the Monument. We consider this a preliminary result that may be verified after reconciliation of plots that are common to both the periodic and annual inventories.

The contribution of pinyon to stand basal area in GSENM closely reflects what is occurring range-wide with the species and forest types in question. The recent drought appears to have eliminated pure pinyon stands from FIA plots in GSENM. It is not known how many pure or near-pure pinyon stands remain within the monument's boundaries, but the data suggest they were rare even before the drought. FIA data show that prior

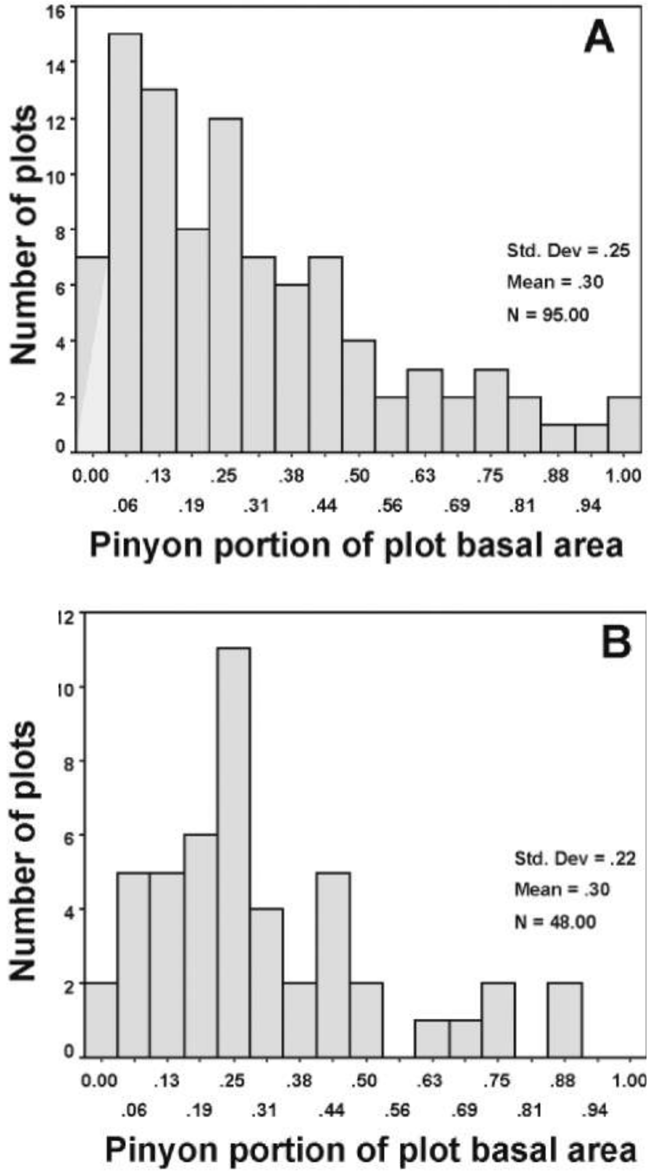

Figure 4. Compositional change in pinyon stands before (A; 1994 – 2002) and after (B; 2003 – 2005) drought on GSENM.

to the recent drought, six percent of GSENM plots had more than 80 percent of their basal area from pinyon species. This number drops to four percent after the onset of the drought, with stands having greater than 88 percent basal area from pinyon completely removed from the sample. There was also a detectable change in stand composition on plots where pinyon contributed relatively little to total basal area, both range-wide and within the GSENM. However, this change was much smaller than in pinyon dominated stands. A possible explanation for this may be the relative ease in which the pinyon ips can spread when trees are densely stocked compared to stands where pinyon trees are rare and/or spread out.

Tree data from GSENM plots detected changes between pre- and post-drought mortality rates in both pinyon and juniper species. In general, the timing and magnitude of mortality on GSENM was comparable to mortality in the pinyon-juniper type as a whole (Figure 5). Common pinyon experienced a small increase in mortality in 2002, followed by a substantial increase in 2003. In the general population, mortality continued to increase through 2005, but at a decreasing rate. The apparent drop in mortality on GSENM in 2005 is likely to be a sampling artifact. Shaw (2006b) confirmed field observations that indicated juniper species had experienced little mortality during the period when the most severe pinyon die-off occurred.

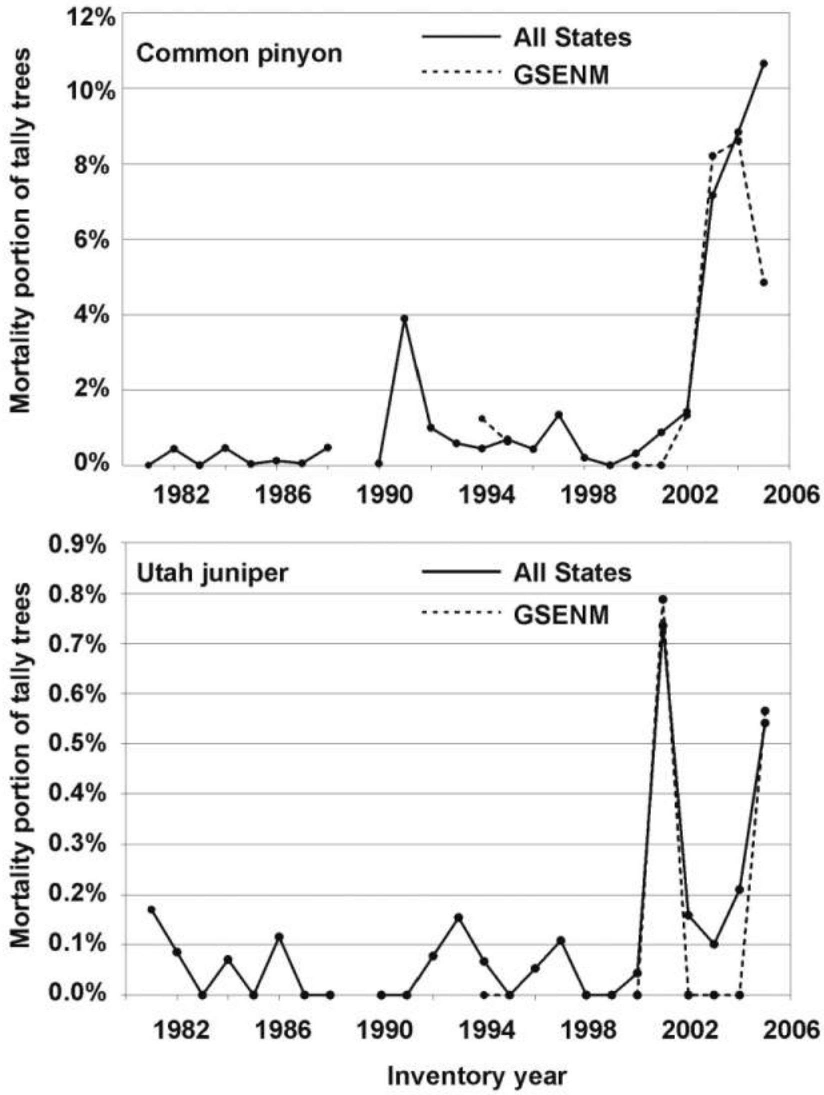

Figure 5. Temporal trends in mortality of common pinyon and Utah juniper, expressed as the proportion of tally trees that were counted as "mortality trees" (see text). Note difference between graphs in the scale of the y-axis.

Pre-drought data show that in "normal" years, juniper mortality is near zero. For example, the five-year mortality rate for Utah juniper is commonly < 0.1 percent. During the drought years, juniper mortality increased dramatically over the background rate, but, at < 1 percent, remains well below the background rates found in other species. As a result, even though the relative magnitude of change was similar between species the absolute change in mortality rate was much higher in pinyon than in juniper species.

Juniper and pinyon species reacted differently to recent drought. Although juniper trees showed an increase in mortality range-wide, the average mortality was still less than 1 percent. Pinyon mortality rose by an order of magnitude, averaging almost eight percent across its range. This reaction has been documented before by Mueller et al. (2005), who found similar differences in pinyon and juniper mortality rates in Arizona. Once established, juniper appears to be quite resistant to drought related stress. Conversely, pinyon seems to be more susceptible to disease and/or insect infestation after prolonged periods of drought. Based on this, one would not expect to see noticeable range contraction of this forest type during stressful periods, but rather a change in stand composition moving toward juniper dominance, as noted in Allen and Breshears (1998).

Conclusions

Drought-related response of pinyon and juniper species was detected across the range of each species as well as on a small subset of FIA survey plots in southern Utah. Both species have seen mortality rates increase by an order of magnitude, with pinyon species incurring a much higher absolute mortality rate. Stands that had a very high proportion of pinyon were impacted more than those stands where pinyon was a lesser component. The data from GSENM closely reflected some of the trends shown in the range-wide dataset, suggesting that this area can be used as a case study for all pinyon-juniper woodlands. However, the percentage of plots having recently dead trees tallied is higher in the Monument than on range-wide plots. This is the case for both pre- and post-drought records. That GSENM has a higher baseline mortality rate should be considered when designing experiments using the monument as a case study for all lands containing pinyon species.

The GSENM appears to be of sufficient size to allow for salient analysis using FIA annual data. Over 300 points occur within the borders of the monument and although less than half are forested, the potential exists to use the grid to cohabitate other resource sampling efforts on these plots, thereby allowing FIA data to be used in conjunction with these other efforts.

Data from both old and current FIA protocols were used to show changes in mortality rates due to stress brought on by drought. This illustrates that some variables that are shared between the two methodologies can be used for temporal and spatial analyses. These analyses should be stronger than those using one dataset or the other. However, care must be taken when choosing variables from both datasets. For example, woodland species such as pinyon and juniper had different thresholds for when they would be measured on a plot. During periodic inventories, a woodland tree species had to meet certain growth form requirements such as a minimum height or diameter. These thresholds are not present in annual inventory. Therefore, some plots that show lower stocking in the periodic data and higher in annual data could be an instance of more trees measured during periodic inventories, not necessarily more trees present on the plot since the last visit.

One of the main goals of the annual inventory system is to provide data on a more timely schedule than was possible under the periodic inventory system. Annual, incremental updates to FIA data make it possible to assess changes in forest health, productivity, composition, and status over time and space. As the body of annual data increases, so should the ability to glean meaningful insights from it. This analysis illustrates the potential to detect changes using only the six years of annual data collected so far. Though trend analysis is strengthened as more years are added, the current data can be useful for predicting future rates of change and identifying future research potential once a more robust dataset exists.

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Seed Propagation of Native Plant Species from Stabilized Dune Environments in Grand Staircase-Escalante National Monument

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ABSTRACT

A distinctive habitat in the Grand Staircase-Escalante National Monument and throughout the Colorado Plateau is the stabilized dune environment, which covers extensive areas and is often disturbed in connection with land use activities. I examined germination requirements for 47 native perennial species found primarily on stabilized dunes. Germination requirements of these species were generally similar to those for closely related species from non-dune environments; there was no germination syndrome that characterized dune plants. A range of syndromes was identified, including absence of dormancy, dormancy lost through dry after-ripening, dormancy lost through cold stratification, physical dormancy alleviated by scarification, and combinations of these mechanisms. A few species were characterized by cue non-responsive dormancy. Most were readily produced in containers using long tubes to accommodate roots and fast-draining sandy mixes. Small-scale restoration of stabilized dune areas disturbed by human activities is feasible using container-produced stock planted in the fall.

Keywords: seed propagation, native plant, restoration, sand dune, physiological dormancy, physical dormancy, germination, scarification, stratification, after-ripening.

Introduction

Sand dune habitats on the Colorado Plateau support a very characteristic plant community. Shrub dominants include *Quercus havardii* (shinnery oak), *Artemisia filifolia* (sand sagebrush), *Ephedra viridis* (green mormon tea), *Atriplex canescens* (fourwing saltbush), *Vanclevea stylosa* (resinbush), *Ericameria nauseosus* (sand specialist subspecies *arenarius* and *nitidus*, rubber rabbitbrush), *Penstemon ambiguus* (bush *Penstemon*), *Eriogonum leptocladon* (sandhill buckwheatbrush), and *Poliomintha incana* (purple rosemary mint). The co-dominant grass species is usually *Achnatherum hymenoides* (Indian ricegrass), but *Muhlenbergia pungens* (sandhill or ring muhly), *Sporobolus cryptandrus* (sand dropseed), *Sporobolus flexuosus* (mesa dropseed), *Sporobolus giganteus* (spike dropseed), and *Pleuraphis jamesii* (galleta grass) may be locally abundant. Characteristic and common perennial herbs of stabilized dunes include *Wyethia scabra* (sandhill mulesears), *Amsonia tomentosa* (woolly bluestars), *Cymopterus newberryi* (Newberry biscuitroot), *Abronia fragrans* (fragrant sand verbena), *Oenothera pallida* (pale evening primrose), and *Rumex hymenosepalus* (canaigre or wild rhubarb). Many other perennial herbs are more or less frequently encountered, and the plant community also includes a host of annual herbs. *Yucca* species are also abundant in stabilized dune environments, especially *Y. angustissima* (Spanish bayonet) and *Y. utahensis* (Utah yucca).

The stabilized dune environment therefore supports a highly diverse flora representing numerous plant families. In the study reported here, I had two primary objectives. First, I wanted to determine whether any particular germination syndromes were characteristic for plants of stabilized dunes. Second, I wanted to develop protocols for the seed propagation and container production of these plants, as an aid to ecological restoration of stabilized dune habitats. I excluded annual plants from my study because container propagation of annual plants is usually not considered practical or desirable; these are better established from direct seeding. In addition, many annual plants form persistent seed banks and might be expected to be difficult to propagate from seed. I focused on common perennial plants that might be needed for ecological restoration of stabilized dune communities, that might reasonably be produced in containers, and for which wild seed collections could be made.

Methodology

Most of the seed collections included in this study were made within the boundaries of Grand Staircase-Escalante National Monument in 2001 as part of a project to grow plants for ecological restoration and for the establishment of a demonstration garden at the GSENM visitor center in Big Water, Utah, which was under construction at the time. Additional collections have been made in subsequent years, and information on some species is based on previous published or unpublished studies. All information included in this paper, including information on related species, is based on my personal experience with seed germination and container propagation for each species.

I carried out my investigations within a conceptual framework developed for determining the germination requirements of unfamiliar plant species (Meyer 2006; Figure 1). Once the seed collection has been cleaned and a preliminary estimate of viability has been obtained, four replicate dishes of 25 seeds are incubated for four weeks under putative optimal conditions (10/20C 12h:12h alternating regime with cool-white fluorescent light during the warm part of the cycle). Germinated seeds are counted and removed at 1, 2, 4, 7, 11, 14, 21 and 28 days, and remaining ungerminated seeds are assessed for viability using a cut test or tetrazolium staining. This set of conditions has been determined to be optimal for a large majority of Intermountain native species. At this point the seed lot is determined to be nondormant, physiologically dormant, or physically dormant (hard-seeded).

If the seeds are physiologically dormant, i.e., they take up water readily but do not germinate within 28 days, then two avenues for dormancy alleviation are pursued. Some species require time in dry storage to lose dormancy, a process called dry after-ripening. In many cases the rate of dormancy loss is positively related to storage temperature, and seeds of some species lose dormancy very slowly if at all at low temperatures, but do lose dormancy at high temperatures (Figure 1). As a provisional dry after-ripening treatment, seeds are stored in sealed vials at 40C for 4 wks, then incubated as described above.

Seeds of many species require moist chilling, also called cold stratification, in order to lose dormancy (Figure 1). The chilling period required is loosely correlated with the habitat of origin for a seed lot. Collections from high elevation habitats where snow persists for many months have longer chilling requirements than seeds from low elevation habitats where soils do not remain cool and moist for prolonged periods. The chilling period tested for a particular seed lot therefore depends on its habitat of origin as well as on known chilling requirements for other lots of the same or closely related species. For this study, I generally used a short chilling duration (8 wks at 2C), because stabilized dune environments are characterized by desert and semidesert climates rather than montane climates.

If the seeds are physically dormant, i.e., they do not take up water (Figure 1), then a scarification treatment is applied, either mechanical scarification (nicking with a razor blade) or heat scarification (2-minute soak in boiling water). The scarified seeds are incubated as described above, and scored for imbibition (swelling) and germination. If the seeds imbibe but do not germinate, they are chilled for four weeks at 2C and then reincubated at 10/20C.

Sometimes seeds cannot respond to chilling unless they have first experienced a period of dry after-ripening (Figure 1). An example is *Atriplex*

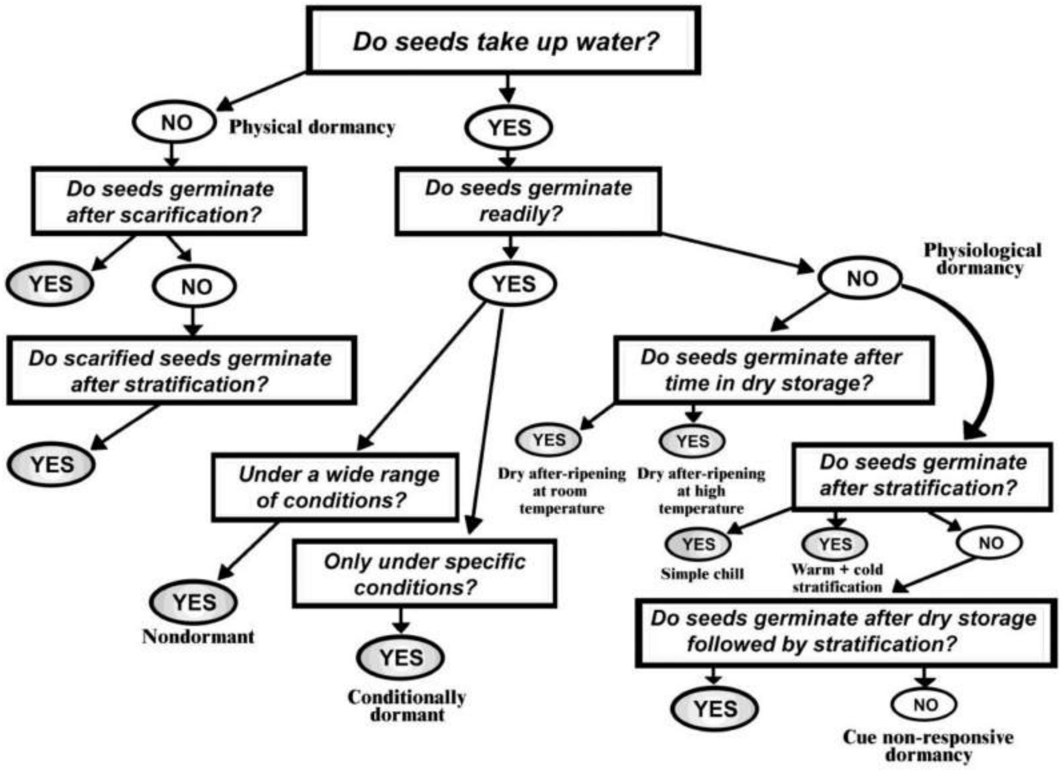

Figure 1. A decision tree for determining the seed germination requirements for a species whose requirements are unknown (reprinted from Meyer 2006).

confertifolia (shadscale), a common dominant shrub of salt desert plant communities. If a seed lot does not respond to either dry after-ripening or moist chilling, then these two treatments are applied in tandem, i.e., the seeds that have experienced dry after-ripening are then subjected to chilling. Sometimes seeds require a period spent imbibed at warm temperatures (warm stratification) before they can respond to chilling. This syndrome is not common in desert plants, but a few species, such as *Fraxinus anomala* (singleleaf ash) have seeds that require warm followed by cold stratification.

And finally, there are species and seed lots that respond minimally if at all to any of the dormancy-breaking treatments described above. These seeds are said to have cue non-responsive dormancy (Figure 1). This kind of dormancy is usually found in species that form long-lived seed banks, so that only a small fraction becomes nondormant each year. These species are the most difficult to propagate from seed.

In order to obtain plants in containers from germinated seeds, I used 10-cubic-inch Ray Leach Conetainers as planting containers. These elongate containers, first developed for conifer seedling production, are better suited for establishment of tap-rooted species than more traditional pots. All planting media were aerated-steam-treated (45 minutes at 60C in a Lindig cart) prior to placement in containers to help prevent damping off fungi and other plant pathogens. Two potting media were used: (1) pure sand (#16 pure quartz silica) with complete added fertilizer and (2) a native plant mix consisting of sieved peat, vermiculite, Agsorb (montmorillonite clay), and sand (2:2:1:2) with complete added fertilizer and dolomite and limestone amendments. For the pure sand mix, the container drainage holes were plugged with cotton prior to filling. For species with seeds that were nondormant or could be rendered nondormant in the dry condition, ungerminated seeds were sown, while seeds that required moist chilling were sown as newly germinated seedlings (radicle <5mm). Plants were grown for 3-5 months under long days in a greenhouse maintained between 17 and 23°C and were watered as needed.

Results

Seeds of stabilized dune environments exhibited a wide range of germination syndromes (Table 1). There was no particular syndrome that seemed to characterize species from the dune habitat. Instead, the germination syndrome observed for each species was usually similar to those previously reported for closely related species within a plant family.

The germination syndrome with seeds completely nondormant at dispersal was characteristic of many stabilized dune species, almost half of those included in the study (Table 1). All species of *Yucca* and *Asclepias* had completely nondormant seeds. The absence of dormancy in these genera is widespread. *Yucca* species from North Dakota (*Y. glauca*) to the Mexican Altiplano (*Y. filifera*, *Y. carnerosana*, *Y. decipiens*), as well as all Colorado Plateau and Mojave Desert species tested (*Y. baccata*, *Y. harrimanniae*, *Y. brevifolia*, *Y. schidigera* in addition to those in this study) were characterized by completely nondormant seeds. The same is true for many additional species of *Asclepias*, including *A. speciosa*, *A. tuberosa*, *A. asperula*, *A. erosa*, and *A. cryptoceras*.

Both members of the Brassicaceae included in this study had completely nondormant seeds (Table 1). Desert and semidesert species in this family often have seeds that are completely nondormant, especially members of the genus *Arabis* (e.g., *A. holboellii*, *A. perennans*) and *Stanleya* (*S. pinnata*, *S. viridiflora*). Other perennial species of *Lepidium* may have nondormant seeds (e.g., *L. fremontii*) or chilling-responsive seeds (*L. davisii*), but annual members of the genus may have cue non-responsive dormancy (e.g., *L. papilliferum*, Meyer et al. 2006). Members of the genus *Ephedra* almost always have nondormant seeds, though high-elevation populations occasionally have a short moist chilling requirement (Meyer, http://www.nsl.fs.fed.us/wpsm/*Ephedra*.pdf). In contrast, even though seeds of several collections of *Rumex hymenosepalus* were completely nondormant in this study, seeds of weedy *Rumex* species have complex dormancy mechanisms (Baskin and Baskin 1998). Another species with nondormant seeds, *Poliomintha incana*, was similar to many other Intermountain members of the Lamiaceae, including *Hedeoma nana*, *Dracocephalum parviflorum*, and *Agastache urticifolia*. Other Intermountain members of this family have seeds that require short to intermediate moist chilling to become germinable (e.g., *Monardella odoratissima*, *Salvia dorrii*).

Most members of the Asteraceae in this study had completely nondormant seeds (Table 1). Only *Wyethia scabra* had an obligate 8-wk moist chilling requirement. *Hymenopappus filifolius* seeds required moist chilling to become nondormant when recently harvested, but lost this chilling requirement through after-ripening in dry storage, so that they became nondormant after three months of storage at laboratory temperature (ca. 22C). This result was in accord with a larger data set on the germination requirements of Intermountain Asteraceae (Paulsen and Meyer 1999). In general, small-seeded members of this family had nondormant seeds, while species with larger seeds (e.g., *Balsamorhiza*, *Wyethia*, *Helianthella*) often had seeds that required chilling in order to become germinable.

Seven families in this study contain a majority of species whose seeds require moist chilling to become germinable, and most of the species we included responded favorably to short (8-wk) moist chilling (Table 1). These included *Eremocrinum albomarginatum* and *Allium nevadense* of the Liliaceae, *Cymopterus newberryi* of the Apiaceae, *Amsonia tomentosa* of the Apocynaceae, *Cryptantha cinerea* of the Boraginaceae, *Eriogonum leptocladon* of the Polygonaceae, *Delphinium andersonii* of the Ranunculaceae, and *Penstemon ammophilus* and *Penstemon angustifolius* of the Scrophulariaceae. The one species that did not follow this pattern was *Penstemon ambiguus*. Many species of *Penstemon* produce seed populations that contain some seeds that respond to chilling but also some seeds that are not responsive (Meyer et al. 1995). This was true to some extent for the two species cited above, but it was true to a much larger extent for seeds of *P. ambiguus* in this study, which germinated to very low percentages (<10%) whether chilled or not. Neither dry after-ripening nor warm stratification had any effect on this lack of response to chilling, meaning that seeds of this species can be considered cue non-responsive. It is not known how seeds of this species become nondormant under natural conditions.

Most of the grass species included in our study had seeds that were either nondormant at dispersal

Family and Species	Germination Requirements				
	Non-dormant	After-ripen	Moist chill	Scarify	Cue non-responsive
Agavaceae					
Yucca angustissima	X				
Yucca baileyi	X				
Yucca utahensis	X				
Liliaceae					
Allium nevadense			X		
Eremocrinum albomarginatum			X		
Poaceae					
Achnatherum hymenoides		X	X		X
Muhlenbergia pungens	X	X			
Pleuraphis jamesii	X	X			
Sporobolus cryptandrus		X			
Sporobolus flexuosus		X			
Sporobolus giganteus		X			
Apiaceae					
Cymopterus newberryi			X		
Apocynaceae					
Amsonia tomentosa			X		
Asclepiadaceae					
Asclepias involucrata	X				
Asclepias labriformis	X				
Asteraceae					
Artemisia filifolia	X				
Ericameria nauseosus	X		X		
Gutierrezia microcephala	X				
Heterotheca villosa	X				
Hymenopappus filifolius		X	X		
Machaeranthera canescens	X				
Townsendia incana	X				
Vanclevea stylosa	X				
Wyethia scabra			X		
Boraginaceae					
Cryptantha cinerea			X		
Brassicaceae					
Arabis pulchra	X				
Lepidium montanum	X				
Chenopodiaceae					
Atriplex canescens	X	X	X		X
Convolvulaceae					
Evolvulus nuttallianus				X	
Ephedraceae					
Ephedra viridis	X		X		
Fabaceae					
Astragalus ceramicus				X	
Astragalus mollissimus				X	
Caesalpinea repens				X	
Dalea flavescens				X	
Psoralidium junceum				X	
Psoralidium lanceolatum				X	
Sophora stenophylla				X	
Lamiaceae					

Table 1. Germination requirements (dormancy-breaking treatments for seeds of 47 plant species found in stabilized dune environments on the Colorado Plateau. Three monocot families and seventeen dicot families are listed in alphabetical order.

Family and Species	Germination Requirements				
	Non-dormant	After-ripen	Moist chill	Scarify	Cue non-responsive
Poliomintha incana	X				
Malvaceae					
Sphaeralcea parvifolia				X	
Nyctaginaceae					
Abronia fragrans					X
Onagraceae					
Oenothera pallida					X
Polygonaceae					
Eriogonum leptocladon			X		
Rumex hymenosepalus	X				
Ranunculaceae					
Delphinium andersonii			X		
Scrophulariaceae					
Penstemon ambiguus					X
Penstemon ammophilus			X		
Penstemon angustifolius			X		

Table 1. Continued

or that lost dormancy through dry after-ripening (Table 1). Seeds of *Sporobolus* species tended to remain dormant indefinitely at laboratory temperatures, but were released from dormancy after 4-8 wks at 40C. This pattern was also found for some non-dune warm season grasses, e.g., *Schizachyrium scoparium* and *Erioneuron pulchellum*, but not for *Sporobolus airoides*, which was nondormant at dispersal or lost any remaining dormancy at laboratory temperature. Seeds of the warm season grasses *Muhlenbergia pungens* and *Pleuraphis jamesii* were also nondormant at dispersal, while seeds of the cool season grass *Achnatherum hymenoides* exhibited cue non-responsive dormancy. This species is known to have highly variable and complex seed dormancy regulation, with roles for dry after-ripening, moist chilling, and removal of restrictive layers by heteromyid rodents, the primary seed dipsersers (McAdoo et al. 1983, Jones and Nielsen 1999). In our trials, there was very little germination in response to high temperature after-ripening or moist chilling unless the restrictive covering was first physically disrupted through scarification in a rotary drum sandpaper scarifier. This procedure damaged many seeds.

Seeds of species in three additional families exhibited varying degrees of cue non-responsive dormancy (Table 1). For *Oenothera pallida* and *Abronia fragrans*, a small nondormant fraction was present, but efforts to break dormancy in the remaining seeds through combinations of high temperature after-ripening and moist chilling were unsuccessful. A similar but less extreme pattern was seen in a long-term study with 23 accessions of *Atriplex canescens*, with a variable fraction nondormant at dispersal, another fraction that was chilling-responsive or became chilling-responsive through dry after-ripening, and another sometimes sizeable fraction that remained cue non-responsive after many years of storage (Meyer and Carlson in press).

The last germination syndrome encountered in the current study was physical dormancy or hard-seededness. True physical dormancy, where the seeds are unable to take up water, has been reported for only a handful of plant families, three of which were included in this study. All members of the Fabaceae, Convolvulaceae, and Malvaceae that were included exhibited simple physical dormancy, with no additional physiological dormancy component (Table 1). The seeds germinated quickly once a scarification treatment permitted uptake of water, and no post-imbibition moist chilling treatment was required. This is in contrast to seeds of some other Intermountain species, such as *Iliamna rivularis* and some collections of *Astragalus utahensis*, which require a short chilling treatment to become germinable once physical dormancy has been overcome. Hard-seededness could be considered another form of cue non-responsive dormancy, and is characteristic of species that form persistent seed banks and slowly release seeds from dormancy over many years (e.g., *Convolvulus arvensis*, *Astragalus spp.*) or whose seeds respond to the heat of infrequent fires (*Iliamna rivularis*, *Ceanothus spp.*). But, because it is readily overcome with mechanical or heat treatments, it is less of an obstacle to propagation than physiologically-based cue non-responsive dormancy.

Once the seed germination requirements for a species were established, it was generally possible to obtain plants in container culture. Most species did equally well in either sand or in the more traditional potting mix, but a few species thrived only in pure sand. These were primarily members of the Fabaceae (*Psoralidium junceum*, *Psoralidium lanceolatum*, *Sophora stenophylla*, *Astragalus ceramicus*) but also included one grass (*Sporobolus flexuousus*) and all the *Yucca* species. Plants were obtained for each species listed, but seedlings of *Allium nevadense*, *Eremocrinum albomarginatum*, and *Cymopterus newberryi* only produced a single leaf and entered dormancy a few weeks after emergence. These plants set miniature bulbs before entering dormancy, but due to lack of knowledge regarding requirements for maintenance in the summer-dormant state and for triggering regrowth, efforts to maintain these plants for subsequent outplanting failed. Most plants of the remaining species survived to outplanting.

Discussion

Based upon determination of germination syndromes for 47 species found on stabilized dunes on the Colorado Plateau, it is evident that there is no syndrome or set of syndromes that characterizes species of dune environments. The full range of germination syndromes was represented, and each species had a germination syndrome that was similar to the syndromes of related species from non-dune environments.

Whatever specialization is required to survive in the dune environment is not directly reflected in germination syndrome. Other seed traits may play a role in this specialization, however. For rubber rabbitbrush, seeds (achenes) of subspecies that are dune specialists have germination requirements similar to those of generalist subspecies from the same climatic regime (Meyer et al. 1989). But the achenes of dune specialists are much larger than those of generalist subspecies, and seedling relative growth rates are much slower (Meyer 1997, Meyer and Carlson 2001). Only a few taxa that are dune specialists have larger seeds than their relatives from non-dune habitats, and no generalizations can be drawn regarding specialization for large seed size.

Different germination syndromes interact with local climate and seed production phenology to produce characteristic germination phenology for each species, whether within the year following production or across years as a persistent seed bank. The Colorado Plateau is characterized by a bimodal distribution of precipitation, with rainfall almost equally distributed between winter and summer, making seedling establishment possible in at least some years in both spring and late summer/fall. Species that produce nondormant seeds early in the season or seeds that after-ripen quickly at high temperature may exhibit seedling emergence after summer monsoonal storms, whereas those that produce seeds that require chilling for germination will almost certainly be spring-emerging. Nondormant seeds that are produced late in the fall, e.g., seeds of *Artemisia filifolia* and *Ericameria nauseosa*, are also likely to germinate in spring. Species with seeds that have physical dormancy or cue non-responsive physiological dormancy are likely to form persistent seed banks, with only a fraction of the seeds germinating each year, whereas species with nondormant seeds or seeds that after-ripen or respond to short chilling are less likely to form persistent seed banks.

It was possible to produce container stock of most species in this study by using long tubes for promoting seedling root growth and a sandy to very sandy potting medium. Only species with summer seedling dormancy presented serious obstacles to container propagation. With careful planning, including opportunistic collection of seeds in years with good seed production, it will be possible to restore small areas of disturbed stabilized dune habitat using container stock. To be successful, the plants must be hardened off prior to outplanting and the outplanting must take place in autumn, so that the plants can root in before being exposed to severe water stress. Sand dune plants depend on deep roots to survive hot weather, and these roots must be in place before the first summer. These guidelines for production and outplanting are not substantially different than those for container stock in non-dune arid and semiarid environments, and in fact, survival in stabilized dune plantings has the potential to be higher than average because of the ability of sandy soils to store water at depth. But if the sand is unstable, a different set of problems associated with sand movement and burial must be resolved. Fortunately, most disturbed stabilized dune habitats are not devoid of plants, and it should be possible to conduct an outplanting without removing the residual plants that will provide protection from wind erosion while the planting is becoming established.

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A *Sclerocactus* Population Crashes: Analysis and Repeat Photography after Four Decades

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ABSTRACT

A unique population of *Sclerocactus parviflorus*, Little Barrel Cactus, was observed along 6 km of Cottonwood Canyon in 1962. Plants were numerous and robust, with many clumps, and some with white or pale pink flowers rather than the usual pink. Photos show an intensively grazed, stressed, damaged landscape, with depauperate shrubs, *Salsola tragus*, tumbleweed, more bare ground than cover, and no cryptogams visible. *Sclerocactus* is sensitive to competition, and responds to lack of it. On occasional drive-throughs in following years, no great change was noted. As late as 2002, plants could still be seen from the road, though perhaps not so numerous; rangeland health was improved, but the ecosystem not greatly changed. With designation of GSENM, grazing was reduced. In 2005, shrubs were healthy and native forbs noted, but *Bromus tectorum*, cheatgrass, had increased dramatically. *Moneilema punctatum*, cactus borer beetle, had moved in. The remnant of the cactus population was difficult to find in the cheatgrass; some were sick or dead. Only 26 live plants were found in the 6 km area in 7 days in 2005 and 2006, where in one 1962 photo over 100 can be counted. 1962 photos were compared with matched scenes from 2005 and 2006. Change in grazing regime, insect predation, and drought appear to be main factors effecting this dramatic landscape change and decline of cactus population.

Keywords: Cactaceae, *Sclerocactus*, repeat photography, grazing, cheatgrass, cactus borer beetle, GSENM, Cottonwood Canyon

Without perspective, we cannot recognize how Western landscapes can change – not only within a few decades, but even from year to year.

Cottonwood Wash Road, a main north-south corridor though the Monument, was built so that men who lived in the towns below Bryce – Henrieville, Cannonville, and Tropic – could more easily get to Page to work on construction of Glen Canyon Dam. After that it served as a scenic alternate to US 89 between Salt Lake City and Arizona. As such, I drove the road in 1962. Observing an uncommon abundance of *Sclerocactus parviflorus*, the little barrel cactus of the Colorado Plateau, I returned in the flowering season, May, and took 2¼" Ektachrome slides of the plants and their surroundings. This cactus is a tall plant, growing to 30 cm or more as a mature adult, and many were easily visible from the road. With so many cacti, I didn't venture far for photos, though I did walk among the plants. Other people or cars were rarely seen.

Sclerocactus parviflorus is not a rare species, nor a soil specialist as other species of the genus may be. Its center of abundance was in lower Glen Canyon and on the San Juan River (before Lake Powell), though it is widespread on the Plateau, and even extends disjunctly into the Uinta Basin near Duchesne. However, this occurrence in a 6-km long, flattish area surrounding Cottonwood Wash Road was unique in the number of plants and the presence of white and pale pink flowers, very rare in the species, amongst the usual vividly pink ones (Heil and Porter 2004). Here were even more plants per unit area than in lower Glen Canyon, the place of most abundance of this species in my long experience with *Sclerocactus* (since 1960).

This cactus most commonly grows in scattered populations, as it does in the rolling desert between this location and highway 89. Usually found as single heads, it can form clumps of either branched heads, or closely-grouped individuals from seeds sprouted from those remaining around the base of the plant. Where it flourishes, more clumps are found; that was true here.

The road extends mostly straight, NNE-SSW. Cottonwood Wash and the Cockscomb parallel it to the west, and the western edge of the Kaiparowits Plateau lies to the east. Scattered cottonwood trees, many of them old, grow near the wash. The Cockscomb is a hogback of Dakota Formation sandstone. Sandstone members of the Straight Cliffs Formation form the west-facing cliffs on the edge of the Kaiparowits. Below them is bedded blue-gray shale of the Tropic Formation in a strike valley behind the hogback hills, the Dakota weathering to a drab, steepish slope overlain by a cap of sandstone. Yellow monoliths of the Gunsight member of the Entrada march down the center of the floor of the canyon. A few steep, strikingly red and white outcrops of the Cannonville member of the Entrada crop out here and there against the base of the west side of the Dakota hogbacks.

The fine, predominantly clay soils of the flats support shrubland with grasses and herbs. In 1962 when so badly overgrazed and trampled, the sparse cover consisted of little more than scattered, broken shrubs, woody shrub litter, exotic plants (tumbleweed, *Salsola tragus*, can be seen on old photos), and these cacti, with much bare soil, little grass, and no cryptogams to be seen.

On occasional drives during later years, the cacti were not in anthesis but still observed. In 1962 one wood-pole powerline traversed the flats; later, another appeared.

Overall, in those early years, the area was not seen to change very much. As late as 2002, I observed plants from the road, though they were not so numerous.

In May 2005 I went back to Cottonwood Wash intending to document this unusual population. The ecosystem was almost unrecognizable. Large shrubs and abundant exotic plants, mostly *Bromus tectorum*, cheatgrass, covered most of the ground. *Sclerocactus* was no longer visible from the car. Long walks over locations previously photographed and other promising areas were necessary to find any individuals. None of the flowers were white. The devastating cactus longhorn beetle, *Moneilema semipunctatum*, had arrived, resulting in dead, sick, or dying plants. As late as 1984 the beetle (Linsley and Chemsak 1984) was thought to be hosted only by *Opuntia* and *Cylindropuntia*. Increasingly, in recent years has it been recognized as a serious cryptoherbivore of the Cactoideae (England 2007:53216).

The goal changed from documenting a now-lost, uniquely numerous population of robust plants, some with white or off-white flowers, to documenting changes to the landscape and to the cactus population.

Materials and Methods

To find plants, georeference, and note their condition, in the locations photographed in 1962 and elsewhere, I drove the 6 km of road, looking for the same scenes and for cacti. I also hiked the flats.

The 1962 camera was a Minolta twin-lens reflex; the 2005-2006 one a digital Sony DSC-S85. The 1962 slides suffered from Ektachrome deterioration, not foreseen at the time. Kodachrome was not available for that size, and the superior Agfa film not always available. I scanned old slides on an Epson 3170 flatbed scanner, and improved each in Photoshop 4 as much as possible. GPS readings were taken with a Garmin 12XL.

Field trips occured May 9-10, 2005, and May 16-18 and September 16-18, 2006. On the May trips it was difficult to find *Sclerocactus* amongst the tall cheatgrass. In September I found more, with cheatgrass at that season down and dead.

Data collected included GPS readings and orientation to other Sclerocacti in aspect and distance; road miles north of highway US 89; height, width, number of heads, and condition of plants; flowering stage, number of flowers; parent rock of soil; plant association, elevation, slope, and aspect; and photos of plants and scenes. Height of plant was measured downslope, and width at the widest part. Width was measured either sighting along a scale or with the prongs of a Vernier caliper (a figure-8 caliper will be used in the future for somewhat better accuracy, as the sides of the epidermis are obscured and obstructed by spines).

Groupings of live plants, in favorable locations or simply not yet found by the beetles, were designated as areas for future monitoring plots.

Monument personnel provided valuable background information, but this cactus population had not been noticed or recorded. Two sources of photographs recording the canyon in recent years were located: on the website of San Francisco photographer A. E. Graves, June 2004, and for several recent years from Austrian cactophile Gerhard Haslinger.

Results

In 2002, the Sclerocacti could still be seen from the car. Though an especially droughty year (Fig. 1) — in fact a drought year statewide — shrubs were larger and healthier, and less ground between the shrubs was bare. Conditions were changed from 1962 but still recognizable.

In 2005, the canyon was greatly transformed. I could no longer see the cacti while driving by. Due to livestock reduction, disturbance from grazing had been gradually reduced in recent years even before Monument designation, but that trend now accelerated. In recent years this allotment was used only for cattle drives, not for extended grazing (personal communication, GSENM Range Specialist Sean Stewart 2006). The flats remained noticeably, but no longer intensively, grazed. In 2005, the ground was covered with deep hoofprints; the cattle drive had been recent and in wet soil. In 2006, I did not see many hoofprints. However, returning a second day, I noted a few unauthorized cattle. A few cattle out of place in a grazing allotment are not unusual.

Shrubs had recovered, though the native *Achnatherum hymenoides* (*Oryzopsis hymenoides*), Indian ricegrass, and *Pleuraphis jamesii* (*Hilaria jamesii*), galleta grass, had not. Indian ricegrass was almost non-existent, galleta grass less sparse but plants were small and heavily cropped. Exotic weeds, especially cheatgrass, moved in and carpeted much of the ground, after a well-watered fall season in 2004 (Table 1). This florescence of cheatgrass hid what cacti remained. Method remained as planned, but with the addition of considerable searching to find plants: at random, in likely habitat, or at scenes of matched photographs.

The 1962 slides were compared with scenery in this 6 km stretch of road to find original photo points. Two of the original scenes were found. Only ten live plants were found in the 6 km area, and three in hilly desert just south, where an estimated few thousand had been in 1962. None had white or pale flowers, rare in the species but not uncommon here in 1962.

In addition to being unstable, as we now know, retention of Ektachrome dyes is a function of careful developing, light, and temperature during storage. The slides held their color for twenty years, then went into a steep decline. Some kept part of the blue and green dyes, on others these hues were almost totally gone. Detail and sharpness are lost with the dye, so perfect restoration of badly faded Ektachromes is not possible. Some slides can be restored to a semblance of original color values, with others degraded almost to sepia. Still, more information is preserved in the color versions than when converted to black and white.

In May 2006, the preceding fall had been drier, so cheatgrass was not as abundant. I relocated the ten *Sclerocactus* plants found in 2005, plus two more live ones not seen in the thicker weeds of 2005. Two of the ten plants found in 2005 had died, I observed only one seedling. Though tiny and easy to miss, seedlings will be seen if abundant. Because of the drier spring and later survey date, cheatgrass was dry but still standing and obscuring the cacti. I observed three plants in open desert on the way to highway 89.

The field trip of September 16-18, 2006, was more successful in finding *Sclerocactus* plants, alive and dead. At this season cheatgrass is not only dead, but flattened down, making it much easier to see cacti. Thirteen additional live plants were found in the 6 km area, also many dead ones, and one more seedling, for a total of 25 in the 6 km area (Table 2). Frequently, *Sclerocactus* plants were near a small unvegetated area, offering reduced competition. None were in occasional stands of pure cheatgrass.

Although cacti are expected to grow a little each year, it was drier in 2006 than 2005 (Table 1),

Figure 1. Film 8. Looking south from east of the road. Top photo May of 1962. Different camera formats made this one difficult to match exactly; bottom photo taken in 2006 is from closer to the monolith. One live plant seen here September 16, 2006. Some information is lost when the Ektachrome, which is already age-degraded, is converted to black and white. The few live plants in the 2006 scene are hidden in vegetation and cannot be seen in this large area photo.

and almost all plants were a little smaller in height and diameter because of less water storage (e.g., see Table 2, plant 4).

On May 9 and 10, 2005, the Sclerocacti were early- or mid-flowering. A week later in May 2006, they were almost at the end of flowering. Anthesis in *Sclerocactus* is correlated with ground temperature (unpublished data, D. Woodruff), so these two flowering seasons were about equal in seasonal development of anthesis.

Matching scenes by viewing the medium format slides was difficult. Driving through the

Table 1: Big Water, Utah Monthly Total Precipitation (inches)
(420688)

Year(s)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
...													
2002	0.01	0.01	0.07	0.00	0.00	0.00	0.00	0.08	1.48	0.83	0.00z	0.00z	2.48
2003	0.00z	0.00z	0.00z	0.00z	0.00z	0.00	0.02	0.55	0.27	0.42	0.63k	0.06h	1.26
2004	0.08e	1.21c	0.21	0.64a	0.05	0.32	0.16	1.40	2.20	1.75	1.88a	0.00z	9.90
2005	0.00z	0.00z	0.73	0.73	0.14	0.25	0.56	1.24a	0.68	1.10	0.00	0.00z	5.43
2006	0.00z	0.00z	4.00c	2.60a	0.00i	2.80f	0.54n	0.00z	0.00z	0.00z	0.00z	0.00z	6.60
Period of Record Statistics 1986-2006													
Mean	0.50	0.69	0.81	0.58	0.30	0.15	0.50	0.78	0.79	0.89	0.48	0.29	5.99
Max	3.16	1.66	4.00	2.60	1.18	0.67	1.33	2.29	2.66	3.53	1.88	0.93	9.00
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	3.22
No. of Years	17	17	18	18	17	18	19	19	19	20	18	16	11
File last updated on Jul 25, 2006													
Note: Provisional data after Mar 2006													
a = 1 day missing, b = 2 days missing, c = 3 days missing, etc... z = 26 or more days missing; A = Accumulations present													
Long-term means based on columns; thus, monthly row may not sum (or average) to long-term annual value													
Maximum allowable number of missing days: 5													
Individual months not used for annual or monthly statistics if more than 5 days are missing													
Individual years not used for annual statistic if any month in that year has more than 5 days missing													

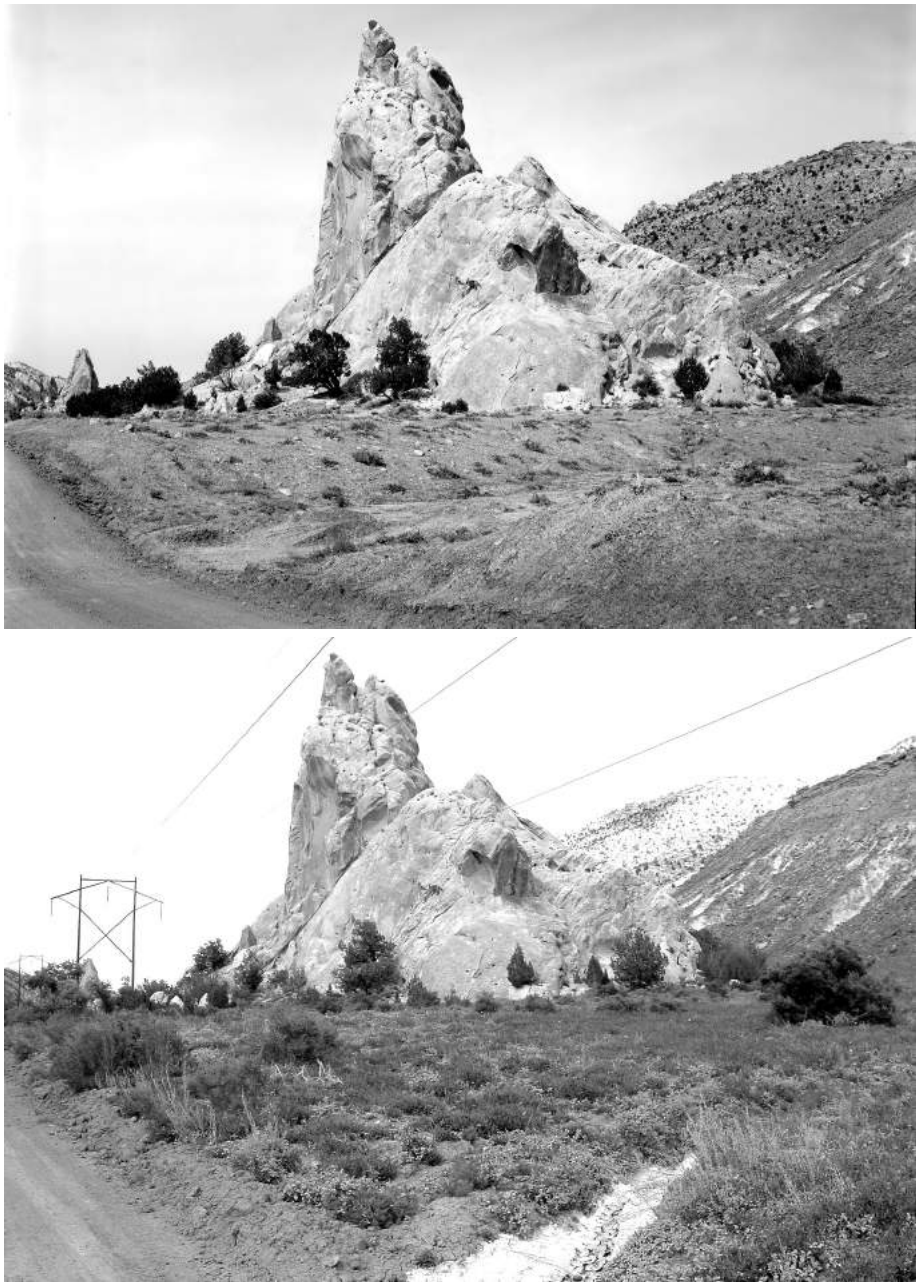

Figure 2. Film A. Top photo April, 1962; bottom photo May 9, 2005. Cacti show up better in an oversharpened version of the 1962 photo; they are towards the monolith, so some may be in sandier soil. Drainage in foreground is smaller but has more alkali. The few live plants in the 2005 scene are hidden in vegetation and cannot be seen in this large area photo, there are two cacti in this 2005 scene, two more were found in fall 2006.

canyon in 2006 while looking for unusual formations or a matching skyline using 8½x11" prints for comparison worked better. It was possible to match three of the four remaining 1962 scenes; photo points were recorded for these. I could not locate one medium-range scene showing only trees next to the wash in the background (Fig. 5).

After National Monument designation in 1996 visitation increased, with risk of cacti being taken for personal use in spite of regulations prohibiting collection. With so much visitation, the dirt road was corrugated and rough much of the year. Visitation probably declined from those using the road over the years as a scenic through-road, but the net effect was a great increase in use due to the area's new status, now approaching 100,000 visits a year on Cottonwood Road (GSENM 2006).

In 1962 the cacti were so abundant that I fo-

Table 2. ***Sclerocactus*** **Plants in Their Areas at Cottonwood Canyon, South to North**

Plant No.	Year[1]	No. of Heads	Parent Rock	No. of Flowers[5]	Height cm	Width cm	Condition[2]	Location	Slope[3]	Bearing[4]
Area 1 Soil derived from Dakota Formation (hill) and Gunsight member of the Entrada (near monolith).										
11	2005	1	Gunst	5	6.4	6.4		East of monolith	1	24(11) N by E
	2006			4	4.6	5.6				
12	2005	1	Dakota	13	18.4	11.4		Towards bottom of hill	13	225(212) W by S
	2006			11	15.3	9.1				
21	2006F	1	Gunst		15.3	9.5		Close to monolith on east side	5	315(302) W by W
Area 2 Plants on a Dakota hill; south of two monoliths; and at their base.										
4	2005	1	Dakota	14	19.1	12.7		On hill	12	245(32) SW by W
	2006			11	18.5	9.9				
5	2005	5	Dakota	(on 3 heads)				On hill	12	245(32) SW by W
	2006			7 (on 3 heads)						
	2006F						Bottom head yellowish			
6	2005	1	Dakota, Some Tr	0	x	x		Near base of hill (transitional slope)		350(337) NNW
	2006			–	–	–	Dead			
Area 3 Soils derived from Gunsight; Dakota; and Tropic shale alluvium with Dakota or Straight Cliffs sandstone.										
13	2005	1	Gunst	15	19.7	8.9		Near monolith	6	220(207) SSW
	2006			13	18.0	8.4				
	2006F				18.7	7.6				
14	2006	4	Dakota	0	51.0	5.1	No flowers	On hill	4	345(332) NNW
	2006F						Looks dry			
22	2006F	1	Tr + D or S		14.0	6.0		Flats	3	312(299) NW by W
23	2006F	3	Tr +D or S + G					Flats	3	312(299) NW by W
24	2006F	7	Tr + D or S + G				Parent body yellowish	Flats	3	312(299) NW by W
25	2006F	10	Tr + D or S					Flats	3	312(299) NW by W

Table 2 (continued). ***Sclerocactus*** **Plants in Their Areas at Cottonwood Canyon, South to North**

Plant No.	Year[1]	No. of Heads	Parent Rock	No. of Flowers[5]	Height cm	Width cm	Condition[2]	Location	Slope[3]	Bearing[4]
27	2006F	2 (two plants)	Tr + D or S	E21.6	8.9			Flats	3	312(299) NW by W
				W21.0	8.9					
28	2006F	1	Tr + D or S	7.6	5.7			Flats	3	312(299) NW by W
9	2005	1	Tr + D or S	7	16.5	9.5		Flats	4	277(264) W by S
	2006			5	16.5	9.5				
	2006F				17.8	8.6	Some yellow at base; apex doesn't look good			
10	2005	4	Tr + D or S	12				Flats	4	277(264) W by S
	2006			10						
	2006F									
30	2006F	2	Tr + D or S					Flats	4	277(264) W by S
31	2006F	1	Tr + D or S + G?		13.3	5.1		Flats	4	277(264) W by S
Area 5 Soil derived from Tropic shale alluvium, with very minor Dakota or Straight Cliffs sandstone										
7	2005	3	Tropic	0				Flats	2	274(261) W by S
	2006			–			Dead			
8	2005	1	Tropic	22	31.1	21.6		Flats	2	274(261) W by S
	2006			27	23.6	10.4				
18	2006	2	Tropic	2				Flats	2	274(261) W by S
29	2006F	1	Tropic		10.2	5.9		Flats	2	274(261) W by S
Area 6 Soil derived from Tropic shale alluvium and Dakota or Straight Cliffs sandstone.										
20	2006F	x	Tr + D or S	x	x	x		Flats	4	271(258) W by S
Area 7 Soil derive from Tropic shale alluvium and Dakota or Straight Cliffs sandstone.										
19	2006F	6	Tr + D or S					Flats	2	208(195) S by W

[1]Denotes Fall (September), otherwise May; [2]Blank if plant is healthy; [3]In degrees; [4]Degrees magnetic, uncorrected, corrected; [5]In May; includes buds; x denotes a missing measurement, multi-headed plants usually not measured; – dead plant, not relevant

Note: Plants 1-3 and 15-17 were south of the 6 km area, scattered in the desert

Figure 3. Film 3. Anthill (bottom right) and rock are still there. Top photo April 1962. Bottom photo September 2006, no live plants and 8 dead plants found.

cused my efforts near the road and didn't investigate close to the scattered Entrada monoliths or the Dakota outcrops at the base of the hogback hills, so it's not known if or how much this species may have colonized other soils than the predominantly clay soils of the flats. As I searched for plants in 2005, I found only five in the two somewhat different clay soils of the flats where they once were so numerous, and saw that some grew in two other soils.

A more diverse flora was found in sandier soil around the base of the monoliths than on the flats. Cover was sparser, and exotic weeds not as prevalent as on the flats, so the cacti had less competition and were more visible. A few cacti were growing on rockier lower slopes of hogback hills of the Dakota Formation, where weedy plants were also fewer. Overall, *Sclerocactus*, sensitive to competition, more often than not was found next to what bare spots remained.

Even in the most badly faded old photos, a number of cylindric cactus shapes with rounded apexes can be distinguished, especially in large prints, or those oversharpened in PhotoShop (those interested may contact the author for original jpegs). The five 1962 scenes each show tens or even over a hundred Sclerocacti in a rough count/ estimation from photos. In matching contemporary

Figure 4. Film 5. Top photo April 1962: “Poster edges” (40%) in Photoshop makes cacti stand out but darkens bare ground. The few live plants are hidden in vegetation and cannot be seen in this large area photo. Bottom photo September 2006: one live plant and two dead in area shown. Outcrops of the Cannonville member of the Entrada formation at top of photos are larger in 2006; photo point is closer.

scenes, none to four live plants each were found in three field visits, and from none to eight dead plants.

Unvegetated ground sometimes cannot be easily distinguished in the black and white versions of the old photos because the litter and surface gravel makes it look dark.

Other Documentation

There is no written documentation of when cheatgrass moved into Cottonwood Canyon in abundance, but it appears to be in 2005. The website of A. E. Graves, a San Francisco photographer, shows a scene in Cottonwood Canyon in June of 2004, matched approximately in May 2006. Cheatgrass was much more abundant in the 2006 photograph of the same scene.

In scans of slides of the Austrian cactophile Gerhard Haslinger from 1991, 1993, 2000, and 2002, no abundance of cheatgrass is shown. Shrubs were smaller and more bare ground exposed than in 2005-2006. Haslinger, who is especially interested in the rarer species of *Sclerocactus* and *Pediocactus*, visited the southwest on extended trips almost every spring from 1988 to present.

Figure 5. Top left, film 4, April 1962: unmatched scene. May 1962: white flowered plant at bottom left; above, plant with pale pink flowers at left, one with pink flowers at right.

Habitat

S. parviflorus is more of a soil generalist than the small endemic species of the genus such as *S. wrightiae*, *S. brevispinus*, *S. spinosior*, *S. pubispinus*, and others, being found in both sandy and clay soils, or cobbled stream terraces. Here it occurs in four kinds of soil.

Sandy soil is close to and derived from the weathering of monoliths of the Gunsight member of the Entrada, or from the Dakota formation of the hogback hills.

Two kinds of clay soils are from the soft Tropic shale alluvium that washes down from the strike valley to the flats sloping gently to Cottonwood Wash. Added are components from the three sandstones, Entrada monoliths, Dakota Formation, or Straight Cliffs Formation at the edge of the Kaiparowits uplift. Cottonwood Road roughly divides soil with more sand, from soil with less sand; below the road the plant association is greasewood (*Sarcobatus vermiculatus*); above the road, greasewood is mostly lost to sandier soil and the association is shadscale-grass.

Average annual precipitation at Brigham Plains monitoring station nearby is 13.8 cm (5.43 inches). Most is received in winter as rain or snow and during monsoons as rain. Range types are rated as Alkali Flat (Greasewood) and Desert Loam (GSENM 2006).

Elevation of *Sclerocactus* locations ranged from 1408 to 1494 m (4620-4990 feet). Exposures in the flats, sloping to the wash to the west and also from north to south, are from South by west (SbW), through West by south (WbS) to Northwest by west (NWbW). Exposure of plants situated close to monoliths and on hills is more varied, from 24° to 350°. Slopes on flats are gentle, from 2° to 4°, and otherwise from 1° to 12°; *Sclerocactus* doesn't grow on steep slopes.

Plots

Data were organized for the possibility of establishing plots to monitor the *Sclerocactus* and its environment, should resources be available.

Discussion

In 2002 the cacti could still be seen while driving by, yet could hardly be found in 2005. This

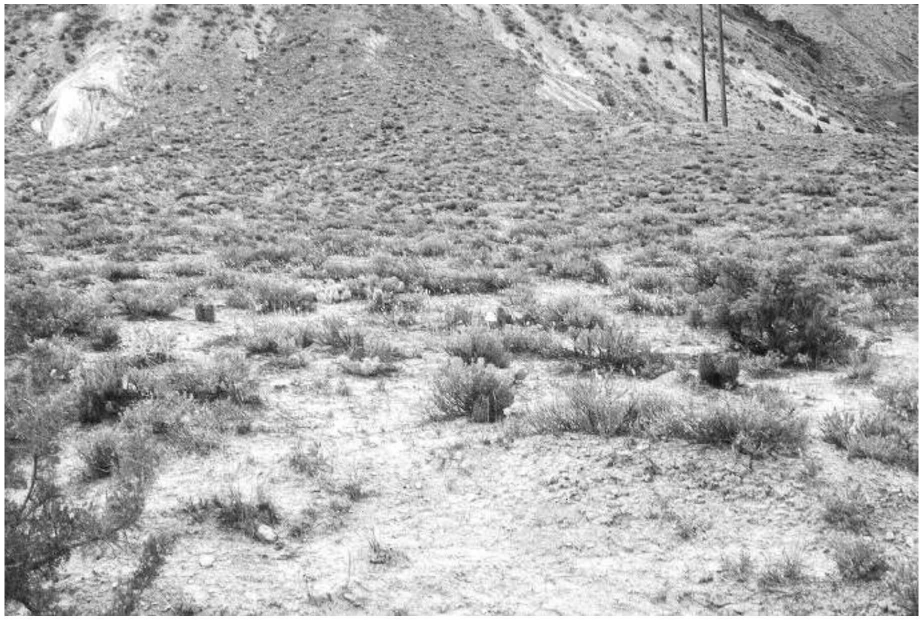

Figure 6. Early summer 1991 in Cottonwood Canyon. No flush of cheatgrass seen. *Sclerocactus* is common but not prolific, as shown in this and other photos from Gerhard Haslinger.

was puzzling. Why was the population so diminished in three years? And if there was significant beetle kill, where were the dead plants?

S. parviflorus is the second-largest species its genus, second only to the genus' "giant", *S. polyancistrus* of California and Nevada; it's not an insignificant plant. One cause of this "disappearance" was abundant cheatgrass. In their reports the Utah Division of Wildlife Resources (2006) relates that even sage plants disappeared into the cheatgrass of 2005. Though it was green on the spring trip of 2005 as well as super-abundant, and dead in spring of 2006, it was only in September of 2006 when it was not only dead but down that significantly more plants could be seen.

In the drought year of 2002 there wasn't much cheatgrass, which partly explains how plants could still be seen from the car then, and be so difficult to find in the springs of 2005 and 2006; alive and dead, they were hidden in the much more abundant and flourishing cheatgrass. This contradicts the fact that cacti are normally easiest to see in the spring when they are blooming.

As to the "disappearance" of dead, beetle-killed plants, to cows dead Sclerocacti are a less visible obstacle (to be avoided) than live ones. Though the timing of deterioration of dead *S. parviflorus* carcasses is not well studied, dead plants stand and then gradually morph into heaps of spine clusters. It's probable that when this area was being used as a stock driveway, a herd of cattle walking on the dead plants, especially when hidden in cheatgrass, broke them into pieces indistinguishable from other litter.

Important factors affecting *Sclerocactus* success are variables in grazing, which with large domestic animals means trampling as well as ecosystem effects, competition including exotic plants, fire, weather variations, herbivory from insects and smaller animals such as rabbits, human disturbance including theft, and fire.

Grazing

Cacti vary in their response to domestic grazing, depending on conditions and species. *Opuntia* species are considered increasers under grazing conditions, and they generally are. Opuntias successfully reproduce vegetatively, so they can easily regenerate after trampling. Members of the subfamily Cactoideae such as our Utah barrel, hedgehog, and ball cacti, do not reproduce vegetatively. When trampled, individual Cactoideae may grow new heads from the remains, but often do not. Because of their succulence, injured cacti are vulnerable to microbial pathogens. Smaller individuals and smaller species are especially at risk, and Cactoideae are slow-growing. For example, in discussing cattle grazing with respect to *S. mesae-verdae*, a small species, quoting from a Bureau of Land Management (BLM)-funded report, "the great danger the populations faced was being trampled on as cows moved from one grazing area to another," as reported by Forest Guardians (2004:1). Once cacti attain a size such that grazers readily notice them, or when sheltered in shrubs, the animals will walk around them. Cattle had just grazed immediately south of Cottonwood Canyon in May of 2005. Cheatgrass was trampled and flattened but not in or next to shrubs or clumps of cacti. Cattle try to walk around obstacles.

At one time the flats in our 6 km area must have had a good cover of native perennial grasses. The cacti would have been in balance with associated flora before overgrazing occurred. For a good example of cacti in balance with grasses and other associated flora, see the pioneering study of an ungrazed area in Canyonlands with intact cryptogams by Kleiner and Harper (1972 and others); *Opuntia polyacantha*, the common hardy dry-fruited pricklypear, and *Sclerocactus parviflorus* lived in a natural state.

Kleiner and Harper discuss the effect of domestic grazing:

> Species which are characteristic of pristine sites may increase or decrease under grazing pressure. In the case of a grazed community, an investigator may never know whether the species now occupy their optimum habitat. It is possible they occupy a larger or smaller niche than would be the case under virgin conditions or they may not occupy the niches compatible with an optimum balance of nature under the given conditions [Kleiner and Harper 1977: 288]

As the 1962 photos show, overgrazing in Cottonwood Canyon reduced competition severely, and the Sclerocacti prospered. When first seen in 1962, due to some fortuitous combination of circumstance and despite the large volume of use by sheep and then cattle, the plants successfully became large enough or sheltered in shrubs, avoided trampling and thrived.

For decades, grazing, first by sheep and then cattle, was uncontrolled in Cottonwood Canyon, now included in the 6751 acres of the Cottonwood Wash Pasture. Through the years, BLM grazing regulation increased. Records are sketchy. The Cottonwood Management Area was established in 1972. In 1978 it was divided into the Coyote Allotment for Kanab users, and the Cottonwood Allotment for Bryce Valley users, and management plans formulated. In 1984, a grazing system revision was made, although in 1987 it was noted that further revision was needed to make the system work. In recent years Cottonwood Canyon was used only as a stock driveway. There are several, contentious permittees, and the area has always been problematic. The rules were not well enforced until BLM Range Specialist Sean Stewart started in 2003 to manage the 12 pastures of the Cottonwood Allotment (one of them being Cottonwood Wash). There is less grazing at present there than ever before. Grazing administration was taken over by the Kanab office of GSENM in fall of 2005. (This paragraph: grazing files, GSENM Cannonville office May 16, 2005; personal communication, Sean Stewart 2006).

As photos and 2005-2006 observations show, with the gradual reduction of grazing, cottonwoods along the wash improved. Erosion reduced, particulary in side washes. Shrubs increased in size, percent vegetative cover, and health. Galleta grass recovered somewhat, but Indian rice grass did not recover well. Percent cover of bare ground decreased significantly. Early-stage cryptogamic cover increased. Native forbs appeared. As shown by Dr. Haslinger's photographs of 1991, 1995, 2000, and 2002, density of Sclerocacti decreased with increased competition, though still abundant in these years.

Competition

Sclerocacti do not tolerate competition. Their strategy is to send roots shallow and far. With the great reduction in competition due to excessive domestic grazing, a wider niche opened up for them. Surviving plants seen in the flats in 2005 and 2006, though mostly surrounded by cheatgrass, were next to bare spots. In the smaller square footage of soils near monoliths or at the base of Dakota hills, in 2005 and 2006 Sclerocacti were more successful per square foot in those locations than on the flats where cheatgrass was prevalent.

Even in a garden with adequate water, Sclerocacti that *Opuntia* plants or weeds were allowed to encroach upon too closely would be found dead in the spring (D. Woodruff, unpublished research 1963-1964).

Exotic Plants

It's possible for exotics to invade without preexisting degradation of the natural environment, but overgrazing with its accompanying severe and lasting effect on the environment makes it easier for them. For instance, in the southeast corner of GSENM,

> …disturbance of soil crusts greatly accelerates the invasion process…Intact soil crusts often present a physical barrier to invasive species establishment and growth by preempting space…germination of native *Stipa* was not affected by soil crust cover, while germination of *Bromus tectorum* was inhibited by intact crust….[Stohlgren et al 2001: 48]

High rainfall after the 2002 drought brought a flood of exotics, mostly cheatgrass and an annual mustard. An explosion of cheatgrass was common all over the state in 2005 (e.g., Utah Department of Wildife Resources 2006); less was observed in the Cottonwood Wash area in 2006, but it was still abundant.

Because of the great variety of rock formations in the Colorado Plateau and therefore in soils derived from them, as well as all the other environmental variables of the Plateau, cheatgrass was slower to invade here because it had to adapt to these soils and other variables (pers. comm. K. T. Harper 2000). But now it has become a menace to native ecosystems on the Plateau. Cheatgrass and other exotics flourish in clay soils of the flats, but not so much in sandy soil around the Entrada monoliths or on Dakota hills.

Cheatgrass takes up moisture and nutrients early in the spring before cacti resume growing. In general, native perennials don't compete well with cheatgrass. It's not known how much of a threat cheatgrass is to *Sclerocactus*, but it seems likely that it is strongly disadvantageous. As cheatgrass germinates in the fall, it's likely to be competitive to vulnerable *Sclerocactus* seedlings. Janet Coles (2004) sees evidence that considerable *Sclerocactus* seedling emergence occurred in the fall. A GSENM Technical Report concludes,

> One of the great ecological threats to the Monument is the spread of non-native invasive plant species, most notably annual grasses…. Because of its strong competitive ability, cheatgrass has replaced seedlings of many native perennial grasses and shrubs….Because germination occurs in the fall, cheatgrass is able to continue growth of its root system through the winter months. The early establishment of its root system allows cheatgrass to acquire water and nutrient resources earlier than other non-established perennials. Because water is a limiting factor for growth in arid and semi-arid environments…removal of water from the upper soil profile by cheatgrass can result in plant depth or a reduction in reproduction success for native species….[Chong 2004:49-50].

Fire

Cheatgrass is well understood to increase fire frequency in a vicious cycle that destroys ecosystem integrity (e.g., Brooks et al 2004). Unlike *Opuntia* which for some species and fire circumstances can recover well from fire, *Sclerocactus* has little capacity for vegetative regrowth from such an event. Not much literature is available on the response of the species of the subfamily Cactoideae to fire. In general, "Succulents fare poorly…The fire effects literature states for many of these species that fire is not common in their habitats due to lack of fuel to carry it" (Gebow and Halvorson 2005:4, 6). But invasion of cheatgrass provides ample fuel, and the damage to cacti is proportionate to the amount of fuel (Gebow and Halvorson 2005:13). If a cactus isn't killed by the fire, its spines can be burned off and then it has no protection from herbivory. In fact, since cacti are nutritious, ranchers in Texas commonly burn the spines off pricklypears so that cattle can eat them without getting "pearmouth", leading to possible infection and ulceration (Uekert 1997).

Drought

Cacti are buffered from drought to some extent by their succulence, more so in larger cacti vs. smaller cacti. Efficacy of this buffering for an individual cactus may be exceeded during a drought of sufficient intensity. The drought in 2002 was severe. Its effect was drastic on many monitored *Sclerocactus* local populations. Only species of small, rare *Sclerocactus* have been monitored, but the following quotations give some indication of the effect of drought on members of the genus:

For *S. wrightiae*:

> In a 1986 report no mention was made of drought impacting cactus, whereas in 2003 drought conditions were noted along with cattle impacts and ATV traffic as possible threats…Several of the sites revisited in 2003 were so stricken by the drought that many perennial shrubs had died, so it is not surprising that a majority of the sites had fewer cacti than reported in 1986 [Clark and Groebner 2003:9-11].

For *S. mesae-verdae*:

> Until the severe drought of 2002-2003, the species appeared to be roughly stable in population numbers… The Four Corners region experienced a historic drought from the period April 2001 through July 2003. The drought not only caused direct mortality of Mesa Verde cactus plants, but also created conditions for animal and insect predators to increase their effects on the cacti. Other indirect effects include more than 70% reduction in the cover of mat saltbush (*Atriplex corrugata*, *A. gardneri*, *A. confertifolia*), which may act as a nurse plant to Mesa Verde cactus seedlings. Flower and fruit set was near zero throughout the drought, as was establishment of seedlings…Overall, between April 2002 and April 2003 the three Colorado plots experienced a 20.4% decline in population…The high mortality we observed was unfortunately not limited to Colorado. The state of New Mexico reported an 80% decline in numbers of Mesa Verde cacti in their study plots [Muldavin, et al. 2003], and the Navajo Heritage Program reported 85% mortality in their plot [Roth, pers. comm. 2003] [Coles 2004:3-5].

Herbivory

Sclerocactus has a cyclic relationship with the cactus borer beetle, *Moneilema semipunctatum*, also called cactus longhorn beetle (Smith 2003), a flat-faced Cerambycid. The beetle finds a colony of *Sclerocactus*, wipes it out or at least greatly diminishes it, then has to find another population. Though flightless, it's a big beetle and can walk fast. Eggs are laid near the cactus, then the larva burrows into the plant, and eats it from within. *Sclerocactus* almost always succumbs, a case of not if, but when. Sometimes a head damaged by a larva (or stepped on by a grazer) will sprout from the remains, but most often not. The larvae favor mature plants, so juveniles may escape being eaten.

A cactophile of many years' field and greenhouse experience with native cacti of the Southwest, Ralph Peters, discussed this cycle on the Cactus Etc email list:

> I have visited some locations over many years (>15 yrs) and have noticed that many populations have a very pronounced cyclic nature resulting from depredation by a borer…The plant dies from the bacteria or from direct damage by the voracious borer. I have seen many other populations at various stages in the cycle. A successful colony, in this context, is one that has many viable seed stored in the ground (the "seed-bank"). Bad weather, borers, etc., may damage the colony but not eradicate it IF there are lots of seed in the ground [Peters 1998].

Although Peters' 1998 examples of borer-affected populations of *S. polyancistrus* and *S. mesae-verdae* began with 1983, an early published report of a borer infesting the genus *Sclerocactus* was evidently the 1984 *Mesa Verde Cactus Recovery Plan* (U.S. Fish and Wildlife Service 1984) which noted attacks on that species. Kass (2001) in a much-referenced paper in proceedings of a 2000 confence wrote about *M. semipunctatum* and *S. wrightiae*. The abstract of Coles and Naumann (2000) from the same conference stated, "The cerambycid beetle *Moneilema semipunctatum* is the principal agent of major mortality events" during a long-term study in Colorado of *S. mesae-verdae* but this was not published. A NatureServe webpage on this species reported:

> Predation by the cactus borer beetle *Moneilema semipunctatum* may cause short term population fluctuations. Significant mortality events caused by the beetle have been recorded at two of the Colorado plots: one in 1988, the other in 1994-1995. A third event began in 2000 in the same plot that experienced the 1988 infestation. Plants in these plots continue to recover slowly from the die-off of large stems

> caused by the cactus borer beetle larvae, although response to the infestations differs between plots (Coles 2003). In 2003 large areas of *Sclerocactus* mesae-verdae suffered massive die-off due to drought followed by insect infestation. Several sites had 100% mortality [E. Roth et al 2003].

C. I. Smith also wrote about *M. semipunctatum* as a predator of *S. mesae-verdae* in 2001 in an unpublished report (USFWS 2006). Renée West (2005) found *Moneilema* sp. infesting *Escobaria sneedii* var. *leei*, Lee pincushion cactus, at Carlsbad Caverns NP that spring. In the same article (West 2005:3) New Mexico's rare plant botanist Robert Sivinski is quoted, "Most of the adult Mesa Verde cacti and Brack's cacti [*Sclerocactus cloverae* ssp. *brackii*] in San Juan County were wiped out three years ago [2002] by this, or the similar species, *Moneilema semipunctatum*."

Knowledge that *Sclerocactus* and other members of the subfamily Cactoideae are now hosts to *Moneilema punctatum* has been slow to spread. In 1984 Linsley and Chemsak in their authoritative series *The Cerambycidae of North America* reported that *Moneilema punctatum* was known to host only on *Opuntia* and *Cylindropuntia*. In a report of rare insects of Mesa Verde NP, Boris Kondratieff (2000: 2) wrote that "Larval hosts [of M. punctatum} are *Opuntia* spp." Again Arthur Evans (2006: 250) wrote in a field guide to California beetles that this beetle's hosts are certain *Opuntia* and *Cylindropuntia* species.

When some of the plants in a population don't bloom, borers are suspect (e.g., plant 7, Table 2), or the epidermis of an infested plant may have a patch of yellowish or reddish discoloration. The apex of the plant may look dry and shriveled, the color of spines faded, or both.

After a population is more or less wiped out by borers, it has to re-establish from the seed bank. Since borers prefer larger plants, if recruitment is successful, the new plants have time to grow into flowering size and produce seeds.

Identifying cause of death of a cactus plant, and therefore assigning mortality by beetle borers, may be problematic. A just-killed plant may sometimes be recognized, opened, and the cavity and typical red color of post-traumatic microbial invasion seen. If granules of dry flesh remain in a dry, dead plant, it's possible to determine if it was killed by a borer by the large hole inside, above the base of the plant. However, in my experience massive die-off of *S. parviflorus* is always beetle kill, and no such die-offs were observed before the beetle began affecting *Sclerocactus*.

Spine clusters remain after the plant epidermis and tissue die and dissipate, at first still assembled in the form of the live plant. But no one has reported how long the spine clusters of a dead plant are identifiable under different conditions such as trampling, wind, and excessive weed growth. Spine clusters of one plant seen alive in 2005 were already beginning to dissipate in 2006. Heaps of flattened spine clusters would soon become unrecognizable. Specific georeferenced dead plants could be monitored from year to year to document how fast they degrade to litter.

A plant weakened by drought could succumb faster to a beetle larva. Mattson and Haack (1987) detail how drought is synergistic with herbivory in affecting plants.

Melyridae beetles were found in the flowers of many of the plants. Their function in cactus flowers is unclear. Vince Tepedino of the USDA Bee Lab at Utah State University, who identified them, says: "They are common in the flowers of many plant species in the western U.S. and some (Mawdsley 2003) think they are important pollinators. Others of us (like me) are more skeptical." (Tepedino, email, Aug 15, 2006).

Herbivory other than from beetle larvae didn't appear to be a significant source of morbidity or mortality to this population. The most significant herbivory by mammals observed was just north of the study areas described on the flats, where the canyon narrows. Chewed-on *Sclerocactus* plants, if not succumbing to rot, develop heads around the damaged area, often termed sprouts. These heads are usually low on the plant. Several large plants at the above location displayed a curious shape, with several heads near the tops of the plants. One individual had a fresh green eaten area near its top, demonstrating the kind of damage that would lead to these strange specimens. Jackrabbits were prevalent here. No dead plants with this configuration were seen.

Human Disturbance, Including Theft

When Cottonwood Road was first constructed the *Sclerocactus* population must have been disturbed by construction. As numerous as the plants were, vehicles or machinery necessary for construction would inevitably have impacted some cacti. By 1962, one powerline had been built through the canyon parallel to the road. Later, a second one was constructed close by. With the population then thriving, it's not probable that this had a long-term effect.

Doubtless some of these plants were removed through the years for gardens, or by cactophiles as specimens or a source of seed. Again, with a large population and little visitation, the consequences would have been minimal, unlike when small populations of scarce endemics are removed for sale by dealers.

Increased visitation adds temptation by increasing exposure. However, Monument status, though increasing visitation, also increases regulation. Visitors are restricted to roads and almost all either sightsee from their vehicles or hike the canyons. BLM Law Enforcement Officer Don Riddle (pers. comm. 2006) reported no known instances of theft, though such instances may not be noticed.

White Flowers in S. parviflorus

White flowers are known, but very rare. Most *S. parviflorus* have vivid pink flowers. Yellow flowers are less common. They did or do occur in Glen Canyon, on the east bank of the Colorado River below its confluence with the San Juan, on the south bank of the San Juan upstream from the confluence, and just east of Navajo Mountain, possibly from old or continuing introgression with the yellow-flowered *S. whipplei* of the Navajo reservation and environs—DNA study could show if this is truly the case. Yellow flowers are predominant in two isolated populations in Utah, one around Torrey and one above White Canyon near Natural Bridges (Heil 1979; Heil and Porter 1994).

Other than that, this species has pink flowers, with very rare exceptions. Though occasionally reported, in many years of study of *Sclerocactus* my personal experience of white flowers is limited to Cottonwood Canyon; an herbarium specimen at NAU from Navajo National Monument; one in an odd-flowered batch from Glen Canyon before the lake; and one in the yellow-flowered population near Torrey.

The white and pale pink flowers seen here in 1962 may still be hidden in the genome of the Cottonwood Canyon plants but not expressed in the relatively few live plants seen in 2005-2006.

Conclusion

Emphasis in cactus research has changed in the years between the 1960s and now, from finding new species of cacti to understanding the species and their ranges better and studying what happens to populations.

When I first drove this road and saw the Sclerocacti, I was in the middle of the story. The Flats were barren, native annuals not visible, and shrubs broken and small. Dead shrub wood was prevalent. No cryptogams were observed; however, snakeweed and tumbleweeds were increasers with grazing. With reduction in competition due to excessive domestic grazing, a wider niche opened up for the *Sclerocactus*.

Of the native grasses, *Pleuraphis jamesii*, gal–leta grass, has persisted better than *Achnatherum hymenoides*, Indian ricegrass, but even now with less grazing, it's not common, and seen mostly in the protection of shrubs or cacti.

In sandier soil around the base of the monoliths, and at the base of the hogback hills where cheatgrass has not invaded, the Sclerocacti may have found a refuge, from which they could spread if conditions were to improve.

Sclerocactus parviflorus is more resistant to drought than the smaller species of the genus, but it can be affected. The succulence of the plants damps down fluctuations in available water, but extremes will overcome this damping. Drought is shown to make plants more susceptible to insects.

Current data cannot verify exactly what happened to these cacti. Some combination of grazing and its effect on the ecology, drought, insect predation, and invasion of exotic plants are the likely factors. I was puzzled in 2005, since I could still see plants in 2002 while driving by, how it could be so difficult to find plants in just three years. Locating many more dead plants in fall 2006, when cheatgrass was dead and down, made this less mysterious. Cheatgrass hid them in the spring. Many died quite recently, weakened by drought and attacked by borer beetles. Since beetle kill itself can account for such massive die-off, the abundance of cheatgrass is likely to be of more importance to recovery of the species through its influence on recruitment from the seed bank than to the die-off per se.

Although sufficiently abundant to be seen from the road in 2002, their numbers had probably declined slowly over the years since 1962, as the grazing which reduced competition so much was itself reduced. Their abundance in 1962 was unique, because *S. parviflorus* is not normally seen in much-abused environments, or just a few may survive in protected places such as rock outcrops.

What happens now? We don't know how genetically distinct this population is, or was, in the Flats. Widely scattered specimens, within the distance introgression can be promoted by bees, can be seen occasionally from Cottonwood Road south of the canyon in favorable soil: in the open desert just to the south, and then again just north of highway 89, they are also reported away from Cottonwood Road in open desert.

Is this Cottonwood Wash population different genetically from other *S. parviflorus* populations? Perhaps the size and abundance of these plants was due to nurture, not nature—growing conditions rather than genetics. The number of white and pale pink flowers was unusual, but this may be due to expression in a large population. If the Cottonwood Canyon population should be different genetically, that would be more motivation for active management.

Management Considerations

What can be done to enhance this population? Monitoring is needed to understand its present baseline condition. Going back again in 2006 I found plants that were dead since the previous year, or impaired (Table 2). Not much recruitment was seen. Recruitment in cacti that reproduce by seed is known to be episodic, with a long period between years favorable for seedling emergence and survival. Beetle predation is also episodic, as mature plants are killed and juveniles and young adults replace them. So monitoring would best be long-term. Spring is favorable for assessing health through the success of anthesis; fall is favorable for finding cacti, unmasked by cheatgrass.

Potential intervention could control the borer beetle. Little information is available on controlling cactus borer beetle per se, though horticultural publications on borers in general may be helpful, such as Townsend (2006) or Starbuck (2003). Sickly plants, those already affected, could be treated, but once the larvae are inside the plant, they're hard to reach and kill. Treating all known *Sclerocactus* plants in the area when beetles are laying their eggs, or perhaps after larvae hatch but before they enter the plants, could be successful.

Not much study has been done on what agent would be effective to kill larvae once inside plants. One study concluded that Knox-Out, a diazinon formulation, was the most effective treatment (Dimmitt 1995); however, diazinon is no longer available. Injection of insecticide into the cavity where the larva is feeding is suggested for the larvae of *Cactoblastis* (another significant cactus predator), also the use of new generation systemic insecticides; however this could be tricky in regard to effective duration vs. pollinators (Zimmermann et al 2004).

After two applications of a strong dilution of triazicide by a Utah Native Plant Society member who has a large cactus collection, he found dead larvae near the plants (pers. comm. Kipp Lee, May 2006). Triazicide, a synthetic pyrethrin, is a replacement for diazinon.

Evidence of a large amount of mortality in this species was not reported before the 1980s, indicating that this beetle predation is not a normal part of *Sclerocactus*' recent evolutionary cycle. Also, plants in general have evolved sophisticated biochemical defenses against predators, and *Sclerocactus* appears to have little or no defense against *Moneilema*.

Nor is competition with the invasive exotic plant cheatgrass a part of *Sclerocactus*' previous evolutionary experience. Persistence of the species in GSENM is heavily dependent upon successful recruitment from the seed bank, and it is well understood that cheatgrass strongly competes with native species' seedlings (e.g., Chong et al 2004). Being slow-growing from seed, *Sclerocactus*' tiny seedlings are especially vulnerable during their first year or so.

Once considered difficult to germinate from seed, at least three Utah cactophiles are successfully growing *Sclerocactus* species. Nursery-grown plants from local seeds could be set out in favorable locations and in favorable seasons to attempt to replenish the population. With a large number of nursery-grown seedlings, perhaps the rare white flower form would be expressed.

Seeds could be collected from mature nursery plants for distribution in favorable locations to augment the on-site seed bank. We are just becoming aware of the activities of seed harvester ants, and what effect that might have on the seedbank onsite. I returned to collect seeds in July when the fruits ripened and to see if ants harvest many seeds in this location. Seeds can usually be found at the base of the fruits, caught at areoles down ribs, or at the base of the plant; I could find very few seeds in September.

Some managers are loath to graze to control cheatgrass because the spring-growing Indian ricegrass would also be affected. But Indian ricegrass can't compete with cheatgrass. According to Utah BLM Range Management Specialist Bob Stager (telephone call, Dec 2006) intense grazing early in the spring to control cheatgrass, so-called flash grazing, would favor a return to a less degraded condition. Lee Hughes, the BLM Arizona Strip ecologist (pers. comm. Dec 7, 2006), says that cows preferentially eat the tender young cheatgrass. This grazing would at least decrease the probability of fire, which is devastating to the environment and favors more cheatgrass. Using this pasture as a stock driveway is disturbance without any positive effect. Another measure is to plant wheatgrass, which can compete with cheatgrass, as native perennial grasses cannot. Pathogens to control cheatgrass are in development.

The story of this plant is a demonstration of how destructive unrestrained domestic grazing can be. *Sclerocactus* profited in the short run from overgrazing, but degradation of the environment made it vulnerable. It would be desirable to see a sustainable natural balance of cactus and other native flora, and this prime area returned to an earlier, less degraded stage of succession.

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The Emergence of Grand Staircase-Escalante National Monument as a Center for Long-term Ecological Research on the Colorado Plateau

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ABSTRACT

Occupying 1.9 million acres of the Colorado Plateau physiographic province, the Bureau of Land Management's Grand Staircase-Escalante National Monument is characterized by gradients in elevation, climate, soils, land-use legacies, and contemporary management regimes that provide a rich matrix for ecological research and monitoring. In the years since its establishment in 1996 as the largest unit in the Bureau's National Landscape Conservation System, the Monument has served as a unique field laboratory for studies investigating a wide range of ecological topics including: broad-scale patterns in plant community composition; the importance of climate and substrate characteristics as factors driving the distribution, structure, and functioning of biological soil crusts; responses of amphibians and terrestrial invertebrates to the cessation of livestock grazing; effects of livestock grazing on vegetation structure and soil biogeochemistry; and the status of arbuscular mycorrhizal fungi communities in relation to field measures of soil quality. In 2005, a promising new phase in the development of the Monument's science program was initiated with the opening of a science-support facility in Escalante, Utah, and with the housing of a U.S. Geological Survey scientist at Monument headquarters in Kanab, Utah. The latter event marks the establishment of a multi-agency science partnership with the Survey's Southwest Biological Science Center, Northern Arizona University, and the National Park Service's Zion National Park to increase opportunities for cooperation, collaboration, and scientific and technical support. Coincident with this new phase of science support and cooperation, new opportunities for ecological investigations are emerging in a number of key areas that will benefit from a regional perspective. Particular needs and opportunities include monitoring of long-term environmental change, restoration of damaged dryland ecosystems, application of research and monitoring to adaptive management of Monument resources, and development of approaches to address human dimensions of current and future resource management challenges.

Keywords: ecology, ecosystem dynamics, long-term monitoring, adaptive management, science-management interface, collaboration

Dynamics of Pinyon-Juniper Ecosystems – The Role of Climate and Land Use in Pinyon Recruitment and Growth

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Editor's note: This project resulted in the following publication:

Nichole N. Barger, Henry D. Adams, Connie Woodhouse, Jason C. Neff, Gregory P. Asner. 2009. Influence of Livestock Grazing and Climate on Pinyon Pine (*Pinus edulis*) Dynamics. *Rangeland Ecology & Management*: Vol. 62, No. 6, pp. 531-539.

ABSTRACT

Over the last century there has been a marked expansion of pinyon-juniper woodlands into grassland and shrubland ecosystems in the West. Although pinyon-juniper populations have fluctuated along elevational and latitudinal gradients with changing climate throughout the Holocene, over the last century local impacts such as livestock grazing, changes in fire regimes, and increasing atmospheric CO_2 concentrations are thought to be more recent drivers of pinyon-juniper woodland distribution. To better understand the role of historical livestock grazing in pinyon-juniper woodland dynamics, we examined pinyon stand dynamics on a near relict mesa site (No Man's Mesa) to a nearby historically grazed, mainland site (Deer Springs Point) in Grand Staircase-Escalante National Monument. No differences in pinyon density or basal area were observed across the sites. Stand age structure of pinyons showed peak recruitment occurred during the early 1900's across both sites; 16% and 17% of the pinyon trees on No Man's Mesa and Deer Springs Point dated to the period 1910-1920, which was a time period of above average precipitation across the Southwest. These results suggest that climate may be the primary driver of pinyon expansion rather than historical livestock grazing at these sites. The occurrence of old trees (> 200 yrs) across all transects provides evidence that pinyons have long been established at these sites and does not constitute expansion of the population into areas where they did not previously exist. Rather, these sites appear to be experiencing "woody thickening" with rapid recruitment over the last century. In addition, the occurrence of old trees across all transects suggests that stand replacing fires have been an infrequent event and supports the findings of other investigators in the region that fire return intervals may be > 400 yrs.

Keywords: pinyon age structure, pinyon recruitment, woodland expansion, livestock grazing, fire

Effects of Past Management Treatments on Vegetation Structure and Dynamics in Pinyon-Juniper Woodlands at Grand Staircase-Escalante National Monument

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ABSTRACT

Pinyon-juniper woodlands cover large expanses of land across the Colorado Plateau. Land managers, elected leaders, public groups, and the research community have been concerned with observed pinyon-juniper expansion corresponding with losses of open grasslands and savannas. This regional expansion is generally believed to result in losses of biodiversity, diminished wildlife habitat and livestock forage resources, degraded watershed quality, and detrimental impacts to recreational uses and aesthetics. In 2000, the Bureau of Land Management Colorado Plateau Managers Coalition adopted a regional Pinyon -Juniper Management Strategy. The primary purpose of this strategy is to present a framework for acquiring scientifically sound information to be applied and utilized in the long-term management of pinyon-juniper woodland communities on the Colorado Plateau. The Merriam-Powell Center for Environmental Research (MPCER) conducted a study in the summer of 2006 to address the effectiveness of past pinyon juniper treatments to support this framework. MPCER surveyed 25 treatments and control areas at Grand Staircase-Escalante National Monument. The treatments were conducted from 1963 to 1988 and the areas treated were chained and then seeded. Treated areas and control areas were surveyed for stand structure and seeding success.

Keywords: pinyon-juniper, biodiversity, vegetation treatments

Cheatgrass Performance in Relation to Soil Characteristics in Colorado Plateau Drylands

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ABSTRACT

Colorado Plateau drylands are characterized by tremendous spatial heterogeneity in soil properties that mediate the bioavailability of water and mineral nutrients. Landscape-level soil heterogeneity often translates to distinct spatial patterning in plant communities, including distributional patterns of invasive exotic plants. Since 1994, studies have been conducted in Canyonlands National Park to investigate cheatgrass (*Bromus tectorum*) relationships with soil properties and geomorphic processes. Experimental studies indicate that establishment and growth of cheatgrass in sandy, calcareous soils of this region are positively related to silt and clay content and the bioavailability of nutrients P, Mn and K. Resource limitations of cheatgrass performance appear to shift seasonally, from water during fall establishment, to nutrients during winter and early spring, and back to water during late-spring seed production. Among-soil variations in cheatgrass performance are greatest during winter and early spring, suggesting an important role for winter nutrient uptake in the generation of spatial patterns. Geomorphic studies demonstrate the occurrence of downslope trends in soil content of silt and clay, rock derived nutrients, and measures of soil magnetic properties along hillslope transects extending from sandstone outcrops to the bottoms of topographic basins. This pattern indicates geomorphic control of ecologically significant soil properties associated with cheatgrass performance, and it suggests that a geomorphic framework is useful for understanding cheatgrass patterns in Colorado Plateau drylands. Field measures of soil magnetic properties, when calibrated to establish landscape-specific relationships with measures of soil texture and nutrient content, may prove useful for conducting rapid assessments of site susceptibility to cheatgrass invasion.

Keywords: biogeochemistry, soil resources, plant invasions, cheatgrass (*Bromus tectorum*), eolian dust, soil magnetic properties

An Evaluation of the Dynamic Soil Properties Pilot Project in Arches National Park, Utah

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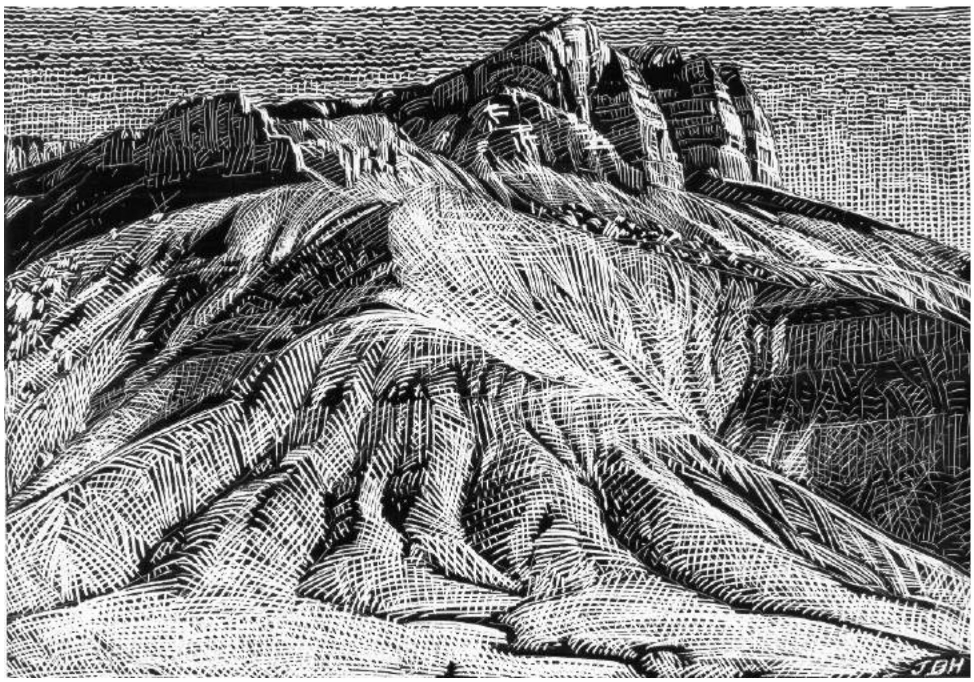
ABSTRACT

Dynamic soil properties are gaining increased attention by the producers and users of soil survey data. Information gathered on near-surface properties, along with vegetation characteristics, can provide soil survey users with important tools for management. Protocols for measuring the dynamic soil properties and interpreting the functions of soils are inadequately addressed in standard soil survey procedure; therefore, there is a need to define protocols for use in future soil inventories of the national parks or soil surveys. A pilot study for the collection of dynamic soil properties was conducted in Arches National Park in Utah in 2005. In addition to providing the park with information for evaluating and managing visitor impact on soils in the park, it was a chance to test sampling procedures, and refine the sampling techniques for use in National Parks or other soil survey areas throughout the country. The sampling was conducted on Begay soils under two plant communities of the Semidesert Sandy Loam (fourwing saltbush) ecological site, a mixed perennial grass/shrub community (PGSL), and a cheatgrass-invaded community (INL). Vegetation properties sampled included herbaceous production and basal and canopy cover, while soil properties included aggregate stability, bulk density, penetration resistance, carbon fractions and $CaCO_3$% for multiple depth intervals. A summary of the sampling procedures used, and an evaluation of those procedures, are presented.

Keywords: soil survey, dynamic soil properties, sampling, ecological site description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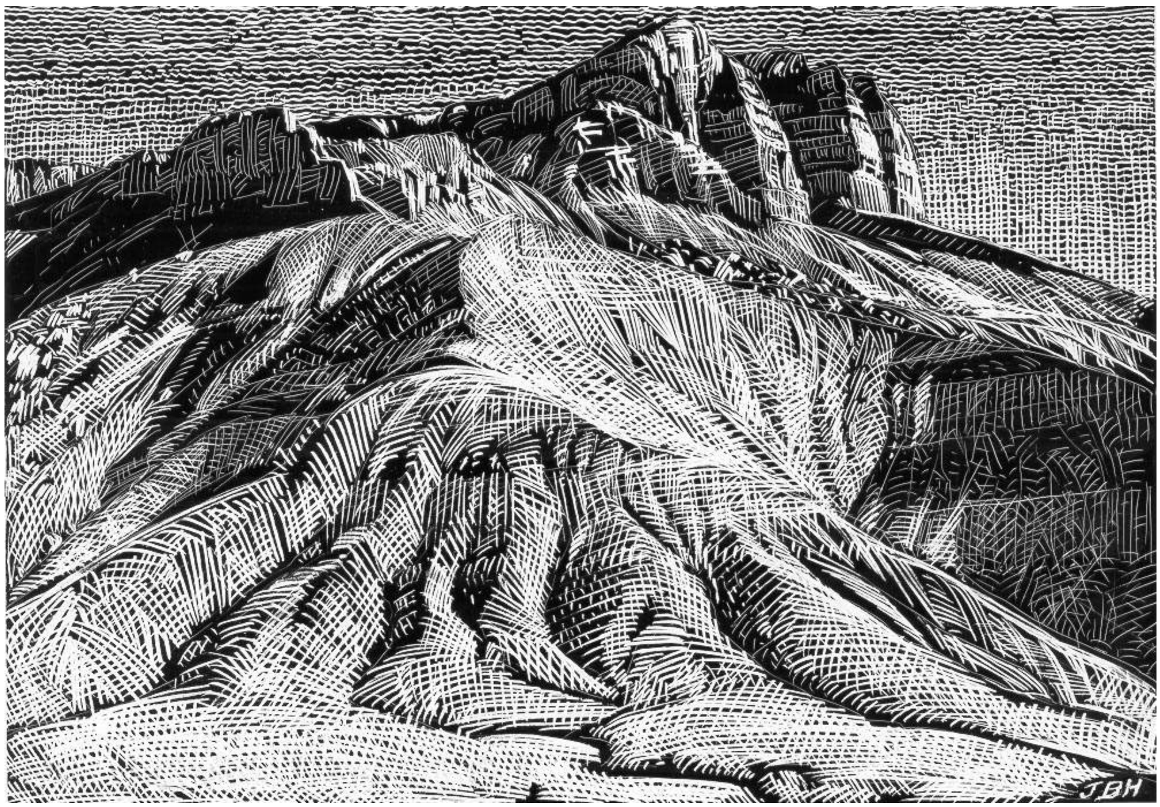

"On a rock we find a pool of clear, cold water, caught from yesterday evening's shower."

– John Wesley Powell, Explorations of the Canons of the Colorado –

Groundwater Discharge from the Navajo Sandstone in the Upper Escalante Basin

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ABSTRACT

In a region characterized by shallow soils and sparse precipitation, perennial streamflow in the Monument is limited to areas of groundwater discharge. Of the several water-bearing sedimentary units within the Monument, the most significant is the Jurassic Navajo Sandstone. This continuous, well-sorted eolian sandstone stores and transmits large quantities of high quality groundwater. Values for the thickness, saturated thickness, hydraulic conductivity, and transmissivity of this important regional aquifer are at or near their maximum within GSENM (Blanchard, 1987; Freethey and Cordy, 1991).

One of the most compelling – yet poorly documented – expressions of discharge from the Navajo occurs in the headwaters of the Escalante River. Over a distance of 20 miles, five tributaries (Pine, Mamie, Sand, Calf, and Boulder/Deer Creeks) enter the river and provide more than 95% of the baseflow for the entire 80-mile length of the river (Wilberg and Stolp, 2005). High rates of groundwater discharge in this area are presumed to reflect the combination of thick Navajo sandstone units overlain on Boulder Mountain by fractured basalt and volcanic colluvium. Previous researchers have hypothesized that the incised tributary canyons intercept groundwater before it reaches the river (Wilberg and Stolp, 2005).

In concert with several partners, BLM has initiated a multi-year hydrologic investigation in the Upper Escalante basin. Objectives include:

(1) Quantifying rates of groundwater discharge within the Monument;
(2) Documenting temporal variability in groundwater discharge;
(3) Describing source areas, flow paths, and travel times for select springs.

Meeting these objectives will provide a solid foundation for understanding the aquifer system that sustains the Escalante River.

Measurements of flow accretions and seasonal/annual variability rely on recurrent seepage runs and a network of streamflow gaging stations. Ongoing field work attempts to better quantify the magnitude and range of variability of groundwater accretions, to improve our understanding of groundwater flows paths and groundwater exchange between surface water systems, and to relate groundwater-surface water dynamics to ecological processes.

Keywords: groundwater, streamflow, Navajo Sandstone, Escalante River

Introduction

The Escalante Canyons section of GSENM encompasses several streams and springs that are fed by groundwater discharge from the Navajo sandstone. This groundwater discharge supports a wide variety of natural resources, including aquatic and riparian habitat for the length of the Escalante River between Escalante, UT and Lake Powell, and is therefore of interest to BLM and other agencies responsible for natural resources management.

Previous research on the Navajo sandstone aquifer in the Escalante basin has been conducted as part of regional (i.e., the Colorado Plateau or the Upper Colorado river basin) characterizations of the aquifer. Blanchard (1986) conducted an assessment of groundwater recharge, flow, discharge, and storage within the Navajo aquifer in the Escalante, Paria, and Wahweap basins. Although his report drew on data from several sources, including a seepage run conducted on the Escalante River in 1981, to conceptualize the groundwater system, it does not explicitly address the Upper Escalante River groundwater system. Other mid-scale assessments of geohydrologic processes in the Navajo aquifer have encompassed areas in the Grand Staircase section of the Monument (e.g., Freethey, 1988 and Spangler et al, 1993). Site-specific issues in the Escalante Basin have been investigated by Goode (1969), Wilberg (1995), Wilberg and Stolp (1995), Rice and Springer (2006, as well as in these proceedings) and Hereford (these proceedings).

The current research effort was initiated in 2001, when GSENM commissioned United States Geological Survey (USGS) to investigate groundwater seepage into the Escalante River. This was accomplished by making successive flow measurements at tributary confluences along the length of the river. The principal finding of the ensuing report was that there are no measurable gains/losses directly to/from the river between Escalante, UT and Stevens Canyon, near Lake Powell (Wilberg and Stolp, 2005). Importantly, however, data from the 1981 and 2001 seepage runs show that there are substantial increases in river flow between the mouth of Pine Creek and the mouth of Boulder Creek. Tributary inflows to this 20-mile river reach account for approximately 95% of the total baseflow in the river at its mouth. The authors speculate that observed accretions in flow are a result of groundwater discharge into tributary streams (Mamie, Sand, Calf, and Boulder/Deer Creeks) that are incised into the Navajo sandstone (Wilberg and Stolp, 2005).

Ongoing work presented herein attempts to provide a more comprehensive description of groundwater discharge, affirm previous findings, and test the hypothesis that tributary canyons are the primary discharge areas for groundwater flow into the Escalante River. This work is important in that it provides a more refined understanding of a groundwater system that supports many resources, both regionally and within the Monument. In addition, this work augments existing data sets and may therefore be valuable in the future for assessments of long-term change.

Methodology

General Setting

The study area is located northeast of Escalante, UT, and encompasses the Escalante River corridor and tributary watersheds between Pine Creek and Boulder Creek (Figure 1). Although the study area is bounded on the west by a steeply-dipping limb of the Escalante Anticline, and there are several gentle folds within the study area, jointing is the predominant expression of geologic structure. Broad expanses of the Navajo sandstone, including several deeply incised canyons, are exposed throughout the study area.

The Navajo is underlain by the Kayenta Formation, which consists primarily of interbedded siltstones, sandstones, and mudstones and likely impedes downward movement of groundwater (Blanchard, 1986). Within the study area, the Kayenta is exposed in the Escalante River canyon below the Calf Creek confluence and in Calf Creek below the lower falls. The Navajo is overlain by the Page sandstone (which has similar hydrogeologic properties as the Navajo) and the interbedded sandstones, siltstones, and silty limestones of the Judd Hollow Tongue unit of the Carmel Formation (Doelling et al., 2000), the fine texture of which generally inhibits vertical water movement into the Navajo (Blanchard, 1986). Wind-blown alluvium occurs on uplands throughout the study area, and valley-fill alluvium occurs along major drainage courses. North of the Monument boundary, vol-

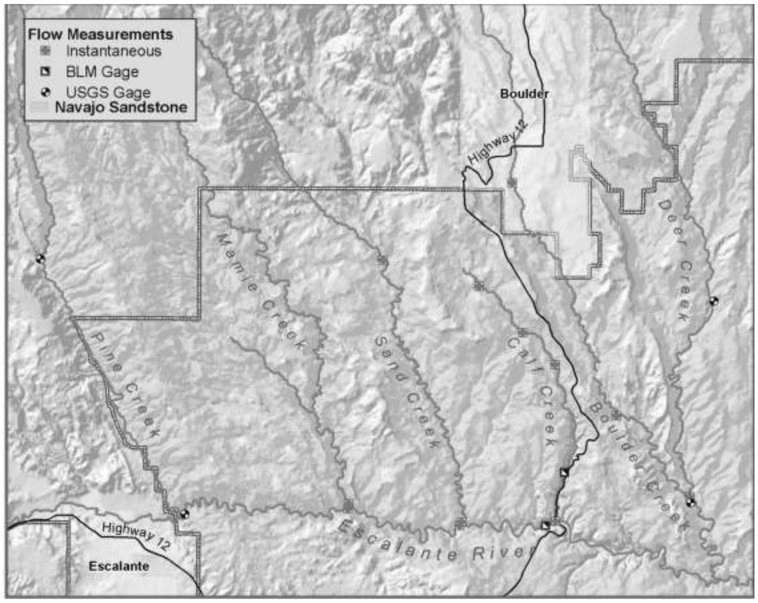

Figure 1. Upper Escalante River study area. Gage records and instantaneous flow measurements were used during seepage runs.

canic tuff, basaltic andesite, and volcanic-derived sediments cover Boulder Mountain.

The extent, thickness (approximately 1,500 feet at its local maximum), and character (clean well-sorted eolian sands) of the Navajo sandstone are such that the unit can store and transmit large volumes of water. Recharge to the aquifer occurs primarily on Boulder Mountain, where relatively high amounts of precipitation fall, primarily as snow, on Navajo outcrops or overlying unconsolidated deposits (Blanchard, 1986). Within the study area, much of the aquifer thickness is saturated. Near Boulder, where numerous irrigation wells withdraw water from the aquifer, generally only the upper 200 feet of the aquifer remain unsaturated (Blanchard, 1986) and most wells are less than 400 feet in depth (Spangler et al., 2002). From Boulder Mountain, water in the aquifer generally moves south through pore spaces and fractures. Seepage from the aquifer occurs in areas where the aquifer is locally perched (i.e., at the base of cross-bed sets) or where the water table is intersected by canyon walls.

Except for Calf Creek, each major tributary has its inception on Boulder Mountain and therefore derives its flow from a mixture of groundwater, snowmelt and runoff, and drainage from soil profiles. The Calf Creek watershed, in contrast, does not encompass areas prone to substantial snowpack and is dominated by slickrock exposures of the Navajo sandstone, and therefore derives almost all of its flow from groundwater.

Field Techniques

Flow measurements were made between July 2005 and October 2006 using a variety of techniques. The USGS operates gaging stations at four locations in the study area (Figure 1): Pine Creek approximately 8.5 miles upstream from its mouth, the Escalante River downstream from the mouth of Pine Creek, Boulder Creek approximately 4 miles upstream from its mouth (downstream from Deer Creek), and Deer Creek approximately 7 miles upstream from its confluence with Boulder Creek. These gages record streamflow at 15-minute intervals, and the data is available over the internet (http://waterdata.usgs.gov/ut/nwis/nwis). (The Boulder Creek and Deer Creek gages were discontinued in 2006 and 2007, respectively.)

In cooperation with USGS, BLM installed two additional gages in November 2005: Calf Creek at the BLM campground (approximately 1 mile upstream from its mouth) and Escalante River at Highway 12 (immediately upstream from Calf Creek). These gages measure water levels every 15 minutes. Using discharge measurements made over a range of flows, a provisional rating curve was developed to convert stage measurements into streamflow estimates.

A series of seepage runs, consisting of near-simultaneous discharge measurements made at several locations along a given stream, provide a spatial dimension to the time-series data generated by the stream gages. Seepage runs have been conducted along Escalante River (July 2005, October 2005, January 2006, and October 2006), Calf Creek (October 2005), and Boulder Creek (January and February 2006). Seepage runs were conducted during periods of dry weather, when streamflow was not affected by surface runoff.

The Escalante River seepage run consists of flow measurements at, and in the river upstream from, major inflows (Mamie, Sand, and Calf Creeks). The Calf Creek seepage run included flow measurements at six locations from the mouth to upstream from Upper Calf Creek Falls, as well as measurement (with a portable Parshall flume) or estimation of inflows from hanging gardens and springs. The upstream-most measurement (above the Upper Falls) was of poor quality, due to shallow water depths and strong upstream winds. Each of the Boulder Creek seepage runs complement gage readings with flow measurements made over a two-day period at two upstream locations. Except for flume measurements of Calf Creek inflows, flow measurements were made using the depth-area-velocity method and were assigned a qualitative accuracy rating for use in estimating measurement error (Buchanan and Somers, 1969; Wilberg and Stolp, 2005).

Other miscellaneous flow measurements were made in Sand Creek (January 2006) and Deer Creek (February 2006). On these occasions, paired flow measurements were made at the mouth of the stream and a single upstream location.

Water quality data (temperature, dissolved oxygen, pH, and specific conductance) was collected with a multiparameter probe during most flow measurements, and has also been collected during routine water quality monitoring. Of these parameters, pH and specific conductance provide the most insight into groundwater flow paths. pH is a measure of the hydrogen ion activity (i.e., the acidity) of water, and in carbonate-cemented rocks such as the Navajo, is controlled by chemical reactions that dissolve or precipitate calcium carbonate. Specific conductance is a measure of the electrical resistivity of water (expressed as microsiemens, or μS), and as such provides a measure of dissolved ion concentrations.

Related work includes initial assessment recharge areas and flow paths for select springs in the study area (Rice and Springer, these proceedings) and an assessment of groundwater-surface water interactions on the Deer Creek floodplain.

Results and Discussion

Gage records from Escalante River and Calf Creek provide measurements of groundwater inflow. (Streamflow records on Pine, Boulder, and Deer Creeks are affected by irrigation withdrawals and return flows and are therefore not considered in this discussion; these data are, however, useful for comparison with instantaneous flow measurements, as described below.)

By subtracting the average daily flows measured on the river at Escalante from those measured at Highway 12, and omitting from consideration snowmelt periods and storm events, the combined inflows from Mamie Creek and Sand Creek can be inferred (Figure 2). These flows are highly variable, as would be expected from relatively large watersheds that derive flows from a variable mixture of snowmelt, storm runoff, and groundwater. In general, during the summer base flow period when groundwater predominates, combined inflows are on the order of 15 cfs.

The size and character of the Calf Creek watershed are such that flows measured at the Calf Creek gage reflect groundwater flows into the system, except during and immediately after storm events (snowmelt was not a factor during the study period). Average daily flows of 6 CFS were consistently measured at the BLM campground (Figure 3).

Measurements of tributary inflows made during seepage runs on the Escalante River are generally consistent with the findings presented Wilberg and Stolp (2005) (Figure 4). The measurements are also consistent with the inferred and measured inflows from Mamie, Sand, and Calf Creeks (described above). Taken together, these data indicate stable base flow inputs from Mamie and Calf Creeks, and variable but substantial inputs from Sand Creek.

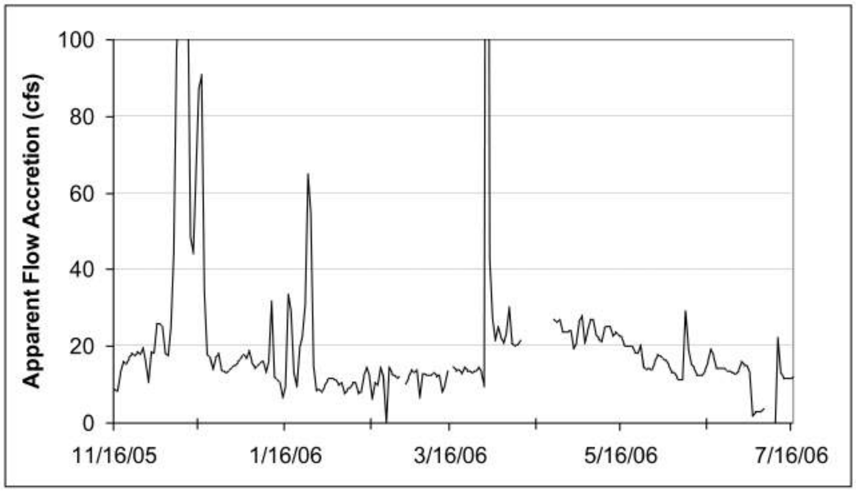

Figure 2. Estimated inflows, in cubic feet per second, to the Escalante River from below the mouth of Pine Creek to above the mouth of Calf Creek, based on average daily flows measured by USGS and BLM gages.

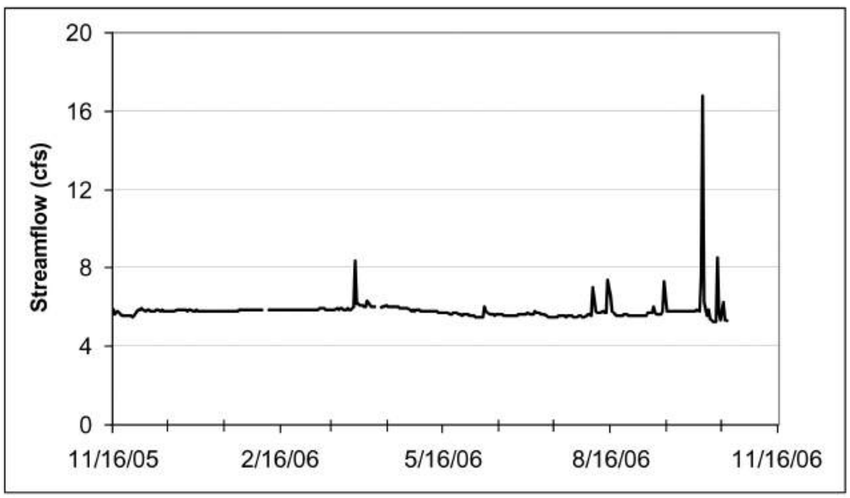

Figure 3. Average daily stream flow in Calf Creek, measured at the BLM campground.

There is wider variability in the calculated gains and losses along the river corridor between tributaries (Figure 5). The "normalized percent error" analytical technique described in Wilberg and Stolp (2005) was used to determine the statistical significance of apparent gains/losses. Three instances of statistically significant inflows were observed, but a consistent pattern was not apparent.

The Calf Creek seepage run provides a snapshot of the distribution of groundwater contributions from the Navajo (Figure 6). The headwater spring complex discharges approximately 1.5 cfs (Rice and Springer., these proceedings). An additional 3 cfs enter between the headwater spring and the base of the lower falls, primarily as diffuse flow from hanging gardens that are ubiquitous in this reach and occur on both sides of the stream. Of this 3 cfs, approximately 0.9 cfs were directly measured or estimated, with slightly more water discharging from the east bank than the west (the remaining flow is the aggregate of seeps discharging into alluvium and very small seeps). The rate of inflow, expressed in terms of cfs per mile, decreased in an upstream to downstream direction, from 1.3 cfs/mile in the vicinity of the upper falls to 0.2 cfs/mile in the vicinity of the BLM campground. Except in the lowest reach, from Calf Creek Spring to the mouth, the apparent gains were statistically significant.

The Boulder Creek seepage runs had coarse spatial resolution; three sites were used to characterize nearly 12 miles of stream. The resulting uncertainty was aggravated by slight flow fluc-

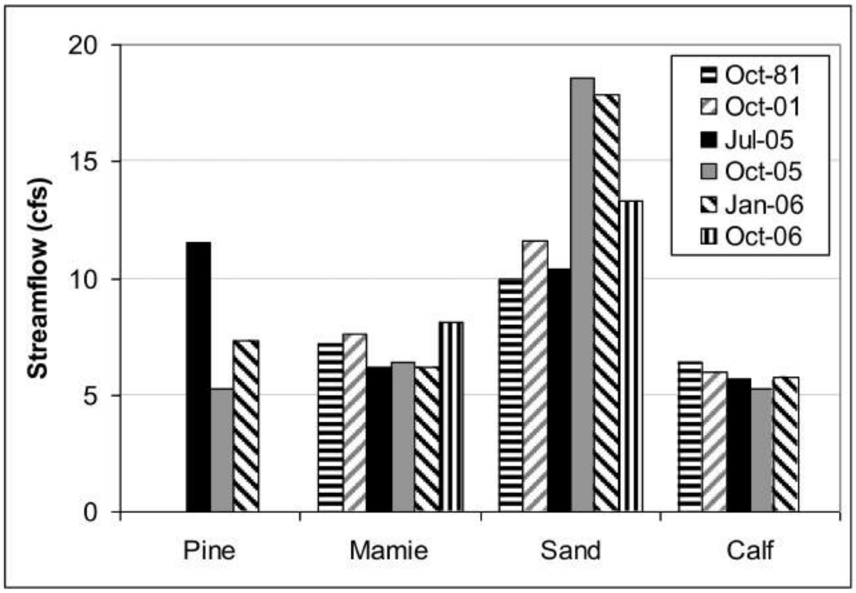

Figure 4. Tributary stream flows measured during Upper Escalante River seepage runs. 1981 data is from Blanchard (1986), 2001 data is from Eilberg and Stolp (2005); other data was collected by BLM.

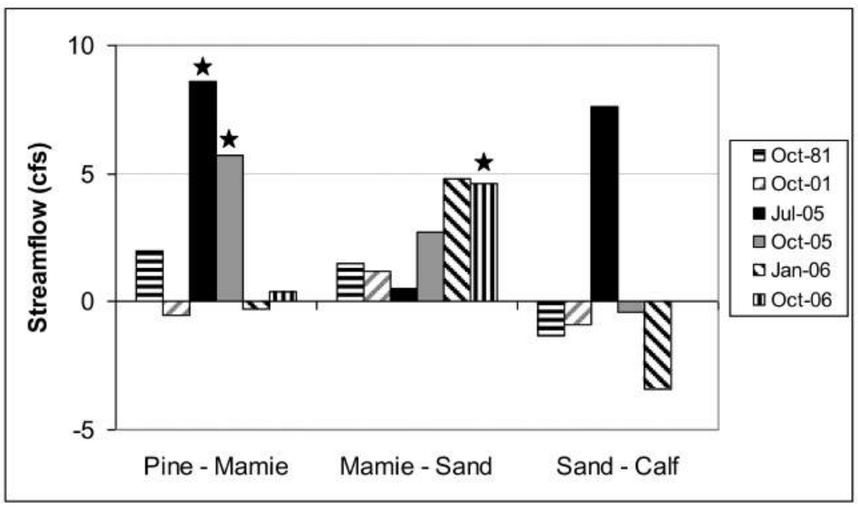

Figure 5. Computed gains and losses of streamflow along the Upper Escalante River between tributary junctions. Stars indicate computed gains that exceed the normalized error (refer to Wilberg and Stolp (2005). Data sources are as for Figure 4.

tuations and the need to infer inflows from Deer Creek. Gaged flows at Boulder Creek and Deer Creek fluctuated by 1 to 3 cfs over each of the two-day measurement periods, and were averaged for this analysis. Based on the findings of a paired flow measurement on Deer Creek (discussed below), inflows from Deer Creek were inferred by adding 3 cfs to the average flow measured at the USGS Deer Creek gage. Despite these limitations, the results of the two seepage runs are quite similar to one another (Figure 7). Although no significant net gains or losses were measured in the eight miles between the vicinity of Boulder and the USGS gage, the data suggests that some flow is lost in the middle reach of Boulder Creek.

Paired measurements on Sand Creek and Deer Creek indicate that significant groundwater inflows may occur in these systems. On Deer Creek, a gain of 3.3 cfs over 6.9 miles was observed in February 2006. On Sand Creek, a gain of 5.4 cfs was observed over 10.2 miles in January 2006.

Water quality measurements were made during all seepage runs except October 2006. No pH data was reported for the 1981 and 2001 seepage runs,

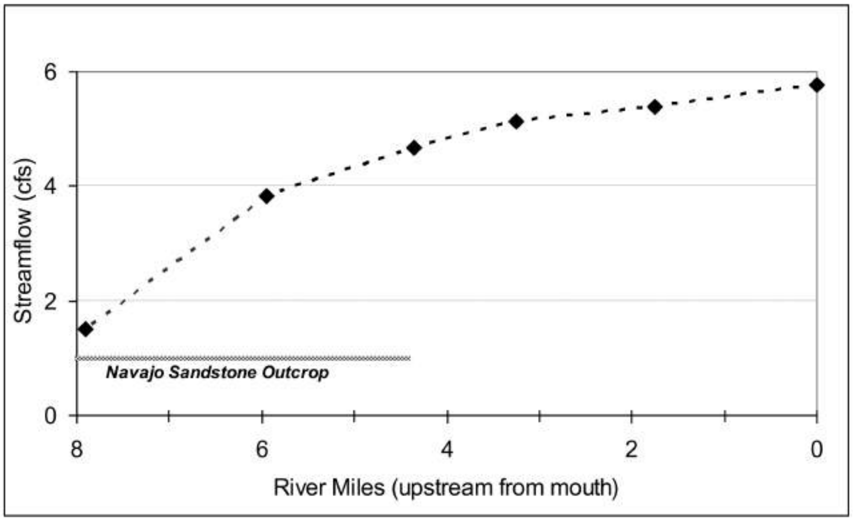

Figure 6. Measured stream flow along Calf Creek during October 2005 (data for the headwater spring discharge is from Rice et al., in these proceedings). The extent of the Navajo Sandstone outcrop is illustrated by the gray line.

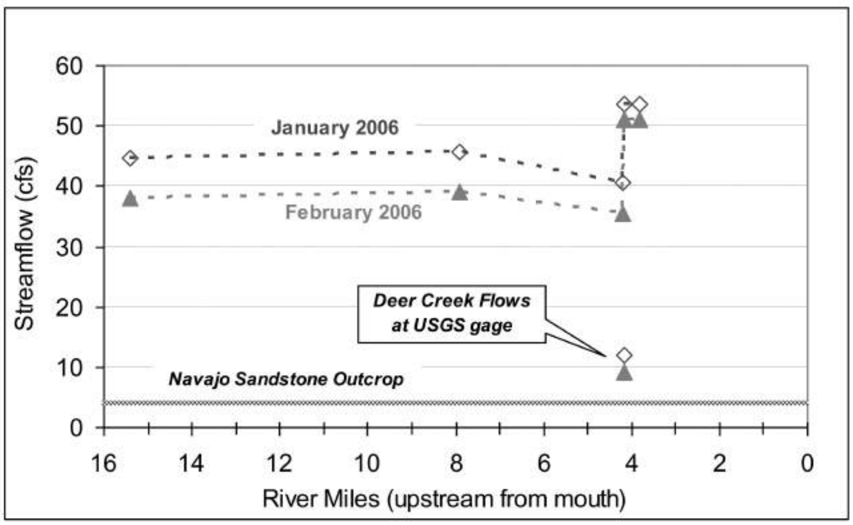

Figure 7. Streamflows along Boulder Creek during two seepage runs. Data for river mile 3.8 is from the USGS Boulder Creek gage, and data for above and below the junction with Deer Creek (river mile 4.2) is inferred.

and pH data collected in the July 2005 and January 2006 seepage runs was rendered inaccurate by equipment problems. Additional data is available from USGS gaging stations and BLM water quality monitoring.

Of 34 specific conductance measurements conducted during seepage runs, only two – both in the river – exceeded 1,000 µS (Figures 8 and 9). Specific conductance was relatively constant between 1981 and 2005 at each of the tributary streams, especially Mamie and Calf Creeks. Mamie Creek consistently had the lowest specific conductance. Specific conductance in the river was more variable, particularly at the upstream end of the study area, but appears to decrease from upstream to downstream. These patterns are clearly evident in the standard deviations and median values of the longer-term data sets (Table 1). The longer-term data also illustrates the consistently high water quality in Calf Creek.

Conclusions

Measured total streamflow accretions within the Monument from Sand, Calf, Deer, and Boulder Creeks are on the order of 15 cfs. Inflows from Mamie Creek have not been directly measured but are likely on the order of 3 to 6 cfs. Inflows from

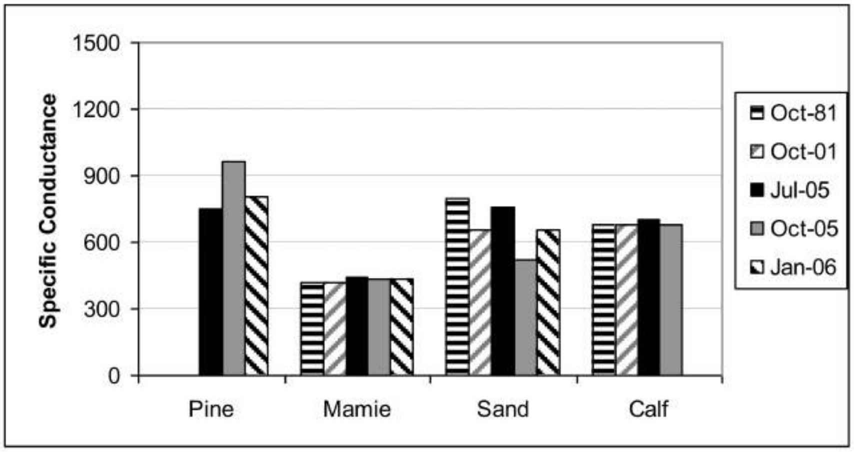

Figure 8. Specific conductance, in µS, measured in tributaries. Data sources are as for Figure 4.

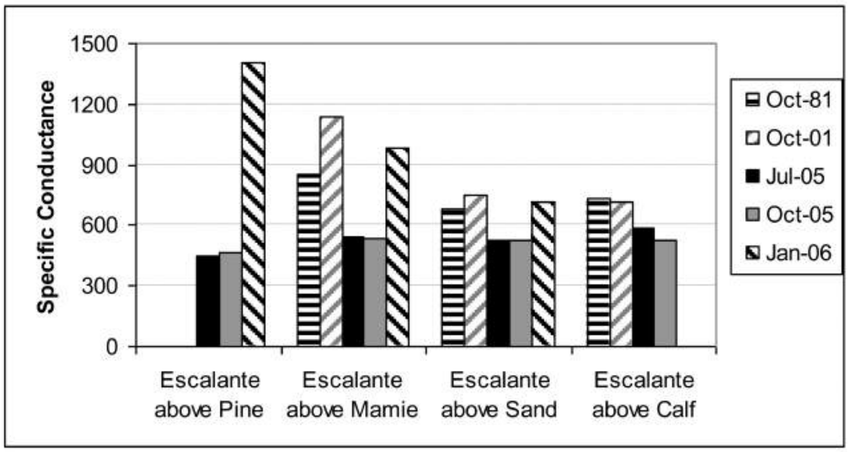

Figure 9. Specific conductance, in µS, measured in the Escalante River. Data sources are as for Figure 4.

the lower segment of Boulder Creek (below the USGS gage) have not been measured, and may or may not be substantial. Direct discharge to the river appears limited to scattered hanging gardens.

Tributary groundwater accretions within the Monument account for at least 25 to 35% of the baseflow for the entire Escalante River baseflows (on the order of 60 cfs near Coyote Gulch). In the context of managing the Monument and the downstream Glen Canyon National Recreation Area, it would be hard to overstate the ecological and social importance of this groundwater system. The large volume of very high quality water that discharges from the Navajo aquifer supports more than 100 miles of river and riparian habitat. The groundwater flow is also integral to the high recreational value of the Escalante Canyons: it provides drinking water, supports shade-providing cottonwood and willow communities, and pleasing aesthetics.

The data presented here represents progress towards a more comprehensive and explicit characterization of groundwater discharge in the Upper Escalante River basin. Groundwater discharge rates, expressed here as streamflow, are arguably the most important descriptor of the groundwater resources in the Monument. The multiple seepage runs and expanded continuous streamflow records described here provide a "baseline" that can be referenced in the future. Calf Creek, in particular, has been described as an "an excellent barometer for groundwater conditions in the Navajo" (Stolp, pers. comm. 2001). Substantial baseflow accretions from the Navajo sandstone occur with the Monument. Tributary groundwater accretions within the Monument account for perhaps 20 to 40% of Escalante River base flows. Inflows occur primarily in the tributary systems, with direct groundwater discharge to the River limited to

	Escalante River at USGS Gage	Escalante River upstream from Calf Creek	Calf Creek upstream from Escalante River
# of Samples	152	68	63
Average	1412	649	649
Median	1255	670	659
Maximum	4350	840	711
Minimum	280	330	458
Standard Deviation	719	95	42

Table 1. Specific conductance, in µS, measured in Escalante River and Calf Creek between 1997 and 2004. Data from the EPA STORET database.

hanging gardens. Interannual variability in these flows appears to be relatively low.

The observed rates of tributary streamflow and calculated rates of seepage directly to the river support the speculations of Wilberg and Stolp (2005) that groundwater discharge occurs primarily in tributary channels. It appears that this occurs primarily in Mamie, Sand, Calf, and Deer Creeks (Figure 10). No seepage run has been conducted along Mamie Creek, but the extent of Navajo sandstone exposure (Figure 1) and the stable streamflows (Figure 4) are similar to Calf Creek and are suggestive of groundwater driven hydrology. Preliminary work in Sand Creek and Deer Creek also suggest substantial amounts of groundwater discharge may occur within the Monument along those streams.

Additional work focused on recharge to, travel through, and discharge from the groundwater system is necessary to inventory the Monument's resources and make informed decisions regarding their protection and utilization. Seepage runs of

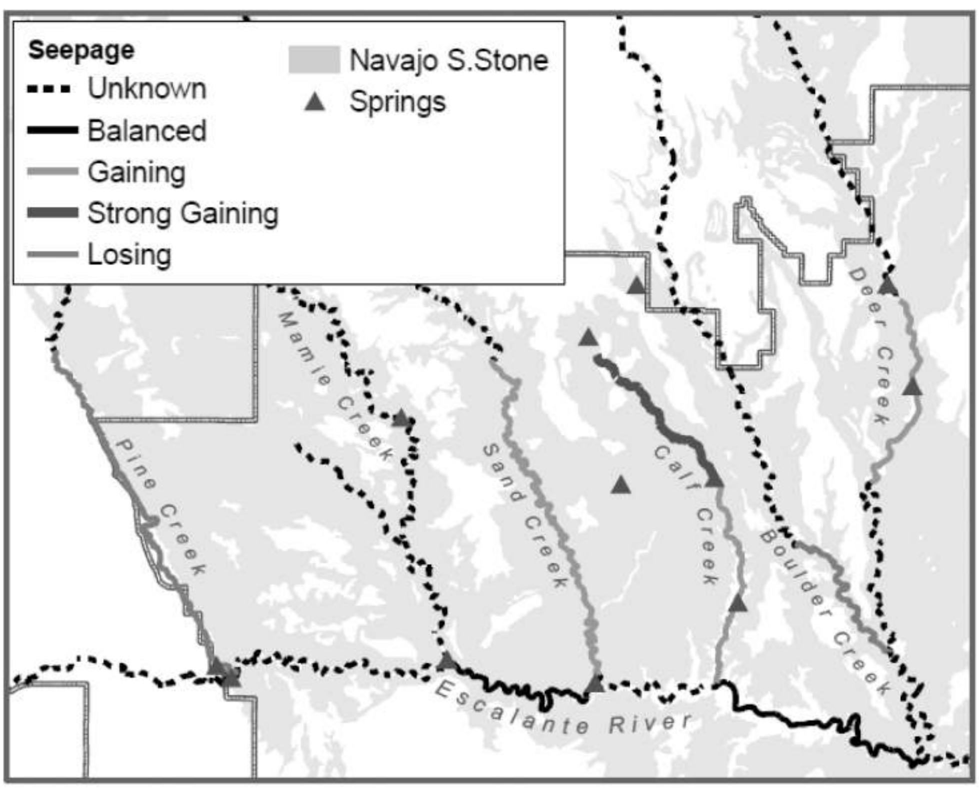

Figure 10. Preliminary identification of stream segments that are "gaining" and "losing" groundwater. The identification of Pine Creek as a losing stream is based on Goode (1969).

several flow measurements should be conducted along Mamie Creek, Sand Creek, and Deer Creek, to locate stream segments that are significant discharge zones. Mamie Creek, especially, would be feasible and would provide important information regarding discharge from the Navajo within the Monument. Also, the USGS gages on Deer Creek and Boulder Creek should be re-activated, if possible. Failing that, periodic flow measurements should be made during base flow conditions, so as to extend the existing record.

Regarding groundwater recharge and transport, groundwater discharging in various areas should be sampled and analyzed to infer recharge areas and transport pathways. The results of the limited work conducted by Rice and Springer (these proceedings) suggest this could be a promising pathway of inquiry. Such studies could be used to identify and appropriately manage recharge areas. Water quality and water table elevation sampling in some of the numerous groundwater wells in the vicinity of Boulder town that rely on the Navajo aquifer could yield broad-scale information regarding travel pathways, and could be conducted at relatively low cost.

Acknowledgments

The author departed the Monument in late 2006, but is grateful for the opportunity to contribute to the understanding of the high quality groundwater resources in the region. He was supported in this work by James Holland and Marietta Eaton, of GSENM, and George Cruz, of the BLM's Utah State Office. Dale Wilberg and Brad Slaugh of the USGS Field Office in Cedar City provided invaluable assistance in establishing the Escalante River and Calf Creek stream gages. Dr. Abe Springer, Steve Rice, and others provided illuminating insights along the way.

Data described in this report is available via the GSENM headquarters.

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Aquatic Invertebrates of the Grand Staircase-Escalante National Monument, Utah

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ABSTRACT

We use multiple years of collections in rivers, perennial wetlands, and ephemeral tinajas to report on overall biodiversity of aquatic invertebrates in the Grand Staircase Escalante National Monument, Utah. A total of 570 samples of aquatic invertebrates was collected at 166 locations. Over the study period, invertebrates were identified from 31 orders, 104 families, and 192 genera. Major habitat types (rivers, perennial wetlands, and ephemeral tinajas) supported unique and taxonomically rich assemblages of invertebrates; taxonomic richness was greatest in rivers. Among rivers, richness of genera of aquatic invertebrates was greatest in groundwater-fed streams and perennial, snowmelt-runoff, rivers and least in flood-prone rivers. Future studies should focus on identifying and collecting invertebrates from unique habitats, especially the numerous wetland-like habitats that occur across the Grand Staircase–Escalante National Monument, such as hanging gardens and alcove pools, as well as ephemeral streams.

RESUMEN

Utilizamos colecciones de años múltiples en ríos, pantanos perennes y tinajas efímeras para hacer un informe sobre la biodiversidad total de los invertebrados acuáticos en el Monumento Nacional de Grand Staircase Escalante en el estado de Utah. Un total de 570 muestras de invertebrados acuáticos fue recogido en 166 sitios. Durante el período del estudio, invertebrados de 31 órdenes, 104 familias y 192 géneros fueron identificados. Todos los tipos principales de hábitat (ríos, pantanos perennes, y tinajas efímeras) abarcaron ensamblajes únicos y taxonómicamente ricos de invertebrados. La riqueza taxonómica de invertebrados acuáticos fue más alta en los ríos. Entre los ríos, la riqueza de géneros de invertebrados acuáticos fue más alta en los arroyos alimentados por agua subterránea y en los ríos perennes de nieve derretida, y más baja en los ríos propensos a inundaciones. Los estudios futuros deben centrarse en identificar y recoger invertebrados de hábitats ú nicos, especialmente en los numerosos hábitats como pantanales que se presenten en todo el Monumento Nacional de Grand Staircase Escalante, como en los jardines colgantes y en las pozas, así como en los arroyos efímeros.

Number of species occupying a habitat is a common measure of biodiversity used by scientists and managers (Hayek and Buzas, 1997). Thienemann (1954) concluded that richness of aquatic invertebrates conformed to three ecological principles: it is proportional to habitat diversity within a locality; it is inversely proportional to amount of extreme habitat conditions; and it is proportional to habitat stability and age of locality. The first principle predicts that richness of taxa increases with increasing spatial heterogeneity. This has been observed for many taxa and is predicted by niche theory (e.g., Abele, 1974; MacArthur, 1975). Application of the first principle in streams generally has shown that richness of invertebrate taxa increases with increasing physical complexity at all spatial scales (Vinson and Hawkins, 1998).

Hydrology (e.g., flow in rivers and permanence of standing water) is a major source of habitat variability that encompasses Thienemann's principles as hydrology controls both structural complexity and disturbance regimes of habitat (e.g., frequency and magnitude offloods). In constructing a conceptual model of streamflow for the continental United States, Poff and Ward (1989) argued that stream communities were influenced by several hydrologic factors; intermittency of flow, predictability of flow, frequency of floods, and predictability of floods. Richness of aquatic invertebrate taxa was predicted to be greatest in streams with predictable stable-flow regimes, to be intermediate in streams with predictable flood regimes, and be least in streams with unpredictable floods or intermittency.

Temperature also exerts tremendous control over richness of aquatic invertebrates. Temperature regimes vary widely in aquatic habitats, but usually in predictable patterns for habitats in the same region (Sweeney, 1984). The annual watertemperature regime has several components, including minimum-maximum, annual, and diel variation, timing of minimum and maximum, rate of seasonal change, and number of annual degree days that influence stream insects (Ward and Stanford, 1982). Water temperature affects growth, feeding, and metabolic functions, but also controls physiochemical parameters such as amount of available dissolved oxygen. Most research on effects of water temperature on aquatic insects has evaluated physiological and behavioral responses to natural and altered thermal regimes (Ward and Stanford, 1982) orin relation to distribution of species latitudinally (Vannote and Sweeney, 1980) and up elevational (Ward, 1986) gradients. Authors who explored relationships between richness of taxa and thermal variation have focused on annual temperature range and generally have found richness of invertebrate taxa to increase with annual variation in water temperature (Vinson and Hawkins, 1998) and decrease with variation in diel temperature (Brussock and Brown, 1991).

Here we make use of multiple years of collections of aquatic invertebrates to report on biodiversity of aquatic invertebrates in an arid region with highly variable hydrologic and thermal regimes, the Grand Staircase–Escalante National Monument, Utah. Our objectives were to describe differences in biodiversity of aquatic invertebrates among major types of aquatic habitats and to describe how overall biodiversity is related to diversity of aquatic habitats.

Materials and Methods

Study Area

GrandStaircase–Escalante National Monument comprises 7,689 km^2 in southern Utah. Elevations range from 1,100 to 3,000 m. At Escalante, Utah (1,616 m), mean annual air temperatures vary from -10°C in winter to 33°C in summer (National Oceanic and Atmospheric Administration, 2002). Mean annual precipitation is ca. 30 cm. Winters are cold and windy and summers are characterized by hot days and cool nights. Moisture falls predominantly as snow in January–May. Early summer usually is dry, whereas intense localized thunderstorms are common in late summer, caused by the North American Monsoon (hereafter, monsoon) when moisture is advected from the Pacific Ocean and Gulf of California (Adams and Comrie, 1997).

Aquatic habitats include perennial and ephemeral streams, springs, wetland ponds, tinajas (ephemeral rock pools), and alcove pools (permanent rock pools located below large cliff pour offs). Streamflows are influenced by groundwater, spring snowmelt, and monsoons. Short-lived monsoonal storm flows can be 50 times greater than mean annual flows and 10 times greater than spring peak flows. Water-temperature regimes also vary widely both within and among systems. Temperatures in some streams can range from zero in winter to >30°C during summer; whereas groundwater-derived systems vary no more than a few degrees throughout the year. Systems also vary widely in width, depth, gradient, shading, allochthonous inputs, and composition of benthic substrate.

Physical Parameters

Streamflow data for major perennial streams in Grand Staircase–Escalante National Monument were obtained from gages maintained by the United States Geological Survey (Table 1). Discharge-regime patterns were then fit into the classification scheme of Poff and Ward (1989). In lentic habitats, dimensions (length, width, depth), and amount and type of shading (either vegetative or topographic) were noted. Water temperatures were collected continuously every 2–4 h using recording thermographs (HOBO Temp logger, Onset Inc., Bourne, Massachusetts) at several lotic and lentic locations (Table 1).

Collections of Aquatic Invertebrates

At 166 locations, 570 samples of aquatic invertebrates were collected. The majority of these sites were streams (103), but samples also were collected in 63 lentic habitats including 7 alcove pools, 1 hanging garden, 8 wetland ponds, 5 springs, and 42 tinajas. Samples of aquatic invertebrate were collected during 1998–2004. A list of sampled sites and coordinates is available from the authors and Grand Staircase–Escalante National Monument, Kanab, Utah. Our sampling strategy was twofold; qualitatively sample as many locations as possible and repeatedly sample across seasons and years a subset of perennial habitats collecting both quantitative and qualitative samples. Lotic aquatic invertebrates were collected both qualitatively and quantitatively. Lentic invertebrates were collected qualitatively. Qualitative samples were collected with a rectangular kicknet (457 by 229 mm) with a 500-µm-mesh net and by hand-picking invertebrates from woody debris and large boulders. All major habitat types (e.g., riffles, pools, backwaters, macrophyte beds) were sampled and composited to form a single sample from each site for each sampling date. Quantitative samples were collected using a Surber net (0.093 m^2) or a rectangular kicknet with 500-µm-mesh nets. For kicknet samples, the area of each sample was ca. 0.18 m^2 (455 by 400 mm). Kicknets (n = 4) or Surber samples (n = 8) were collected in four different riffles and composited to make a sample of ca. 0.74 m^2.

Laboratory Methods

Qualitative samples of invertebrates were processed in their entirety, i.e., all organisms were removed and identified. Quantitative samples of invertebrates were subsampled if the sample appeared to contain >500 organisms following the methods of Vinson and Hawkins (1996).

Analysis of Invertebrate Biodiversity

Due to difficulty in assigning species names to many immature aquatic insects, most individuals were identified to genus and all data reported herein are at the genus level. Filtering data in this way improved our capacity to make comparisons among habitat types and habitats with different sampling efforts. Samples were then standardized to presence-absence, so that quantitative samples could be compared to qualitative samples.

Differences in biodiversity of aquatic invertebrates among major habitats were evaluated using accumulation curves, which measure how many new taxa are found as sampling effort increases either by sampling more locations, dates, or identifying more individuals (Ugland et al., 2003). We calculated moothed-taxa accumulation using EstimateS, version 8.0 (http://purl.oclc.org/estimates). Taxa-accumulation curves were constructed for: 1) actual observations and a Chao-2 estimated based on presence-absence data from all sites (Chao, 1987); 2) three major habitat types (tinajas, wetlands, and streams); and 3) three major hydrologic classes of perennial streams (perennial flood prone, perennial runoff, and mesic groundwater).

Non-metric Multidimensional Scaling

Non-metric multidimensional scaling was used to examine differences among assemblages of

Type	Locality	Dates	Discharge ($m^3 s^{-1}$) or water temperature (°C)			
			Maximum	Minimum	Mean	Maximum diel range
Discharge	Deer Creek, USGS Station 09338900	2001–2007	0.2	0.1	0.2	NA
Discharge	Boulder Creek, USGS Station 09339000	1950–2007[a]	7.1	0.1	0.8	NA
Discharge	Escalante River, USGS Station 09337500	1911–2007[a]	24.1	0	0.5	NA
Discharge	Pine Creek, USGS Station 09337000	1950–2007[a]	5.8	0	0.2	NA
Temperature	East Fork Boulder Creek, near Highway 12	January 2000–October 2001	23.6	−0.2	9.2	19.7
Temperature	Calf Creek, near Highway 12	May 2000–June 2001	25.6	3.7	15.4	15.8
Temperature	Calf Creek, near source	April 2000–June 2001	15.2	8.6	13.7	4.7
Temperature	Deer Creek, at Burr Trail Bridge	January 2000–September 2001	22.4	0.2	10.2	11.5
Temperature	Escalante River, near Escalante, UT	January 2000–September 2001	31.1	−1.0	8.8	18.6
Temperature	Escalante River, at Highway 12 bridge	May 2000–September 2001	29.1	−0.6	13.5	11.9
Temperature	Pine Creek, at lower Box Canyon trailhead	January 2000–June 2001	22.1	−0.6	8.0	11.5
Temperature	Pine Creek, at upper Box Canyon trailhead	January 2000–September 2001	18.2	−0.6	8.8	10.9
Temperature	Tinaja near Highway 12	June 2000–June 2003	27.5	4.1	16.2	9.6
Temperature	Tinaja near Boulder Creek	May 2001–October 2001	23.2	0.2	18.1	3.4
Temperature	Tinaja near Boulder Creek	May 2001–October 2001	38.3	0.2	19.4	28.3

[a] Indicates data record was not continuous; data are available from the United States Geological Survey.

Table 1. Summary of mean daily stream discharge and instantaneous water temperatures collected at ca. 4-h intervals within Grand Staircase-Escalante National Monument, Utah; NA indicates not applicable.

Measure	All locations	Rivers	Lentic habitats: Alcove pools	Hanging gardens	Wetlands, ponds, lakes, reservoirs	Springs and seeps	Tinajas
Number of locations	166	103	7	1	8	5	42
Number of samples	570	420	14	1	14	5	118
Total genera of invertebrates	192	168	39	8	42	13	58
Total genera of insects	165	151	34	8	32	11	48
Genera of Coleoptera	39	32	14	6	14	5	18
Genera of Diptera (non-Chironomidae)	35	33	7	2	4	1	10
Genera of Ephemeroptera	18	18	2	1	2	1	2
Genera of Heteroptera	10	9	4	1	3	2	7
Genera of Megaloptera	1	1	0	0	0	0	0
Genera of Odonata	16	14	6	0	5	1	6
Genera of Plecoptera	16	16	0	0	0	0	0
Genera of Trichoptera	29	27	1	0	4	1	5
Genera of Crustacea	13	7	2	0	4	1	7
Genera of Mollusca	8	7	2	0	5	1	1

Table 2. Summary of aquatic macroinvertebrates collected during 1998-2004 by habitat type in Grand Staircase-Escalante National Monument, Utah

invertebrates among habitats (Primer- E, version 5.2.8, Primer-E Ltd., Ivybridge, United Kingdom). We used ordinations based on Sorenson/ Bray-Curtis distance measurements to provide graphical representations of assemblage patterns. In two-dimensional ordination, samples that group in proximity indicate similar assemblages, whereas samples far apart indicate relatively dissimilar assemblages. Significance of a priori grouping of habitat (streams, tinajas, and wetlands) was tested with analysis of similarity. Analysis of similarity has the advantage over discriminate analyses of not requiring assumptions about normality or homogeneity of the community data. In this test, the statistic R is a measure of effect size, where $R = 1$ indicates that samples within a group are more similar to each other than members from other groups, and an $R = 0$ indicates that withingroup similarity is equal to among-group similarity. An R near 1 indicates strong grouping, whereas an R near 0 indicates weak grouping. Genera influencing these patterns were determined using indicator-species analysis (Dufrene and Legendre, 1997) in the computer program PC-ORD (version 4.41, MJM Software, Gleneden Beach, Oregon). We focused our interpretation of indicator-species analysis to genera unique within a single habitat type. Statistical significance of indicatorspecies analysis was determined through Monte-Carlo randomization to determine applicability as indicator taxa.

Results

Aquatic Invertebrates

Invertebrates were identified from 31 orders, 104 families, and 192 genera (Table 2). Diversity was greatest among insects. We collected the following number of genera: 39 Coleoptera, 35 Diptera (excluding Chironomidae), 18 Ephemeroptera, 10 Heteroptera (aquatic Hemiptera), 16 Odonata, 16 Plecoptera, 29 Trichoptera, 13 Crustacea, and 8 Mollusca.

The Chao-2 estimator, which uses rarity as a correction factor (http://purl.oclc.org/estimates), suggested the true number of genera at these sites was 245 (Fig. 1a), 22% more than the 192 genera we collected. Rarity in our samples was high; 23% of all genera collected (45 genera) were at only one location and 52% of all genera collected (100 genera) were at ≤ 5 locations.

Each of the primary habitats evaluated supported diverse assemblages of aquatic invertebrates (Table 2). Perennial wetlands were characterized by genera of Coleoptera, Diptera, Heteroptera, and Odonata. Ephemeral tinajas had

Measure	Boulder Creek (perennial runoff)	Calf Creek (mesic groundwater)	Escalante River (perennial flood prone)
Number of samples	33	55	78
Total genera of invertebrates	67	83	82
Total genera of insects	65	76	78
Genera of Coleoptera	10	18	21
Genera of Diptera (non-Chironomidae)	13	16	18
Genera of Ephemeroptera	14	8	12
Genera of Heteroptera	4	4	3
Genera of Megaloptera	0	0	0
Genera of Odonata	2	9	5
Genera of Plecoptera	9	2	5
Genera of Trichoptera	13	18	13
Genera of Crustacea	1	4	2
Genera of Mollusca	1	2	2

Table 3. Summary of aquatic macroinvertebrates collected during 1998-2004 in three streams in Grand Staircase-Escalante National Monument, Utah

high richness of Coleoptera, Diptera, Heteroptera, Odonata, and Crustaceans. Invertebrate assemblages in streams varied depending on stream, but overall they were characterized by having high richness within Diptera, Plecoptera, Trichoptera, and Mollusca. Streams had the greatest richness of genera, followed by perennial wetlands, and then seasonal tinajas (Fig. 1b). No genera-accumulation curve reached an apparent asymptote suggesting each of these habitats likely harbors numerous additional taxa.

Richness of aquatic-invertebrate genera in Calf Creek (a mesic groundwater stream) was 1.2 times greater than the Escalante River (a flood-prone perennial stream) and similar to Boulder Creek (a perennial runoff stream) after 30 samples (Fig. 1c). Calf Creek supported the most genera of Odonata, Trichoptera, and Crustacea. Boulder Creek supported the most Ephemeroptera and Plecoptera. Escalante River supported the most genera of Coleoptera and Diptera. Richness of Heteroptera was similar among all three streams.

Using ordination by non-metric multidimensional scaling, assemblages of invertebrates at Grand Staircase–Escalante National Monument appeared to group by habitat type; streams, perennial wetlands, or tinajas (Fig. 2a). Overall grouping by analysis of similarity was significant with a global $R = 0.45$ ($P < 0.001$). Lentic habitats (wetlands and tinajas) formed distinct groups separate from lotic habitats (streams versus wetlands, $R = 0.354$; streams versus tinajas, $R = 0.522$; $P < 0.001$ for both). Different lentic and lotic habitats also appeared to have distinct faunas ($R = 0.207$, $P < 0.001$), with the largest differences occurring among stream classes.

Boulder Creek, Escalante River, and Calf Creek exhibited distinct differences in assemblages of invertebrates using non-metric multidimensional scaling (Fig. 2b). Groupings were statistically significant (analysis of similarity, overall $R = 0.290$, $P < 0.001$). Pairwise analysis of similarity showed that each of these streams were significantly different ($P < 0.001$) from each other and that the effect size (R) was large (Calf Creek versus Boulder Creek, $R = 0.355$; Calf Creek versus Escalante River, $R = 0.288$; Boulder Creek versus Escalante River, $R = 0.252$). Indicator-species analysis showed a large number of genera of insects unique to each stream (Table 4). Boulder Creek had assemblages of invertebrates common to clear lotic waters; namely high numbers of genera of Ephemer-optera, Plecoptera, Elmidae (Coleoptera), and several genera of Trichoptera typical of mountain streams. Calf Creek was typified by organisms common in rivers with constant discharge and temperature regimes; namely several genera of Dytiscidae (Coleoptera), Limnephilidae (Trichoptera), and numerous Odonata. Escalante River was characterized by fewer unique organisms. Taxa that only occurred in the Escalante River were typical of desert streams, including the mayfly Cameleobaetidius (Ephemeroptera: Baetidae), the burrowing crane fly Rhabdomastix

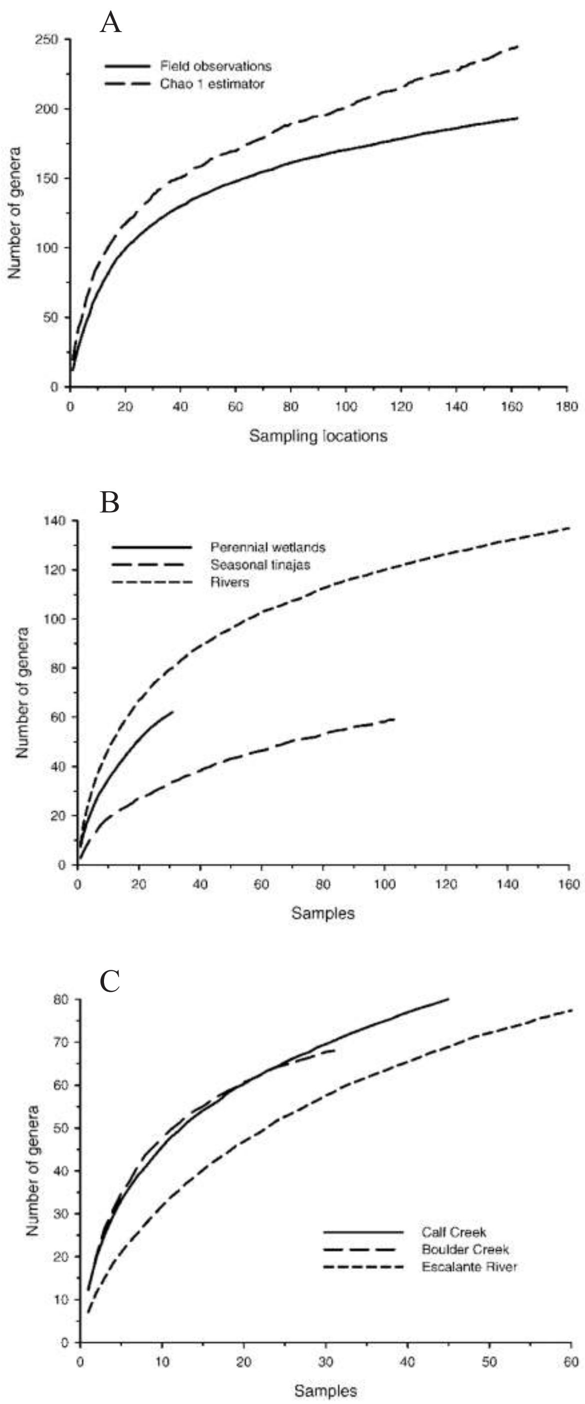

Figure 1. Accumulation curves for genera of aquatic invertebrates based on field collections and the Chao-2 estimate: A) for all sites sampled; B) for three primary aquatic habitats (perennial wetlands, ephemeral tinajas, and rivers); and C) for three major types of rivers in Grand Staircase-Escalante National Monument, Utah

(Diptera: Tipulidae), and two dragonflies (Odonata: Gomphidae).

Streamflow and Longevity of Water

Streamflow regimes within Grand Staircase–Escalante National Monument varied widely among streams (Table 1). Escalante River was characterized as a perennial flood-prone stream (Poff and Ward, 1989), and exhibits both a large sustained runoff each spring due to snowmelt (typically ca. 4 $m^3 s^{-1}$) and frequent unpredictable floods caused by late-summer monsoon storms that can exceed 10 $m^3 s^{-1}$. Pine Creek and Boulder Creek were classified as perennial runoff streams (Poff and Ward, 1989). These streams have annual, snowmelt, peak flows of ca. 2–3 $m^3 s^{-1}$ and few high flows occur in response to monsoon storms. Calf Creek and Deer Creek were classified as mesic groundwater streams. These streams are characterized by steady low flows ca. 0.15 $m^3 s^{-1}$ and little seasonal fluctuation in flow throughout the year either in response to snowmelt or monsoon storms.

Although we were unable to quantify longevity of lentic habitats, habitats suspected to be perennial based on occurrence of obligate wetland plants generally were located within drainages (e.g., steep-walled canyons) or directly below high, rock-wall, pour-offs in topographically shaded areas. Tinajas were the most prevalent ephemeral lentic habitat. Tinajas occurred both within and outside of defined drainages. These habitats filled quickly following storms. Field observations suggested that duration of water in tinajas was highly variable and depended on surface area and volume, shading, and air temperatures.

Water Temperatures

Water temperatures in rivers exhibited strong seasonal patterns, with temperatures $\leq 31.1^{o}$C occurring in summer in the Escalante River, although other streams typically were cooler (Table 1). Minimum water temperatures occurred in winter and were near 0^{o}C for most locations. One exception was near the headwaters of Calf Creek, where temperature varied little year around. Deer Creek and Calf Creek, both mesic groundwater streams, exhibited warmer winter temperatures than other rivers. Maximum diel variations varied from ca.

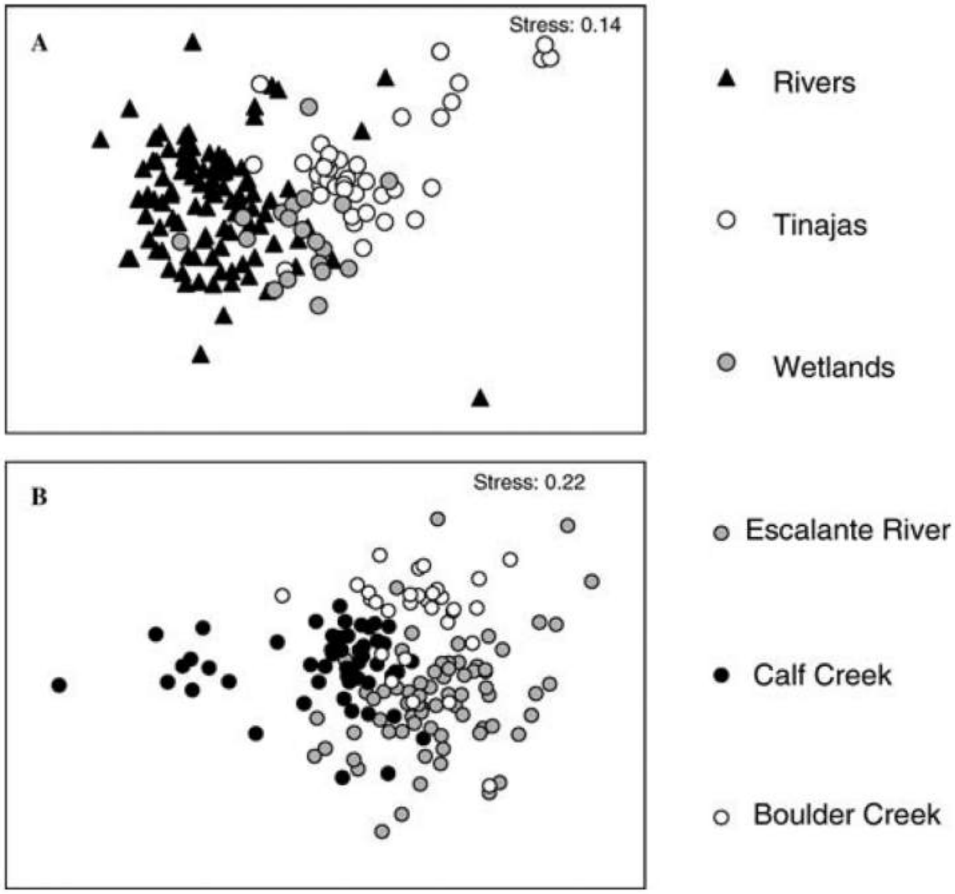

Figure 2. Ordination of genera of invertebrates with non-metric multidimensional scaling using presence-absence data to compare: A) three dominant habitat types (perennial wetlands, ephemeral tinajas, and rivers;) and B) three rivers with different hydrologic regimes in Grand Staircase-Escalante National Monument, Utah. Each point represents invertebrates collected at a single site on a single date. Points in poroximity represent similar assemblages of invertebrates and points more distant indicate differing assemblages.

5°C in headwaters of Calf Creek to near 20°C in Escalante River and Boulder Creek. Annual ranges of water temperature varied from ca. 7°C at headwaters of Calf Creek to >30°C in the Escalante River.

In general, water temperatures in tinajas were similar in winter and warmer in summer than river temperatures (Table 1). The maximum temperature of a tinaja recorded in summer was 38°C. Tinajas shaded from direct sunlight had lower maximum temperatures and narrower daily ranges in summer than those exposed to the sun. We also observed an ameliorating effect of precipitation in summer on water temperatures in tinajas (Fig. 3). Shortly after storms, the diel range in water temperature decreased only to increase as water evaporated over successive days. New storms would increase water volumes and restore thermal stability until evaporation again reduced water volume.

Discussion

Grand Staircase–Escalante National Monument appears to have a diverse assemblage of aquatic invertebrates compared to other southwestern regions that have been surveyed. In a survey of tributaries from Grand Canyon National Park, Arizona, Oberlin et al. (1999) collected 42 genera, compared to the 151 genera we found in streams of Grand Staircase–Escalante National Monument. Likewise, Haden et al. (2003) collected 49 taxa in a survey of 92 river miles of the Green and Colorado rivers in Canyonlands National Park, Utah. We found 109 taxa of invertebrates in 42 tinajas, whereas Anderson et al. (1999) collected 44 taxa of aquatic invertebrates from 460 tinajas in and adjacent to Capitol Reef National Park, Utah. In other studies of southwestern tinajas and wetlands, researchers consistently have found fewer taxa. For example, Baron et al. (1998) collected

Order	Family	Genus	Boulder Creek (perennial runoff)	Calf Creek (mesic groundwater)	Escalante River (perennial flood prone)
Amphipoda					
	Gammaridae	*Gammarus*		X	
Arhynchobdellida					
	Erpobdellidae	*Nephelopsis*		X	
Branchiopoda					
	Daphniidae	*Daphnia*		X	
Coleoptera					
	Elmidae	*Cleptelmis*[a]	X		
		Stenelmis			X
	Scirtidae	*Elodes*		X	
	Hydrophilidae	*Enochrus*			X
	Dytiscidae	*Stictotarsus*		X	
		Hygrotus			X
		Laccophilus			X
Decapoda					
	Cambaridae	*Orconectes*		X	
Diptera					
	Athericidae	*Atherix*[a]	X		
	Ceratopogonidae	*Culicoides*			X
		Dasyhelea			X
	Culicidae	*Culex*		X	
	Stratiomyidae	*Caloparyphus*[a]		X	
		Euparyphus[a]		X	
	Tipulidae	*Rhabdomastix*			X
Ephemeroptera					
	Ameletidae	*Ameletus*[a]	X		
	Baetidae	*Camelobaetidius*			X
	Heptageniidae	*Epeorus*[a]	X		
	Siphlonuridae	*Siphlonurus*[a]	X		
Gastropoda					
	Lymnaeidae	*Radix*		X	
Heteroptera					
	Corixidae	*Corisella*		X	
	Notonectidae	*Notonecta*[a]		X	
Isopoda					
	Asellidae	*Caecidotea*		X	
Odonata					
	Aeschnidae	*Anax*		X	
	Coenagrionidae	*Enallagma*[a]		X	
		Ischnura		X	
	Cordulegastridae	*Cordulegaster*		X	
	Gomphidae	*Gomphus*			X
		Erpetogomphus			X
	Lestidae	*Archilestes*		X	
Plecoptera					
	Chloroperlidae	*Suwallia*a	X		
		Sweltsa	X		
	Nemouridae	*Amphinemura*[a]	X		
		Malenka[a]	X		
		Zapada			X
	Perlidae	*Hesperoperla*	X		

Table 4. Genera of aquatic invertebrates that are unique to three streams in Grand Staircase-Escalante National Monument, Utah, withdiffering streamflow regimes (sensu Poff and Ward 1989).

Order	Family	Genus	Boulder Creek (perennial runoff)	Calf Creek (mesic groundwater)	Escalante River (perennial flood prone)
	Perlodidae	*Skwala*		X	
Trichoptera					
	Glossosomatidae	*Glossosoma*		X	
	Hydropsychidae	*Arctopsyche*	X		
	Lepidostomatidae	*Lepidostoma*[a]	X		
	Leptoceridae	*Oecetis*			X
		Ylodes			X
	Limnephilidae	*Amphicosmoecus*			X
		Limnephilus		X	
	Philopotamidae	*Wormaldia*		X	
	Seriocostomatidae	*Gumaga*[a]		X	
	Uenoidae	*Oligophlebodes*		X	

[a] Indicates statistically significant difference ($P < 0.05$) using indicator-species analysis.

Table 4. Continued.

64 taxa of aquatic invertebrates from 76 intermittent stream pools and Kubly (1992) collected 95 taxa of aquatic invertebrates from 12 tinajas in the White Tank Mountains, Arizona.

We suggest two reasons for the high number of taxa in Grand Staircase–Escalante National Monument. First, habitat diversity appears high. This diversity is expressed among major habitat types, e.g. streams, perennial wetlands, tinajas, alcove pools, and spring-seeps, but also is expressed within habitat types, especially streams and tinajas. Streams within Grand Staircase–Escalante National Monument varied widely with respect to their flow and thermal regimes. Although located in proximity to one another, all major streams had distinct differences in predictability, frequency, and timing of high flow events. Poff and Ward (1989) hypothesized that differences in these hydrologic variables result in changing contributions of biotic and abiotic processes that act to determine assemblages of invertebrates. Our data support this idea, as each class of stream we evaluated appeared to support a different assemblage of aquatic invertebrates (Fig. 2b), which led to high overall taxonomic richness (Fig. 1). Diversity in habitat conditions among lentic habitats was similarly high, particularly among tinajas. Tinajas varied widely with respect to their solar exposure, permanence of water, assemblages of wetland plants, water temperatures, and amount of organic matter. This variability influenced assemblages of aquatic invertebrates and added to overall diversity of organisms collected in these habitats (Fig. 1). Secondly, we suggest high diversity of invertebrates in Grand Staircase–Escalante National Monument also is promoted by its geographic position, which provides a large regional pool of available colonizers. Grand Staircase–Escalante National Monument is located at the juxtaposition of two ecoregions, the Western Cordillera to the north and the Cold Desert to the south (Omernik, 1987). This region is also at the location of three intersecting biotic provinces of Dice (1943); Artemisian (the Great Basin), Navahonian (Colorado Plateau), and Mohavian (Mojave Desert). Likewise, we collected several taxa associated with more Neotropical assemblages that are likely relict taxa from more temperate times in the arid Southwest (e.g., *Telebasis*, Odonata, Coenagrionidae; *Smicridea*, Trichoptera, Hydropsychidae; *Leucotrichia*, Trichoptera, Hydroptilidae).

To our knowledge, aquatic habitats in Grand Staircase–Escalante National Monument and the broader Colorado Plateau have not been quantified with respect to diversity. The work presented here provides a strong empirical foundation for the need to inventory habitats and habitat characteristics and for monitoring changes in assemblages of invertebrates over time. Future studies should focus on identifying and sampling new habitats, especially the numerous wetlandlike habitats that occur across the Colorado Plateau, such as hang-

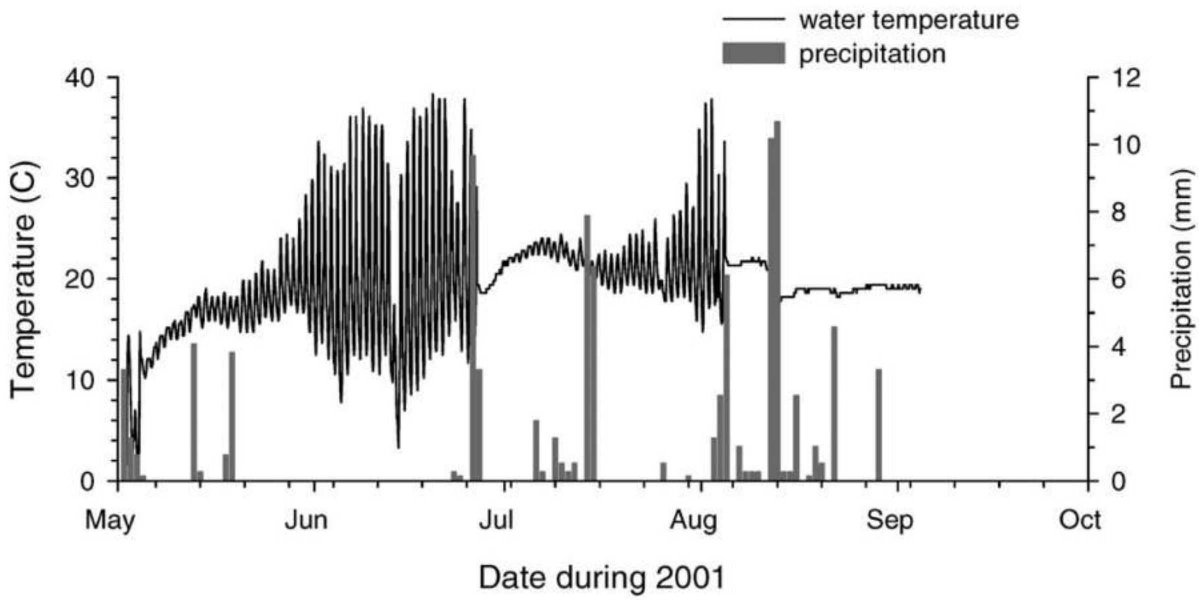

Figure 3. Continuous water temperature recorded at ca. 4-h intervals on an exposed tinaja near Boulder Creek, Grand Staircase-Escalante National Monument, Utah, and precipitation recorded at Escalante, Utah, May - September 2001.

ing gardens and alcove pools, as well as ephemeral streams, because these are poorly sampled and may be first affected by future changes in climate.

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Paria and Escalante River Water Quality Management Plans

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ABSTRACT

The Utah Division of Water Quality, in cooperation with the Bureau of Land Management, Canyonlands Soil Conservation District and several other governmental and non-governmental partners, recently completed water quality studies for the Escalante and Paria Rivers which flow through Grand Staircase-Escalante National Monument.

The Escalante River was listed on Utah's 303(d) list of impaired waters in 2002 due to exceedences of the 20°C temperature criteria for cold water species of game fish and other aquatic life. Subsequent monitoring, field studies, and review of historic data indicate that the Escalante River's temperature regime is primarily a result of natural conditions. The evidence supporting this conclusion was provided in part by comparing the temperature regime of the Escalante River with a reference stream, Mamie Creek, a tributary that flows out of Box Death Hollow Wilderness. The Division of Water Quality has recommended changing the fisheries beneficial use of Escalante River from a cold water to a warm water designation along its entire length which will more accurately reflect its true potential and actual use.

The Paria River was also listed as impaired due to exceedences of Utah's water quality standard for total dissolved solids (TDS), established to protect its agricultural beneficial uses including irrigation and stock watering. Potential anthropogenic sources of TDS such as irrigation return flows were considered negligible in comparison to the contribution from local geological sources. The Tropic Shale formation is prevalent throughout the watershed and is the primary source of TDS loading. As a result, site specific TDS criteria were calculated for the two reaches of the Paria River assessed as impaired to more accurately reflect the naturally elevated concentrations found in those areas.

Keywords: water quality, water studies, Escalante and Paria Rivers, monitoring

Analysis of Groundwater Flow in the Deer Creek Floodplain, Grand Staircase-Escalante National Monument

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ABSTRACT

I will present preliminary findings of a research project focusing on groundwater – surface water interactions on the Deer Creek floodplain in Grand Staircase-Escalante National Monument (GSENM). Deer Creek is one of six major perennial tributaries to the upper Escalante River that flows through GSENM, and groundwater flow through the Deer Creek floodplain supports an outstanding riparian area as well as a 'sensitive' orchid species. The rate and distribution of groundwater movement through the Deer Creek floodplain is not well understood. It could be that soil variability, perhaps a reflection of past channel locations, is a major driver of groundwater dynamics in the floodplain aquifer. The project attempts to quantify the volume of groundwater accretions reaching Deer Creek through the floodplain and to document spatial variability in groundwater flow paths. Field techniques include use of existing and newly installed piezometers, fine-scale soil surveys, specific conductance measurements, and historical stream discharge and precipitation data. Findings will be placed in a regional context through use of seepage runs and spring inventories conducted by other researchers. Results from this study will enhance our understanding of the role of precipitation pulses and soils heterogeneity in controlling flow through this and other similar floodplains. This is important to an area of such diversity. Furthermore, the data retrieved will aid in the understanding of surface water groundwater interactions in the area. Knowledge of those dynamics in an area of ecological concern is important for the future of water resources management.

Keywords: floodplain, groundwater, flow paths

Upland Free Water: Past, Present, and Future in Grand Staircase-Escalante National Monument

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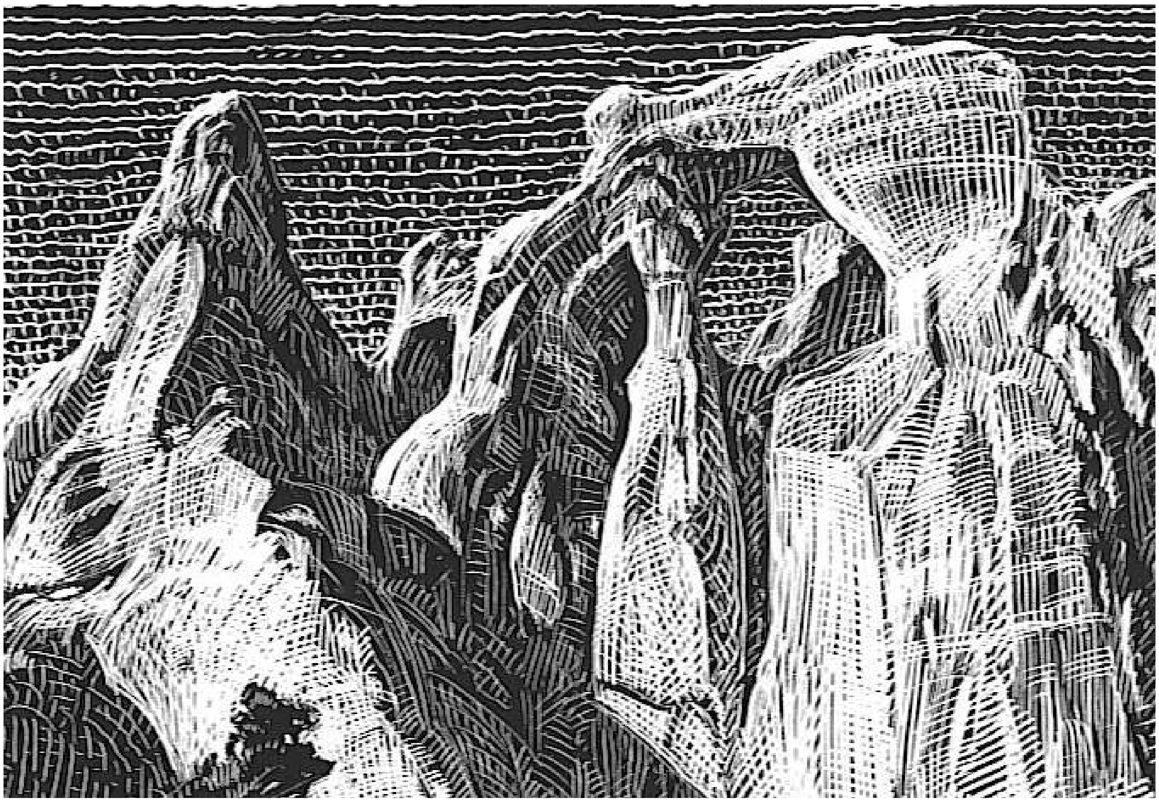
ABSTRACT

Humans dramatically altered the temporal and spatial availability of free water during the past century in uplands of the Colorado Plateau. Livestock producers, and wildlife and public land managers installed numerous catchments, wells, troughs and tanks to disperse livestock and provision both livestock and water-dependent wildlife with water. In contrast, during times before European settlement, when naturally occurring free water was rare and irregularly distributed, there are currently few areas beyond range of free water for mobile wildlife. Recent work in the Flagstaff area has confirmed that human-made devices substantially prolong and more uniformly distribute free water. Moreover, heavy use by elk and ravens is consistent with speculations that the presence of both species depends on artificial waters in the Flagstaff uplands. More surprising, carnivores and birds are nearly the sole users of natural waters in declivities, whereas herbivores more heavily use artificial waters on flatter open sites, presumably to reduce risk of predation. Other similar or perhaps unexpected effects on wildlife are likely in other areas. Beyond this, we know little about landscape-level hydrologic effects, interactions with soil properties, utilization of vegetation by livestock, and resulting changes in vegetation composition, although finer-scale research shows soil compaction and loss of native vegetation near livestock tanks. With future probable drying and more certain warming of the Colorado Plateau, there is an imperative to understand the benefits of artificial waters to valued wildlife resources as well as potential impacts of these waters on ecosystem structure and function at multiple scales in places such as Grand Staircase-Escalante National Monument (GSENM). We propose an integrated research program in GSENM focused on natural and artificial upland waters, informed and facilitated by stakeholders in this vital resource.

Keywords: upland waters, livestock, wildlife, climate change

Geology & Paleontology



"Do remember that in the great circle of life for (dinosaur) tracks, new ones are slowly coming to light just as surely as old ones are swept away."

– Dr. Alan Titus, GSENM Paleontologist –

Tracks and Burrows in Jurassic Dune Deposits

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ABSTRACT

Animal tracks and burrows are abundant in portions of the Jurassic Navajo and Entrada Sandstones of southern Utah. These trace fossils are especially well preserved in wind-blown (eolian) sandstones because they disrupt the distinct layering produced by sand avalanches and by migration of wind ripples. Tracks at Coyote Buttes were both made and buried in dry sand that freely avalanched as the animals moved across the steep dune slopes. Although the surface expression of such tracks is erased, the lower parts of the tracks are preserved. Large burrows (up to 63 cm in diameter) in the Entrada Sandstone were excavated high on dune slopes into sand that had been made cohesive by infiltrating rainwater. The abundance of tracks and burrows demonstrate that the ancient dunes must have periodically received enough rainfall to support a thriving ecosystem.

Keywords: trace fossils, Navajo, Entrada, sandstone, eolian, paleoecology

Introduction

When a geologist sees a formation of sedimentary rocks exposed on a canyon wall or coastal cliff, a question immediately arises: What kind of a place was this when the sediment was delivered (before it was cemented into rock)? Sediments accumulate at the surface of the earth. Sandstones, for instance, can record sediment accumulations in ancient river channels, desert dunes, beaches, tidal inlets, or deep-sea floors. In each of these kinds of places, animals moving over or through the sediment make distinctive records – trace fossils – that are of great help in determining the environment of deposition. These trace fossils are not only more abundant than body fossils (skeletal parts), but they also directly record something that skeletal remains cannot – animal behavior. Further, unlike body fossils, they are unlikely to be transported away from where they were formed.

In southern Utah and northern Arizona, many of the canyon walls reveal sandstones deposited in vast inland deserts. In this paper, I describe signs of ancient life from two sandstones widespread on the Colorado Plateau – the Lower Jurassic Navajo Sandstone (about 190 million years old), and Middle Jurassic Entrada Sandstone (about 160 million years old; Fig. 1). The abundant trace fossils in parts of these formations indicate that there was (at least periodically) enough rainfall on the dunes to support a thriving ecosystem (Loope and Rowe, 2003).

Whether it is moved by wind or water, sand almost always moves as migrating ridge-like piles – ripples (less than 2 cm-high) or dunes (higher than 0.5 m). When the flow is strong enough to move the grains, the dunes and ripples migrate and produce cross-bedding (Fig. 2). Crossbeds slope in the downflow direction, because the steep, downflow side of the migrating dunes or ripples is repeatedly buried. By itself, the crossbedding in the Navajo and Entrada Sandstones doesn't tell us that the environment of deposition was a desert; we have to look for other clues. Probably the best evidence that these formations were deposited by sand-laden winds is the great abundance of wind-ripple deposits; wind ripples make layers that are quite different from water-laid ripples (Hunter, 1977). Bones and other skeletal fossils are very rare in both formations, but trace fossils can be very abundant, and these support the other lines of evidence for a desert environment (as opposed to the aqueous environments).

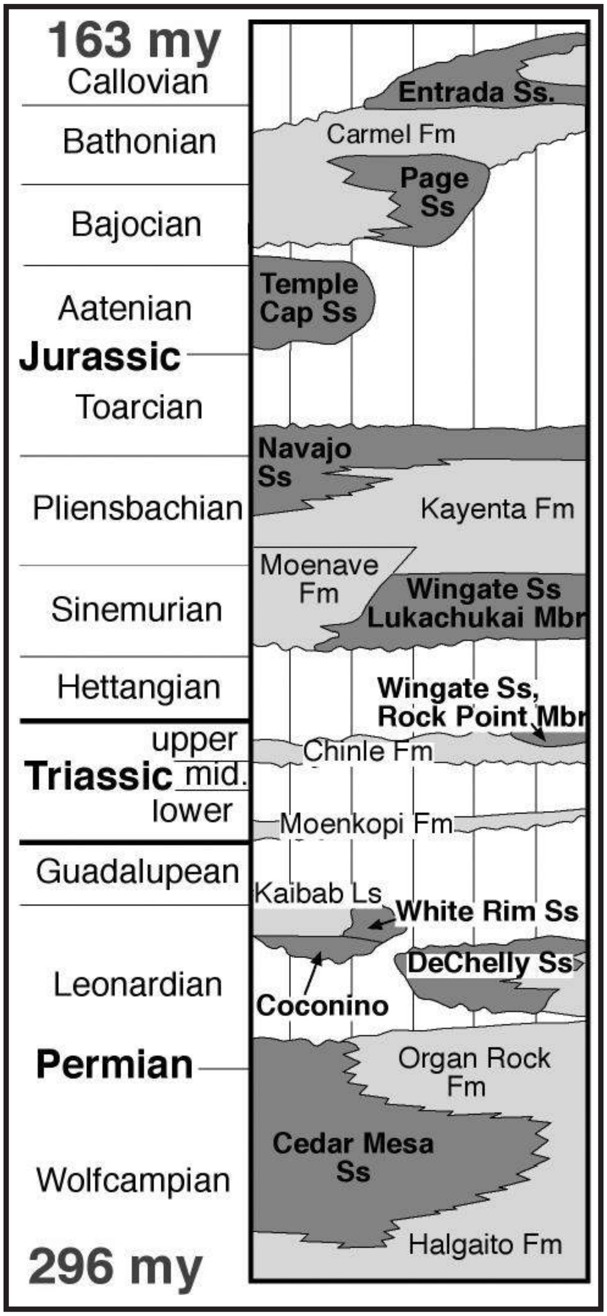

Figure 1. Stratigraphic column showing eolian (wind-blown) sandstones (dark shading) of the Colorado Plateau (from Blakey et al., 1988).

Green plants, the primary producers in ecosystems, are sparse on actively migrating dunes, so few animals can live in dunefields. Most of these animals are small, and many have adapted to the harsh habitat by becoming nocturnal. A walk over a desert dune in the early morning commonly reveals abundant animal trails, many of which start or stop at the throat of a burrow. Although most of these tracks and burrows are destroyed as

Figure 2. Crossbedding in the Navajo Sandstone, produced by large dunes migrating left to right. Horizontal lines are erosion surfaces produced by migration of the troughs between dunes. Each set of crossbeds (interval between successive horizontal lines) is only a fraction of the full height of the original dune. Avalanche layers are indicated by a's, wind-ripple layers by w's.

erosion removes sand from the upwind side of the dune, tracks and burrows are preserved within the crossbeds that escape scour as the dunes migrate and climb over one another. Some geologists have argued that moistening of the loose sand is a requirement for the preservation of tracks and trails, claiming that all dry-sand tracks are eroded away. In this paper, I'll attempt to show that many of the tracks in the Navajo Sandstone were both made and preserved in dry sand.

Tunneling into subtropical dunes allows animals to avoid the intense heat of the surface and to escape predators. Some of the animals that live in dunes – the sand swimmers – can force their way into and through loose, dry sand. The sand collapses immediately behind these animals; all that is left is a disruption of the layering in the sand. Other modern animals dig burrows that stay open because they are surrounded by cohesive material. Dune sand lacks the material that makes most soils cohesive (silt, clay, and organic matter), and it therefore is cohesive only when it has been moistened (sand castles on the beach). Tunnels excavated in damp sand stay open only as long as the sand remains moist. Burrows dug into damp

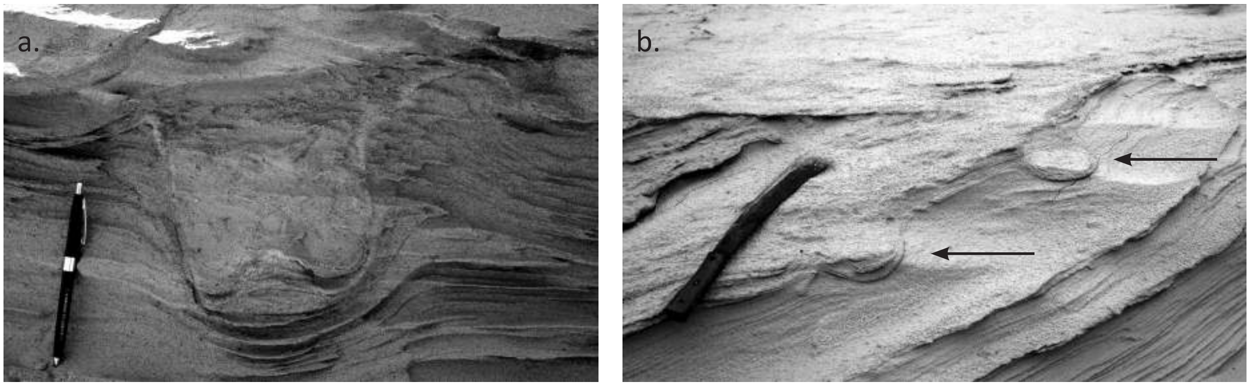

Figure 3. 1,000-year-old bison tracks buried within the Nebraska Sand Hills and seen in cross-section. (a) Note the cloven hoof, and the down-bending of the layering. Track is within nearly horizontal, wind-ripple lamination). (b) Bison tracks (arrows) in steep crossbeds. From Loope (1986).

Figure 4. Human tracks across a rain-moistened dune. Note the many “crumbs” of cohesive sand (Coral Pink Sand Dunes, Utah).

sand are relatively common in some parts of the Entrada Sandstone, and some of them are surprisingly large.

Tracks in the Navajo Sandstone at Coyote Buttes

When an animal steps on the soft, layered sand on a dune slope, it bends the layers downward in a distinctive way (Fig. 3). If the sand is moist, abundant “crumbs” or blocks of sand are formed (Fig. 4), and the animal’s foot does not sink very deeply into the sand. If the sand is dry, the animal’s feet sink deeply and produce long avalanches of dry sand with each step (Fig. 5).

Most of the tracks at Coyote Buttes are visible in cross-section (side-view instead of map-view). Only two of the tracks I’ve seen there contain broken blocks of moist sand, but thousands show smooth bending of the sand layers. The numerous tracks that show the smooth folding (Fig. 6) are preserved within sand layers that were formed by avalanching. In parts of the Navajo where tracks are absent, the layers formed by avalanching are up to 10 cm thick and are many meters wide. The avalanches that display the tracks are much thinner and narrower than typical avalanche layers in the Navajo (Fig. 1).

Some of the tracks appear in a line, suggesting a trackway seen in cross-section (Fig. 6). The upper part of each of the tracks in the line is truncated by a flat, erosional surface. A closer look shows that some of the tracks in the line are older than others – they deform slightly different layers (Fig. 6). This is the pattern to expect if a moving animal disturbs steep, loose (dry) sand: the animal repeatedly makes an avalanche and then steps on it. So, although some tracks are older than others, they are only seconds older. When tracks like this are made, it may look (from above) as if the avalanches erase the tracks, but the tracks are deep and only the top part each track is erased.

It therefore appears that nearly all of the tracks at Coyote Buttes were made in dry sand. Each sand layer was dry when it avalanched into position, and when an animal disturbed it, it slid again to make another avalanche. When the wind blows over dunes in areas without animal life,

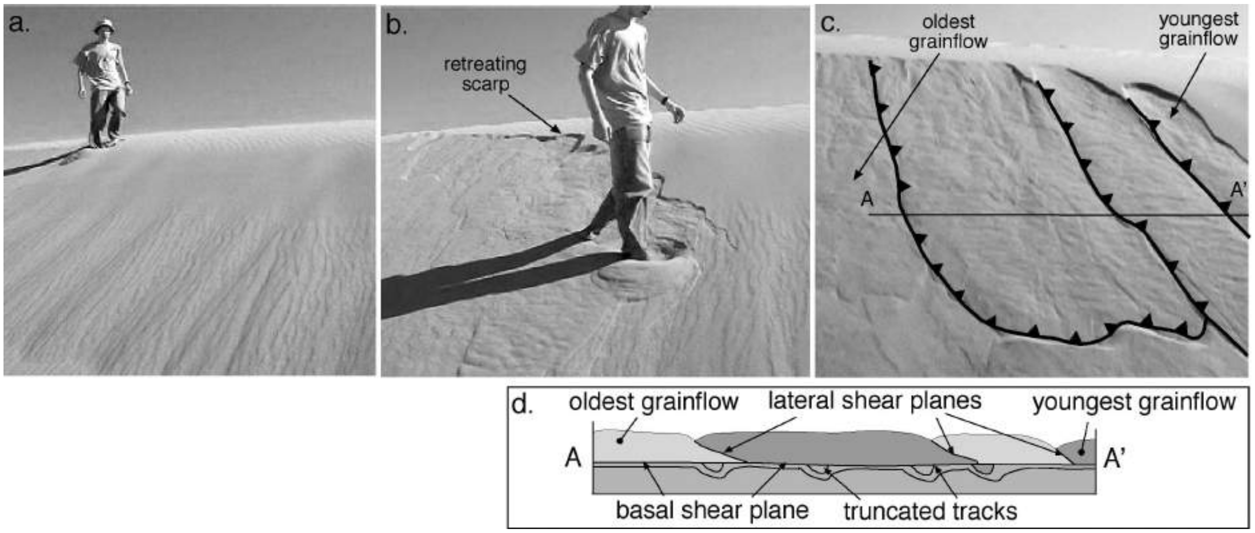

Figure 5. An animal moving across a dry dune slope (a) generates avalanches (b) and then steps on them. The surface expression of tracks is obscured (c), but the tracks deform the layers to a greater depth than the sliding sand can erase (d). Killpecker Dunes, southwestern Wyoming; from Loope (2006a).

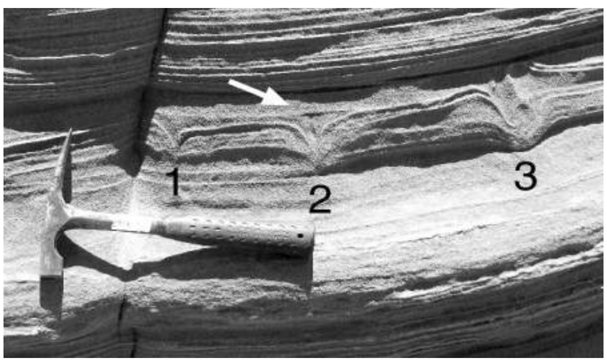

Figure 6. Thin avalanche layers with three down-folded tracks made by an animal moving across the dune slope from left to right. (Navajo Sandstone at Coyote Buttes). The view is of a near-vertical rock surface, looking in the downslope direction. The white arrow marks an avalanche layer. This layer overlies an erosion surface that cuts tracks 1 and 2, but the erosion surface and the overlying avalanche layer are folded by track 3. Conclusion: tracks 1 and 2 are a few seconds older than the track 3, and the animal started a dry-sand avalanche with each step; from Loope (2006a).

avalanching is rare and each avalanche is thick. The avalanches that have tracks in them are thin because the repeated disturbances cause frequent avalanching.

Just because dry sand is easy to erode doesn't mean that dry sand tracks can't be preserved in the rocks. It is certain that many dry-sand tracks, dry-sand avalanches, and wind-ripple layers made with dry sand were eroded after they were deposited, and before they were buried. But it is also certain that the Navajo Sandstone reaches a thickness of 700 meters, and that nearly all of the sand now in the formation was transported and deposited while it was dry. Apparently the Jurassic wind wasn't a perfect eraser: more dry sand was deposited than was carried away.

Burrows in the Entrada Sandstone Near Escalante, Utah

The distinct, relatively thin layering that is produced by avalanching on dune slopes and by the migration of wind ripples allows geologists to see features that would be invisible in crudely bedded deposits. Anything that disrupts the layering requires an explanation. Some broken and folded layers in eolian sandstones record ancient earthquakes (Horowitz, 1982). Before the sand is cemented into sandstone, but after it has been buried below the water table, shaking can turn it into quicksand. During the brief time during which it changes from solid to liquid, and then back to a solid, the sand can flow several meters, creating large folds. Avalanche layers are more likely to do this because they are more porous than wind-ripple deposits. Cohesive sand above the water table is sometimes broken by small faults when the sand below it turns to quicksand.

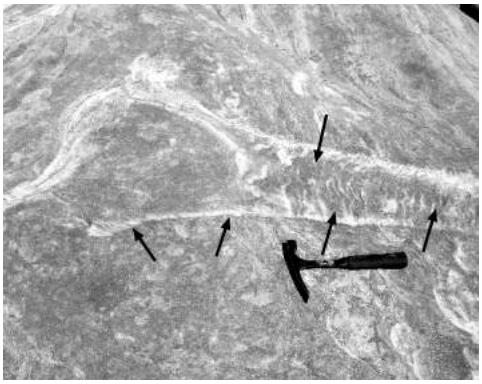

Figure 7a

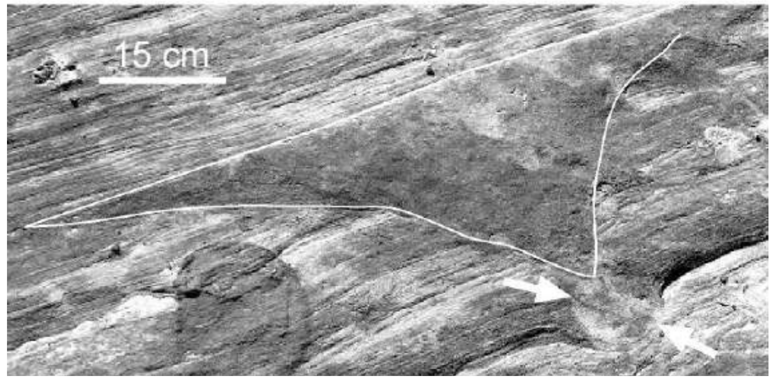

Figure 7b

Trace fossils also disrupt the layering in dune deposits, but these disruptions are usually easy to distinguish from the quicksand features. As described above, the weight of an animal can create small, distinct folds in the sand layers. Animals that dig into dunes disrupt or terminate the layers that they encounter. Near Escalante, Utah, cylindrical burrows of several different sizes cut the layering in the upper part of the Entrada Sandstone. Insects probably made the smallest burrows, which are less than 5 mm in diameter. Some of the burrows, however, reach a diameter of 63 cm and lengths greater than 3 m . Fairly large vertebrates – comparable in size to a badger– must have made these excavations.

Animals dug the burrows relatively high on the dune slopes, far above the groundwater table. The burrows slope downward at about 20º, and sometimes end in an expanded chamber. Some of the burrows are filled by structureless (non-layered) sandstone, and others contain large, angular blocks of layered sandstone that must have formed during collapse of the burrow. Several of the burrows, however, are filled by crossbedded sandstone (Fig. 7a). The crossbeds indicate that small drifts of wind-blown sand entered the open throats of the burrows and progressively filled them.

These burrows clearly could not have been dug into dry sand; the only likely explanation is that they were excavated into rain-moistened sand. When the dune's surface dried, the wind again began to transport loose sand; some of this sand drifted into the open burrows. Because body fossils are almost completely absent from the Entrada Sandstone, the identity of the burrower remains unknown (Loope, 2006b).

Medium-sized burrows, ranging from 25-35 mm in diameter are also common in the Entrada.

Figure 7c

Figure 7. Burrows in the Entrada Sandstone near Escalante, Utah, and in a modern dune. (a) Large burrow that cuts large-scale crossbeds, descends to the right at about 20º, has sharply defined margins, and is filled with small-scale crossbeds (arrows). Burrow was dug into rain-moistened dune sand and was eventually filled by drifts of loose sand (moving left to right) as the dune progressively dried. (b) Cone-shaped top of a cylindrical, medium-sized burrow that was probably dug while the surface sand was dry and subsurface sand was moist. The cylinder is seen in cross-section between the white arrows. After sediment filled the cone, the surface was eroded flat, and was then buried by migrating wind ripples. (c) Three burrows dug by a kangaroo rat into the base of a modern dune—a possible modern analog for the burrow shown in B. The surface of dune slopes toward the viewer at 32º, and is dry. The upper parts of the burrows are conical with angle-of-repose slopes. Blocks of cohesive sand that are present in the cone-fills were dug from moist sand that lies at shallow depth. [(a) from Loope, 2006 b; (b) and (c) from Loope, 2008].

Some of these burrows change upward from parallel-walled cylinders to cones just before they terminate below an undisturbed layer (Fig. 7b). A possible explanation for these burrows is that they were excavated after a rain-moistened dune surface had started to dry out. By this explanation, the throats of the burrows are wide because dry sand at the top of the burrow continuously collapsed as the burrowing progressed, but after the animal reached moist sand, the walls were stable. When kangaroo rats dig in modern dunes, the uppermost parts of their burrows are cone-shaped; blocks of moist, cohesive sand in the filled cones indicate that moist sand lies a short distance below the surface (Fig. 7c). Another possible explanation for a cone-topped burrow is that the uppermost part of a moist-sand, cylindrical burrow collapsed as the dune surface progressively dried.

Conclusions

Tracks and burrows are locally abundant in both the Lower Jurassic Navajo Sandstone and the Middle Jurassic Entrada Sandstone. These trace fossils are visible because they disrupt distinct layering produced by avalanching sand and migrating wind ripples. Some geologists have claimed that tracks made in dry sand are not preserved in ancient strata. The Navajo contains a huge volume of sand layers that were deposited under dry conditions, and locally abundant animal tracks that disrupted them while they were dry. Although many dry-sand layers and tracks may have been eroded by Jurassic winds (and thus not preserved), these features are nevertheless prominent in the rock that is preserved. The upper Entrada Sandstone contains many animal burrows, some of which exceed half a meter in diameter. The burrows probably provided escape from the high daytime temperatures that prevailed in the subtropical sand sea. The burrows were dug into rain–moistened sand, and drifts of wind–transported sand filled several of them with small crossbeds. These trace fossils demonstrate that, for at least a small portion of their depositional timespan, the Navajo and Entrada sand seas received sufficient rainfall to support an active animal population.

Acknowledgments

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The First Record of Cenomanian (Late Cretaceous) Insect Body Fossils From the Kaiparowits Basin, Northern Arizona

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ABSTRACT

The Middle Cenomanian age middle member of the Dakota Formation (ca. 96 mya) has yielded three fossil odonate naiad (dragonfly larva) specimens in the southern portion of the Kaiparowits Basin. All three specimens appear to represent a single species of anisopteran, possibly of gomphid affinities. This is the first report of Cretaceous odonate body fossils from the western United States and possibly one of the only known occurrences of Cretaceous odonates in North America.

Keywords: Odonata, Insecta, Cretaceous, Dakota, Utah, Cenomanian, Anisoptera, Kaiparowits

Introduction

Over the last six years, Grand Staircase-Escalante National Monument's paleontology program has overseen an intensive interdisciplinary, cooperative effort to inventory the Monument and surrounding Bureau of Land Management (BLM) lands' Cretaceous fossil resources. This has been undertaken not only so that these resources can be managed judiciously, but also to help further define the exact significance of the Monument's Late Cretaceous paleontology, on both regional and global scales. These inventory efforts have emphasized macrovertebrates, however all fossil resources with known significance, including flora, invertebrates, and traces have been documented.

In spring 2005, local residents of the town of Big Water reported finding fossil turtle material in the lower member of the Dakota Formation on non-Monument BLM lands just over the Arizona state border. While conducting a general follow up inventory in response to that find in the summer of 2005, one of the authors (LBA) discovered an exceptional fossil flora locality (referred to informally as "Bug Ledge") in the Dakota Formation. This site is located in some of the southern-most outcrops of Cretaceous rocks in the Kaiparowits Basin (Figure 1), also on BLM lands. By chance, RSB was looking for new localities for his dissertation research on floral response to the Cenomanian-Turonian extinction event, and was made aware of the site. During the first collecting effort by RSB in 2005, a single, complete odonate naiad fossil was recovered by LBA, which was subsequently given to the senior author. Subsequent collecting by the senior author and LBA from the same horizon and locality produced a second, partial, but well-preserved fossil naiad specimen. A third collecting effort at Bug Ledge by M.H. Graffam, also with the BLM, resulted in the finding of a third specimen tentatively assigned to Insecta. Additional collecting at the locality is now limited by an extremely hazardous overhanging ledge that imminently threatens to collapse (Figure 2).

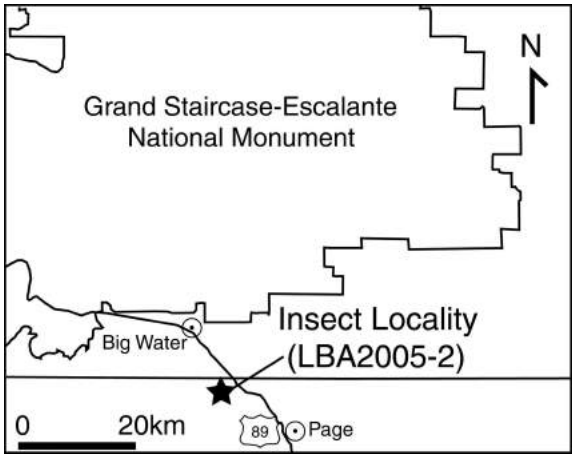

Figure 1. Reference map showing general location of new fossil insect locality (LBA2005-2) reported herein.

Figure 2. Photograph of quarry where all three insect specimens were collected. Insect and flora horizon indicated by white caption "insect layer."

In spite of their relative abundance in Eurasia and South America, Cretaceous fossil odonates are rare in North America. No Late Cretaceous odonate records have been published for North America, and Late Cretaceous insect body fossils are in general, exceedingly rare in the southern portion of the Western Interior Basin (WIB). Given the rarity of Late Cretaceous insects in the southern WIB, and the apparent absence of Cretaceous odonates from the North American fossil insect record, we view the Kaiparowits Basin occurrence as highly significant, particularly because the site has excellent potential to yield additional specimens.

Stratigraphic/Environmental Context

The odonate specimens were all collected from a 30 cm interval of laminated yellowish-tan-to-grayish colored mudstone near the top of the Middle Member of the Dakota Formation (Figure 3) *sensu* Eaton (1991). The Middle Member is dominated by mudstone immediately below the insect locality, but lateral equivalents along strike are relatively thick, amalgamated channel-fill sandstone bodies, indicating the mudstones were deposited in interfluvial lacustrine or paludal environments. Much of the mudstone throughout the member is either carbonaceous or filled with carbonaceous plant debris. Evidence of rooting and thin paleosols was also observed (Figure 3). Fluvial, paludal, and lacustrine environments were also inferred for the Middle Member by Gustason (1989) who additionally hypothesized the Kaiparowits region lay landward of the advancing Cretaceous Western Interior Seaway on a low relief coastal plain at the time of its deposition.

Analysis of the flora collected from the insect horizon shows it to be comprised solely of angiosperms, with at least five recognized leaf morphotypes. The assemblage is dominated by a single taxon provisionally referred to the Myrtaceae (Myrtle family). Another common floristic element includes infloresences tentatively assigned to *Eoplatanus serrata* Schwarzwalder and Dilcher, 1981 (family Platanaceae-sycamores), although easily identifiable foliage of that taxon (Wang, 2002) was not observed.

The Middle Member has yielded radiometric dates of 97.9 +/-0.5 mya near its base (Beik et al., 2003) and 95.97 +/- 0.22 mya in the middle portion (Dyman et al., 2002). This strongly suggests that the fossil odonates, which occur very high in the member, are younger than 96 mya, but older than the lower upper Cenomanian *Calycoceras canitaurinum* Ammonoid Biozone which is recognized in the lower portion of the Dakota's Upper Member (Titus et al., 2005).

Description

The site has yielded only three specimens. Two are incomplete, representing only abdominal sections, while the other is essentially complete. The most complete specimen (LBA2005-2-I1)

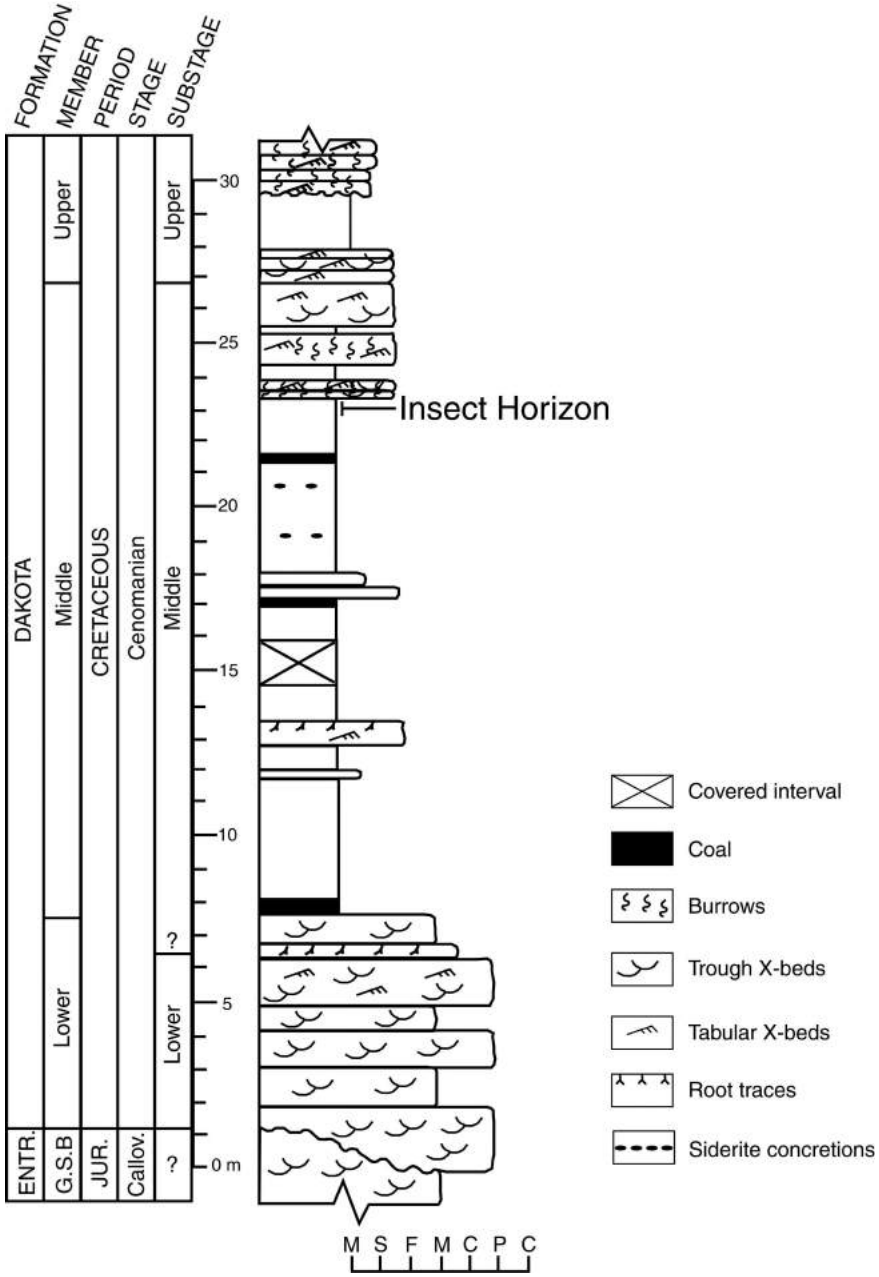

Figure 3. Stratigraphic column for the "Bug Ledge" locality showing the level from which the fossils were collected. Abbreviations are as follows: ENTR.-Entrada; G.S.B.-Gunsight Butte; Jur.-Jurassic; Callov.-Callovian. Grain size fractions are as follows: M-Mudstone; S-Siltstone; F-Fine sandstone; M-Medium sandstone; C-Coarse sandstone, P-Pebble conglomerate; C-Cobble conglomerate.

consists of an impression and its counterpart in a fine-grained tan mudstone (Figure 4.1). The length from the front of the head to the rear of the abdomen (not including the paraprocts and epiproct) is 14 mm, with an average width of approximately 3 mm. The head appears small relative to the body, with a width of only 2 mm and a length of 3 mm. The thorax measures 3.2 mm long, and averages 3 mm wide. Impressions of two wing buds can be seen projecting over the first abdominal segment. The abdomen is 8 mm long and 3 mm wide, tapering to 1.7 mm width at the distal end, and is divided into at least eight segments. Two relatively long, narrow, tapering paraprocts (about 5 mm by 0.4 mm at the widest point) project posteriorly from the cercus. All three left legs are preserved and are complete, including tarsi. The middle and posterior legs on

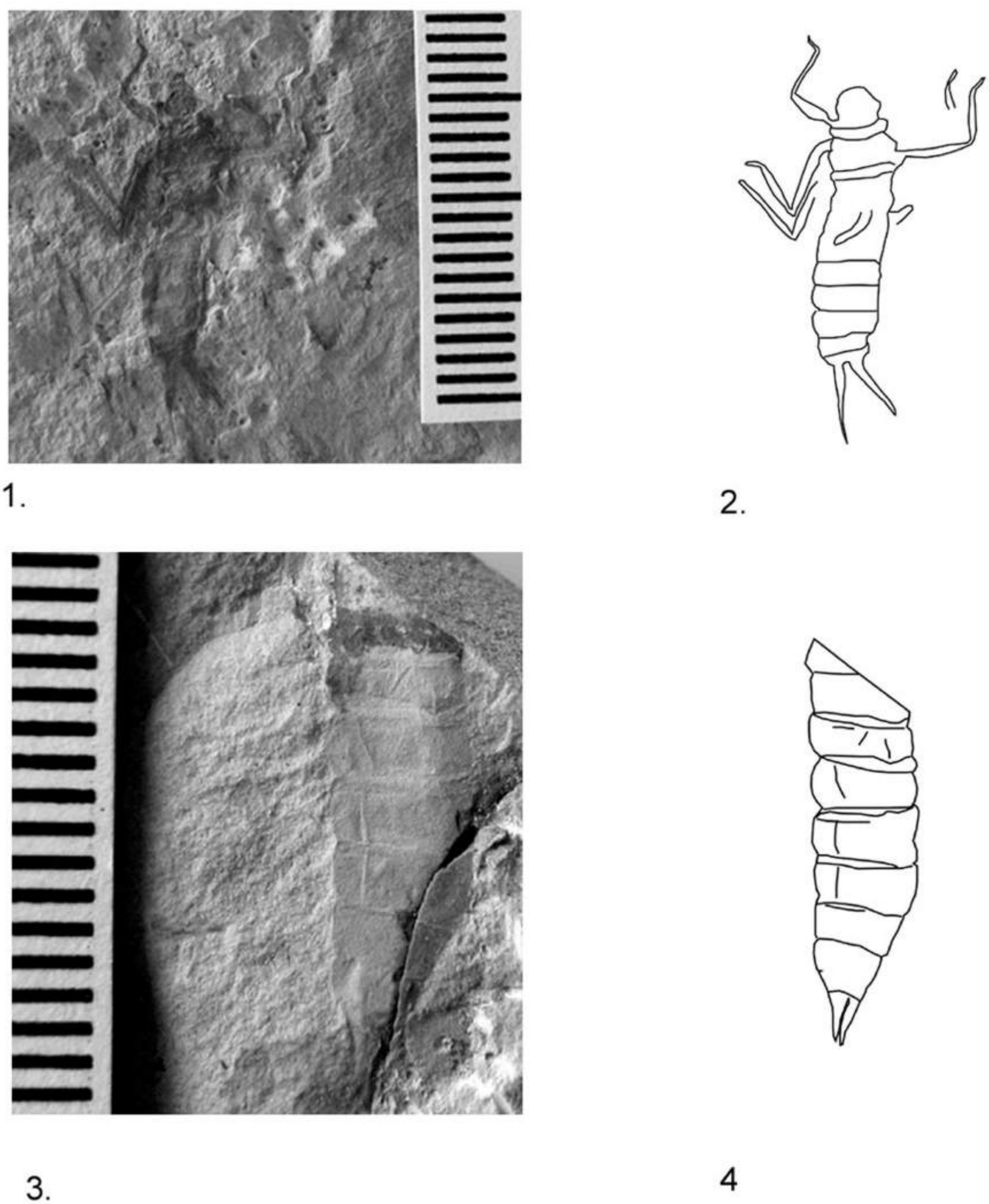

Figure 4. Odonate naiad specimens from the Bug Ledge locality. 4.1 LBA2005-2-I1 photograph of best specimen; 4.2 Camera lucida drawing of same specimen; 4.3 LBA2005-2-I2 photograph showing detail of abdominal segmentation preserved; 4.4 Camera lucida drawing of same specimen. Scale on left of photographs is in millimeters.

the right side were damaged during preparation and only preserve the femora and tibiae. The right anterior leg was not observed.

Specimen LBA2005-2-I2 is only an abdomen, preserved as a laterally crushed impression (Figure 4.2). Eight segments are preserved, indicating a nearly complete abdominal section. The long paraprocts seen in LBA2005-2-I1 are not visible in I2, which may be an artifact of preservation or preparation or could indicate that two taxa are represented. However, in other regards the specimens appear quite similar. The third specimen (LBA2005-2-I3) appears to show five segments, although there is some question as to whether it may actually be a gastropod. Neither the anterior or posterior ends are preserved. It adds little to the description of the taxa other than to say it agrees in general size and arrangement of the segments with the other two specimens.

Discussion

The short para- and epiprocts make assignment of these specimens to the Anisoptera *sensu* Carle and Wighton (1990) relatively certain. The relatively small head size relative to overall body proportion and the slender body form is more characteristic of aeschnidiids, but family level assignment awaits more detailed study. However, we note the very close similarity of the Dakota specimens with nymph specimens from the Crato Formation of Brazil assigned to *Nothomacromia sensibilis* (Carle & Wighton, 1990), particularly in the proportions of the long, forcep-shaped paraprocts (Bechly, 1998).

Conclusions

A review of the available literature indicates that no other Cretaceous-age odonate fossils have been reported from the Western Interior Basin. Although on a global basis, the Mesozoic fossil record of anisopterans is relatively robust (Grimaldi and Engel, 2005), they are extremely rare in North America in the pre-Cenozoic. The most prolific and diverse stratigraphically-constrained Cretaceous insect assemblages known from North America are the amber inclusion faunas described from the Campanian age Foremost Formation of Canada (Pike, 1994) and the Raritan Formation of New Jersey (Turonian-Maastrichtian) (Grimaldi et al., 1989). However, odonates are exceedingly rare in amber insect faunas probably because resinous deposits form in thickly forested ecotypes, whereas odonates generally occur around open water or marshy areas. Late Cretaceous insect localities in North America yielding compressional body fossils in paludal or lacustrine facies have generally only yielded rare cockroaches (blattids) (Labandiera, personal communication 2006). Development of alkaline or ash-smothered lake facies in the Western Interior of the United States during the Miocene-Eocene interval led to the preservation of outstanding compressional insect faunas, such as those found in the Green River and Florissant formations, which have yielded a number of odonate taxa (Grande, 1984; Scudder, 1890; Mayer, 2003). Such facies are rare in the Late Cretaceous of North America. The fact that two well-preserved fossil odonates have been recovered from the Bug Ledge locality automatically makes it one of the most important Cretaceous insect localities known from the Western Interior and demonstrates it could someday provide a critical window into North American Cretaceous insect diversity.

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An Updated Summary of the Cretaceous-aged Lizard Faunas of Grand Staircase-Escalante National Monument

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ABSTRACT

Cretaceous age sedimentary rocks are exposed throughout Grand Staircase-Escalante National Monument (GSENM). The lizard fossils from these units comprise at least three faunas. The oldest lizard fauna is from the Dakota Formation (Cenomanian) and is taxonomically intermediate between known Early Cretaceous and Late Cretaceous faunas. The next youngest fauna is from the Smoky Hollow Member of the Straight Cliffs Formation (Turonian). This fauna includes mostly scincomorphan and anguimorphan taxa; some are similar to other Late Cretaceous faunas. The Dakota and Straight Cliffs formations have no known microvertebrate-producing equivalents elsewhere in North America. The youngest fauna is from the Kaiparowits Formation (Campanian). Although a distinct fauna, it does share taxa with similar aged faunas of the northern Western Interior.

The nearly continuous Cretaceous-aged sediments of GSENM provide an unparalleled opportunity to study long term evolutionary and paleobiogeographical patterns of lizards within a confined geographical area.

Introduction

Upon establishment of Grand Staircase-Escalante National Monument (GSENM) in 1996 a tremendous amount of paleontological resources, in both square miles of potentially productive exposures as well as inestimable scientific significance, was protected along with a wide variety of other natural and historic resources. Among the paleontological resources known to exist within the boundaries of GSENM are extensive rock exposures (Fig. 1) containing fossils of terrestrial vertebrates from the Late Cretaceous, or the end of the Age of Dinosaurs (approximately 98-75 million years ago). Much of this early information was the result of the groundbreaking research on early mammals from these rock units (Cifelli 1990a, 1990b, 1990c, 1990d, 1990e; Eaton 1993, 1995; Eaton and Cifelli 1988; Eaton, Cifelli et al. 1999). However, there remained almost no information on non-mammalian vertebrates from the Cretaceous, including lizards. The earliest report on lizards was a description of an unusual taxon of polyglyphanodontine lizard (McCord 1998). This was followed the next year by another report of polyglyphanodontine lizards from an older horizon than that reported by McCord (Nydam 1999b) and a series of faunal lists from various fossil-bearing horizons within the Cretaceous-age sediments of the Kaiparowits Plateau (Eaton, Cifelli et al. 1999). The faunal lists of Eaton et al. (1999) are valuable in that they established for the first time, and remain to this day, the most comprehensive single source describing the observable diversity (from sharks to mammals) of the microvertebrate fossil taxa from the Cretaceous of the GSENM. With regard to lizards there were six taxa, or potential taxa (only one identified to the genus level), recognized from the oldest of the Cretaceous-aged rock units, the Dakota Formation (Cenomanian); 12 taxa (four identified to

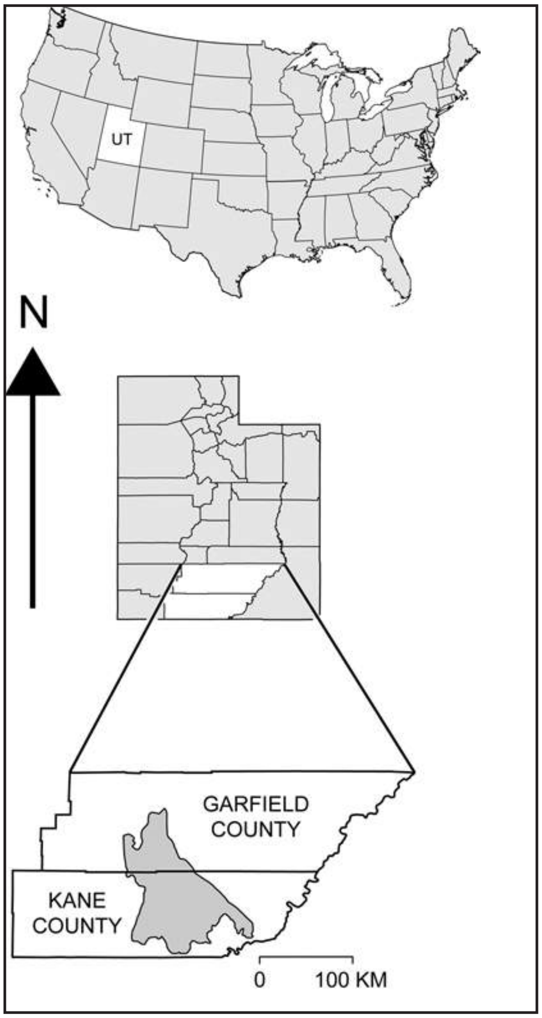

Figure 1. Distribution of Cretaceous-aged rocks (gray shading in the expanded Garfield and Kane counties) in southern Utah. Much of the indicated exposures are within the boundaries of Grand Staircase-Escalante National Monument.

genus, two identified to species) recognized from the Smoky Hollow Member of the Straight Cliffs Formation (Turonian); four taxa (only one identified to species level) recognized from the John Henry Member of the Straight Cliffs Formation (Coniacian-Santonian); two taxa (only family level identifications) recognized from the Wahweap Formation (Santonian?-early Campanian); and 14 taxa (five identified to genus, six identified to species) recognized from the Kaiparowits Formation (Campanian).

Following the conclusion of my dissertation research on the lizard fossils of the Early Cretaceous (including those of central Utah) I began an investigation specifically into the lizards of the Late Cretaceous of southern Utah. This work is ongoing and includes reanalysis of the materials collected by Drs. Eaton and Cifelli that were the basis for the faunal lists mentioned above and additional collection of established and new localities within GSENM. As a result of these renewed efforts and the ever improving/changing interpretations of lizard taxonomy and systematics, updates and changes to the faunal lists of Eaton et al. (1999) are inevitable and both Drs. Eaton and Cifelli have, and continue to support, encourage, and facilitate this work.

At the writing of this paper I find myself in what I hope is the “middle” of this current study of lizards from GSENM. My initial plan was for a quick redescription of the collected materials, but it was soon apparent that the lizard remains from the GSENM and surrounding areas represent a much more complex and intriguing record and a single project has itself “evolved” into a series of projects investigating the evolutionary patterns of multiple taxonomic groups. Much of this work is still ongoing. This report is a summary of completed studies and an extended preview of the current status of projects that are still in progress. More formal treatments of the systematics of the lizards from the Cretaceous of the GESNM are, and will be, part of more comprehensive reports available as a series of separate manuscripts that are published (Nydam 1999; Nydam et al., 2007; Nydam and Voci, 2007), or in progress. Many, but certainly not all, of the taxonomic assignments made in the faunal lists of Eaton et al. (1999) have been or will be changed or modified. Many of their identifications at the genus and/or species level were based on specimens of generally similar morphology to known lizard taxa from other Late Cretaceous localities from more northern latitudes (for review of the relevant taxa see Estes 1983). While some of these assignments, at least at the genus level, appear to be accurate (e.g., *Odaxosaurus* and *Chamops* in the Kaiparowits Formation), many either cannot be confirmed or actually represent new species. This should not be read as a criticism of Eaton et al. (1999), indeed, while focusing on the mammals they still did a far superior job than some who have focused on lizards. Although not all original taxonomic assignments can be supported, the relative diversity of fossil lizards reported by Eaton et al. (1999), as measured taxonomically or morphotypically, is supported by the results of the current study.

What can now be added is a greater understanding of the richness and complexity of lizard faunas of GSENM that represent the longest nearly continuous record of Cretaceous-aged taxa in one place in North America.

Methodology

Analysis of fossil lizard taxa from GSENM includes study of previously collected specimens housed at the Museum of Northern Arizona (MNA), Flagstaff; the Sam Noble Oklahoma Museum of Natural History (OMNH), Norman; and the Utah Museum of Natural History (UMNH), Salt Lake City. Newly recovered specimens were collected by bulk sampling of microvertebrate producing localities. These samples were processed using the underwater screen washing techniques outlined by Cifelli (1996). All specimens collected by the author are deposited at the OMNH.

Results

The fossil lizard taxa from the Cretaceous of GSENM occur in three distinct faunas (this is a minimum estimate as the John Henry Member of the Straight Cliffs Formation and the Wahweap Formation are known to produce microvertebrate fossils, but yields are too low to make meaningful comparisons and are not included in this report). These faunas are, from oldest to youngest, the Dakota Formation, the Smoky Hollow Member of the Straight Cliffs Formation, and the Kaiparowits Formation.

Dakota Formation

The Dakota Formation was deposited during the Cenomanian (early Late Cretaceous) and is the oldest of the Cretaceous-aged rock units within GSENM (Eaton 1991; Lawrence 1965; Peterson and Waldrop 1965). Lizard specimens recovered from the Dakota Formation include jaw fragments, vertebrae, and isolated osteoderms (body armor). The vertebrae are very fragmentary and add little to the taxonomic assessment of the lizards. Jaws and osteoderms indicate the presence of both scincomorphan and anguimorphan taxa. The scincomorphan taxa include specimens that are similar in dental morphology to both *Dimekodontosaurus* and *Harmondontosaurus*, taxa known from the Mussentuchit Member of the Cedar Mountain Formation (Albian-Cenomanian; Mussentuchit Local Fauna; Nydam 2002), but the specimens are too fragmentary to support formal taxonomic assignment. Several jaw fragments are referable to the genus *Bicuspidon* (*Bicuspidon* sp.), an unusual, but very common scincomorphan from the Mussentuchit Local Fauna closely allied to polyglyphanodontine lizards (Nydam and Cifelli 2002; Nydam et al. 2007). The specimens of *Bicuspidon* from the Dakota Formation are rare and represent individuals significantly smaller than those represented by most of the known specimens from the Cedar Mountain Formation. Other jaw fragments represent a new taxon that appears to be closely related to *Contogenys*, a Late Cretaceous-Paleocene taxon closely related to xantusiids (Gao and Fox, 1996). Several fragmentary jaws are almost certainly referable to *Scincomorpha*, but too incomplete for more comprehensive identification. Several relatively thick, non-imbricating osteoderms with rugose (though decidedly non-crocodylian) ornamentation were recovered (all as isolated elements) that most likely belong to one or more scincomorphans.

Anguimorphan and closely related taxa from the Dakota Formation are rare and represented by a single, nearly complete dentary of a possible xenosaurid and several thin, imbricating osteoderms with vermiculate sculpturing that are referable to Anguidae. There is one varanoid specimen; a jaw fragment with the wide base of a tooth with plicidentine (basal infoldings). Another jaw fragment is characterized by pseudothecodont implantation of a broken, but likely distinctly recurved tooth is possibly from a snake, but no definitive vertebrae have yet been recovered to confirm the presence of a snake in the fauna.

Smokey Hollow Member of the Straight Cliffs Formation

The Smoky Hollow Member of the Straight Cliffs Formation is generally considered to be late(?)Turonian in age and is characterized by a basal lignite and upper mudstones (Cifelli 1990c; Eaton 1991; Eaton, Cifelli et al. 1999; Peterson and Waldrop 1965). One of the most consistently productive horizons for microvertebrates in the Cretaceous of the GSENM are the upper mudstones of this unit.

Scincomorphans from the Smokey Hollow Member of the Straight Cliffs Formation are represented by numerous teeth of a new species of the massive-toothed polyglyphanodontine *Dicothodon*, and, a single specimen referable to *Chamops* (a common component of other Late Cretaceous faunas; Estes 1983; Gao and Fox 1991; Gao and Fox 1996; Peng et al. 2001). Additional scincomorphan specimens include a jaw fragment with very low-crowned (possibly heavily worn) teeth and several relatively thick, keeled, imbricating osteoderms. Although Eaton et al. (1999: p. 347) concluded that the fauna of the Smoky Hollow Member of the Straight Cliffs Formation had a distinctly Late Cretaceous composition, several lizard specimens appear to be closely allied to paramacellodid lizards, a primitive lineage common to the Late Jurassic of North America and the Late Jurassic-Early Cretaceous of Europe (Evans 1995). At least two distinct morphotypes referable to Paramacellodidae are found in the fauna and it is possible that the isolated osteoderms belong to one or both of these "taxa."

Although different than the new species from the Dakota Formation, there is another new species of a *Contogenys*-like taxon from the Smoky Hollow Member of the Straight Cliffs Formation. This and related taxa from the Cretaceous of GSENM are currently the focus of a study by the author and Mr. B. Fitzpatrick.

There is moderate diversity of anguimorphans and varanoids from the Smoky Hollow Member of the Straight Cliffs Formation. Thin, imbricating osteoderms with a vermiculate ornamentation as well as a fragmentary jaw are almost certainly anguid. The anguid jaw is not referable to the common Late Cretaceous anguid *Odaxosaurus* and likely represents a new taxon. There are possibly three different species of varanoid from the Smoky Hollow Member of the Straight Cliffs Formation all of which are distinguished based on gross differences in tooth morphology. Large, non-imbricating osteoderms with rugose ornamentation are referable to Varanoidea.

Characteristic vertebrae (round cotyle/condyle, well-developed zygosphene and zygantra) and a jaw fragment with a closed, but not fused Meckelian groove and pseudothecodont implantation of a conical, strongly recurved tooth indicate the presence of at least one taxon of snake in the Smoky Hollow Member of the Straight Cliffs Formation.

Kaiparowits Formation

The Kaiparowits Formation is the youngest of the Cretaceous-aged rock units in GSENM. It is composed of stacked mudstones with interbedded channel sandstones and accounts for the prominent blue-grey Bad Lands (e.g., The Blues) characteristic of much of the northern regions of the monument. The age of the Kaiparowits Formation is Campanian (Eaton 1991; Roberts et al. 2005) and it is rich in microvertebrates (Cifelli 1990a, 1990d; Cifelli and Johanson 1994; Eaton 1991, 1999; Eaton and Cifelli 1988; Eaton, Cifelli et al. 1999; Eaton, Diem et al. 1999) as well as dinosaurs (this volume).

The scincomorphans from the Kaiparowits Formation include numerous Borioteiioids (a.k.a. "teiids" & polyglyphanodontines, see Nydam et al., 2007 for an updated taxonomy) that were described by Nydam and Voci (2007). Many of these taxa are similar to other non-polyglyphanodontine taxa known from other Campanian-aged faunas (e.g., *Chamops* and related taxa), but there is also at least one new genus and species. Polyglyphanodontines are represented by a new species of *Peneteius* (Nydam et al. 2007). Non-borioteiioidean scincomorphans include another new taxon of a *Contogenys*-like lizard (Nydam and Fitzpatrick, 2009), cordylid-like taxa referable to *Aocnodromeus* sp. and Cordylidae indet., and at least six taxa that are morphologically distinct, but too fragmentary for referral beyond Scincomorpha indet.

Anguimorphans are represented by numerous jaws referable to *Odaxosaurus* cf. *O. pricsus*. Numerous osteoderms referable to Anguidae likely belong to the same taxon as no other anguids are known from the unit. Varanoids are represented by numerous fragmentary remains tentatively referable to the genera *Parasaniwa* and *Labrodioctes*. Some more fragmentary varanoid specimens remain taxonomically indeterminate. Jaw fragments and vertebrae of at least one taxon of snake were also recovered from the Kaiparowits Formation.

Discussion

The presence of *Bicuspidon* sp., a *Dimekodontosaurus*-like taxon, a *Harmondontosaurus*-like taxon, a varanoid, and even a snake in the Dakota Formation is not surprising as closely related representatives are known to occur in the slightly older (latest Early, or medial, Cretaceous) Mussentuchit Local Fauna of the Cedar Mountain Formation of central Utah (Gardner and Cifelli 1999; Nydam 2000, 2002; Nydam and Cifelli 2002). The new *Contogenys*-like taxon, possible xenosaurid, and anguid establish what appear to be the earliest examples of lineages more common to the Campanian-Maastrichtian of the Western Interior. The presence of the primitive family Paramacellodidae has not been confirmed, though representative taxa are known from the Mussentuchit Local Fauna (Nydam 2002) and also from the overlying Smoky Hollow Member of the Straight Cliffs Formation. Although this report represents a significant revision of what was known at the time of Eaton et al. (1999), it should still be considered preliminary as ongoing work in Dakota Formation within GSENM will undoubtedly improve our knowledge of this lizard fauna.

The lizards of the Smoky Hollow Member of the Straight Cliffs Formation are taxonomically, or at least morphotypically, distinct from those of the Dakota Formation, but like the later includes taxa known from older faunas and taxa representative of younger faunas. Most striking is the presence of likely paramacellodids in the Smoky Hollow Member fauna. Paramacellodids are more common to Late Jurassic-Early Cretaceous lizard faunas and represent an older pan-Laurasian distribution (Evans 1993, 1995, 1998; Evans and Chure 1999; Nydam 1999a) for which some representatives survived into the medial Cretaceous (Nydam 2002). The continued presence of paramacellodids into the Turonian of southern Utah may indicate that central-southern Utah maintained a collection of relictual taxa of these more primitive lizards. This is not without precedent. A series of relictual taxa of sphenodontians and basal lepidosauromorphans have been described from the Tamaulipas region of Mexico (Reynoso 1997, 1998, 2000; Reynoso and Clark 1998). Conversely, some paramacellodids share many morphological characteristics of their teeth with some modern skinks and cordylids (Estes, 1983; personal observation) and the fragmentary remains from the Smoky Hollow Member of the Straight Cliffs Formation may actually represent more advanced taxa. Recovery of more complete remains is necessary to test support for either of these hypotheses.

Among the other scincomorphans from the Smoky Hollow Member of the Straight Cliffs Formation the new species of *Dicothodon* is a representative of what is now recognized as a genus with a relatively long temporal duration and a distribution restricted to the more southern latitudes of North American (Nydam et al. 2007). The presence of a specimen referred to the genus *Chamops* represents the earliest occurrence of this taxon. More complete material is required to determine whether this represents *C. segnis* or a new species. Specimens of the new species of a *Contogenys*-like taxon are the most commonly recovered lizard remains from the Smoky Hollow Member of the Straight Cliffs Formation.

The jaw fragments of anguimorphans and varanoids from the Smoky Hollow Member of the Straight Cliffs Formation are too fragmentary for specific identification. The osteoderms recovered are certainly anguid and quite possibly belong to *Odaxosaurus*, but the systematic value of osteoderm morphology has not been satisfactorily demonstrated for identification of anguids beyond the family level. The presence of varanoids and a snake are not unexpected in this fauna. The specimen referred to the primitive anguimorphan *Dorsetisaurus* by Eaton et al. (1999) was reviewed and it is more likely a varanoid lacking plicidentine (similar to *Colpodontosaurus*).

The Kaiparowits Formation lizard fauna is the most diverse of the three described herein, but it also shares characteristics with the other two faunas. Like older faunas from GSENM, the Kaiparowits Formation lizards include another new species of a *Contogenys*-like lizard and a polyglyphanodontine (*Peneteius*; Nydam et al. 2007). Unlike the two older faunas, the Kaiparowits Formation has a more recognizable diversity of borioteiioids similar to the "teiids" known from more northerly localities (Nydam and Voci, 2007).

Conclusions

The Cretaceous-aged lizards of Grand Staircase Escalante National Monument provide an important addition to the record of lizard evolution in North America. These faunas represent the only known series of successive faunas from the early Late Cretaceous (late Cenomanian through mid Campanian) that is also geographically restricted.

Recognizable trends throughout these series of lizard faunas is the presence of the polyglyphanodontine taxa *Bicuspidon*, *Dicothodon*, and *Peneteius* in the Dakota, Straight Cliffs, and Kaiparowits formations, respectively, as well as the iterative presence of apparently closely related new species of *Contogenys*-like taxa in each fauna. Of the three faunas reviewed above, the lizards of the Kaiparowits Formation (Campanian age) share the most taxa, at least at the genus level, with other known lizard faunas from the Late Cretaceous, almost certainly a consequence of being the only fauna in GSENM for which paracontemporaneous microvertebrate faunas are known in other regions of the Western Interior. It is this uniqueness of the microvertebrate faunas of the Dakota and Straight Cliffs formations (as well as the Wahweap Formation, though not reviewed here) that makes the continuing investigation into the lizards, and other taxa, important to a more complete understanding of the evolutionary and paleobiogeographical patterns of the North American fauna.

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Note in Proof

Since the submission of this manuscript in 2007 the project on the *Contogenys*-like lizards from southern Utah has been published (Nydam and Fitzpatrick 2009).

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Grand Staircase-Escalante National Monument: A New and Critical Window into the World of Dinosaurs

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ABSTRACT

The Kaiparowits Basin Project was initiated in 2000 in order to explore Upper Cretaceous deposits preserved within Grand Staircase-Escalante National Monument. In particular, emphasis has been placed on excavation and study of macrovertebrates from two Campanian-aged units—the Kaiparowits and Wahweap formations. Results to date have been abundant and spectacular, with multiple new vertebrate taxa recovered. Significant finds include diagnostic remains of dinosaurs that more than double the known diversity of this group from the Kaiparowits Formation. Several dinosaur taxa are now represented by exceptional materials, including mostly complete skulls and postcrania, as well as integumentary impressions. Concurrent geologic studies have established a chronostratigraphic framework and provided key stratigraphic and sedimentologic and paleoenvironmental insights. Preliminary project results provide key support for the hypothesis of latitudinally arrayed regional faunas, with the degree of north-south faunal mixing yet to be determined.

Keywords: biogeography, dinosaurs, Kaiparowits Formation, paleontology, vertebrates, Wahweap Formation

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Introduction

Grand Staircase–Escalante National Monument (GSENM), encompassing 1.9 million acres of rugged terrain in southern Utah, was the last major region within the contiguous United States to be mapped (Fig. 1). Formally designated by Presidential Proclamation in 1996, the monument was established in large part to facilitate preservation and study of its diverse natural resources, both living and fossil. Within the boundaries of GSENM are abundant exposures of several Upper Cretaceous formations concentrated in the central region of the monument known as the Kaiparowits Basin. These formations preserve one of the most continuous Cenomanian–Campanian terrestrial records anywhere in the world (Eaton and Cifelli, 1988). Paleontological research conducted in the late 20th century documented the tremendous paleontological potential of these deposits. However, the majority of this work (conducted over a period of about two decades) focused on surface collection and screen-washing of microfossils, with an emphasis on mammals (Cifelli, 1990a, b, c; Eaton, 1991, 1999a, b, 2002; Eaton et al., 1999). With regard to macrofossils, several institutions—in particular, Brigham Young University and the University of California, Berkeley—have conducted sporadic work, mostly in the Kaiparowits Formation (Parrish and Eaton, 1991; Hutchison, 1993; Eaton et al., 1999). Although most of the recovered remains were fragmentary, these early efforts amply demonstrated the potential for recovering a diverse range of vertebrate macrofossils within the Kaiparowits Basin.

In 2000, the Utah Museum of Natural History (UMNH) at the University of Utah, in conjunction with GSENM, initiated the Kaiparowits Basin Project (KBP), aimed at collecting and researching terrestrial and freshwater vertebrate fossils from the Kaiparowits Basin of GSENM. In particular, the project has focused on the Kaiparowits and Wahweap formations' macrofossil record undocumented by previous microvertebrate researchers. In 2001, the University of Utah established a collaborative agreement with the Bureau of Land Management (assistance agreement JSA015003), which resulted in financial assistance from the BLM via GSENM. The specific research objectives of the KBP can be summarized as follows:

1) Collect vertebrate, invertebrate, ichnological, and paleobotanical fossils from the Kaiparowits and Wahweap formations to provide the first detailed macrovertebrate record from Utah for this critical time period.
2) Establish a high-precision temporal, depositional, taphonomic, and paleoenvironmental context for the richly fossiliferous Kaiparowits–Wahweap alluvial package in the Kaiparowits Basin.
3) Use the paleontological and geological results to reconstruct as accurately as possible the succession of Late Cretaceous terrestrial ecosystems in the Kaiparowits Basin.
4) Place the above findings into a regional framework and investigate large-scale patterns and processes relating to ecology, evolution, taphonomy and biogeography.

To date, UMNH teams have logged a total of 440 days of fieldwork on this project, amounting to 1850 person days (with one person day equaling an eight-hour work day for one person), for a grand total of about 15,000 person hours in fieldwork alone. During this time, the total area surveyed in both the Wahweap and Kaiparowits formations totaled ~23,500 acres. Over 600 vertebrate localities have been discovered and mapped; hundreds of macrofossil sites have now been surface collected or excavated. Results to date have been abundant and spectacular, exceeding initial expectations in virtually all categories, with many discoveries representing new genera or species (Titus et al., 2001; Kirkland et al., 2002; Sampson et al., 2002, 2004; Smith et al., 2003). Moreover, preservation is frequently exceptional—particularly with regard to the abundant dinosaur remains—including articulated skeletons and integumentary impressions. Commonly found nondinosaurian macrovertebrate taxa include a variety of crocodilians, turtles and fishes. Trace fossils are also common, encompassing not only vertebrate traces such as dinosaur tracks, but also remarkably preserved insect traces (Roberts and Tapanila, 2006; Roberts et al., 2007). Additional paleontological results include collection and preliminary identification of a wide range and diversity of plant morphotypes.

Since its inception this project has sought to place newly discovered vertebrate fossils into a well constrained stratigraphic and paleoenvironmental context. Thus, geologic inventory has

Figure 1. Late Campanian (~75 Ma) North America, depicting the Cretaceous Western Interior Seaway subdividing the continent. Key Western Interior Basin geologic formations are shown. *Abbreviations:* A, Aguja Formation; D, Dinosaur Park Formation; F, Fruitland and Kirtland formations; J, Judith River and Two Medicine formations; K, Kaiparowits and Wahweap formations.

paralleled the paleontological work, providing key insights into these Late Cretaceous paleoenvironments. Highly significant is the discovery of multiple volcanic ash (bentonite) horizons at varying stratigraphic levels within the Kaiparowits Formation. Radiometric analysis (Roberts et al., 2005a) has provided the requisite temporal context, indicating that the Kaiparowits Formation was deposited over a geologically brief interval of about 2 million years, spanning 76 to 74 Ma. Geologic work, combined with taphonomic and paleontological results, has also provided key insights into the paleoenvironmental context of the Wahweap and (particularly the) Kaiparowits formations.

This paper summarizes our current state of knowledge with regard to the geology and paleontology of the Kaiparowits and Wahweap formations, highlighting the results of the KBP. It also provides a brief discussion of the implications of these results for understanding the diversity, biogeography, and evolution of Campanian faunas in the Western Interior Basin (WIB). The reader should keep in mind, however, that this contribution comprises a brief review of a work in progress; for example, most of the specimens described herein have been recovered in the past several years and are currently under study. Thus, it is expected that a similar review written in as little as five to ten years would provide a considerably more resolved picture.

Institutional abbreviations

RAM, Raymond M. Alf Museum, Claremont, CA; UCMP, University of California Museum of Paleontology, Berkeley, CA; UMNH, Utah Museum of Natural History, Salt Lake City, UT.

Geologic and Paleoenvironmental Context

This KBP has targeted the Upper Cretaceous Kaiparowits and Wahweap formations, which together represent an eastwardly prograding clastic wedge deposited after the final retreat of the Cretaceous Western Interior Seaway (KWIS) in Utah (Peterson, 1969). These strata are part of an extensive late Mesozoic sedimentary package deposited within coastal and alluvial plains that together comprise the Cordilleran foreland basin. The sediments are derived from the actively evolving Sevier fold and thrust belt to the west and the Mogollon highlands to the south (Goldstrand, 1992; Lawton et al., 2003).

Kaiparowits Formation

The Kaiparowits Formation consists of approximately 860 m of late Campanian age strata that accumulated in a mosaic of fluvial and floodplain settings inland of the western margin of the KWIS (Eaton, 1991; Roberts, 2007). Thick floodbasin pond and lake deposits, large channels, and poorly developed paleosols suggest that deposition occurred in a relatively wet alluvial system. Roberts et al. (2005a) used radiometric data to constrain the age of Kaiparowits deposition to between approximately 76 and 74 Ma, making this unit penecontemporaneous with the fossiliferous portions of several other formations in the WIB, including Dinosaur Park, Judith River, Two Medicine, and Fruitland formations (Fig. 2). The most fossiliferous portion of the Aguja Formation of southwest Texas (Upper Shale member) was previously regarded as penecontemporaneous with the above-named formations (Lehman 1997); however, recent study indicates a younger age, likely spanning the latest Campanian and early Maastrichtian (Atchley et al., 2004; Sankey et al., 2007). The Kaiparowits Formation is highly fossiliferous, particularly the middle member, with vertebrate remains preserved within both channel and overbank deposits. Prior to 2000, macrovertebrate collection in the Kaiparowits Formation was almost exclusively restricted to the limited area of badlands along U.S. Highway 12 (Fig. 2). However, recent exploration of more remote exposures to the south have been very productive, highlighting the potential for continued success in locating and excavating new vertebrate localities, especially along Death Ridge, Fossil Ridge, South Canaan, and Four Mile Bench (Fig. 2).

Wahweap Formation

Conformably underlying the Kaiparowits Formation is the Wahweap Formation, a 350–480 meter-thick unit divided into four informal members that span the entire middle Campanian (~80.8-76.1 Ma; Jinnah et al., in review). The formation consists largely of fully alluvial to tidally-influenced fluvial and overbank sandstones and mudstones laid down by meandering and braided streams and their associated floodplains (Eaton, 1991; Pollock, 1999).

With the Campanian strata of the Kaiparowits Basin now firmly constrained in time, the region becomes one of a small handful of areas in North America that have both relatively continuous Campanian terrestrial fossil records and established chronostratigraphic control, both of which are critical for making meaningful regional and global faunal and floral comparisons. Future plans include refinement of the temporal resolution of the Kaiparowits Formation and especially the Wahweap Formation by dating additional bentonites and through dating of detrital zircons from fine-grained siltstone facies. Improved age assessments are particularly important in light of the unexpectedly short duration recently documented for the 860 m-thick Kaiparowits Formation (~2 Ma; 76.1-74.0 Ma). Additional geologic goals include improving our understanding of the physical controls on basin formation. Among the most

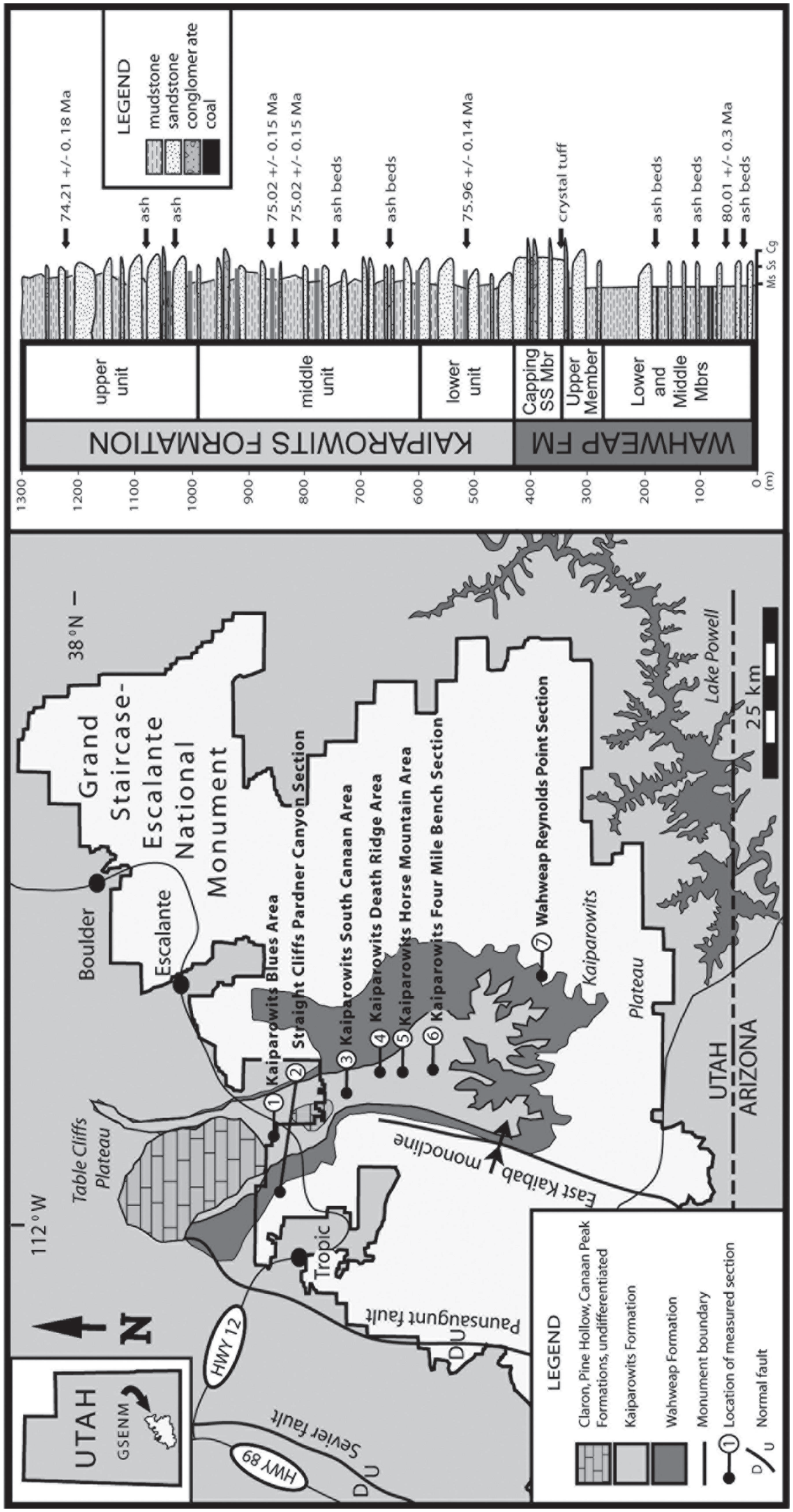

Figure 2. General locality map for the Kaiparowits Basin, with primary study locations (numbered) and a composite measured section along U.S. Highway 12 in Grand Staircase-Escalante National Monument. (Modified from Eaton, 1991; Roberts et al., 2005a).

intriguing results of our preliminary investigations is the revelation that the Kaiparowits Formation has one of the highest sediment accumulation rates (~41 m/Ma) in the WIB (Roberts et al., 2005a). Thus, using a combination of data (e.g., sandstone provenance analysis [e.g., Dickenson and Suczek, 1979] and uranium-lead dating of detrital zircons [Gehrels, 2000]), we plan to assess the relative roles of tectonics, climate, and sea level changes on basin development, and ultimately, on fossil preservation.

Paleontologic Results

Overview

Our knowledge of the Kaiparowits Formation fauna is substantially better than that for the Wahweap Formation. This disparity is largely due to the fact that the Kaiparowits Formation is significantly more fossiliferous than the underlying Wahweap. In addition, however, much more field time has been devoted to the Kaiparowits Formation. Systematic paleontological work in the Wahweap Formation began in the late 1980s, with a strong focus on microvertebrates, and particularly mammals (Eaton and Cifelli, 1988; Cifelli, 1990b). Aside from isolated teeth and bone fragments, macrovertebrates from the formation remain poorly understood. Nevertheless, crews from the UMNH and the Utah Geological Survey have discovered a number of promising new vertebrate localities, particularly within the floodplain–dominated middle and lower members (e.g., Kirkland et al., 2002). Recent findings include several well preserved dinosaur skulls and associated skeletons, which are currently being prepared and identified (see below), as well as abundant dinosaur trackways. These discoveries indicate that many more exciting specimens remain to be unearthed from the Wahweap Formation, and the paucity of prelate Campanian vertebrates in the central portion of the WIB (Lehman, 1997) increases the significance of those specimens that are recovered.

As noted above, sporadic, institution-based collection of vertebrates in the Kaiparowits formation began in the early 1980s, with a focus on microvertebrates; taxa identified include 13 fishes, 14 lizards, and 22 mammals (Eaton & Cifelli, 1988; Cifelli, 1990a, b, c, d; Eaton, 2002). Since 2000, the KBP has almost doubled the known species diversity from this unit. Given that comparable Late Cretaceous units in the WIB have been prospected regularly for many decades, or over a century in some cases (e.g., Dinosaur Park Formation, Hell Creek Formation), the diversity of macrovertebrate species already recognized from less than a decade of collecting supports the notion that the Kaiparowits Formation will yield a similarly high diversity of terrestrial macrovertebrates. Importantly, the majority of vertebrate taxa (both micro- and macro-) are known only from fragmentary remains, suggesting that we have only begun to realize the potential of these deposits. Below we summarize current knowledge of the vertebrate faunas of the Wahweap and Kaiparowits formations, with an emphasis on macrovertebrate results from the KBP. Also briefly reviewed are the invertebrate and paleobotanical results, which are informing paleoecological reconstructions of the Kaiparowits Formation in particular.

Fishes

To date, the Wahweap and Kaiparowits formations have yielded evidence of at least 17 genera of fishes (Eaton et al., 1999). The cartilaginous fishes (chondrichthyans) are relatively diverse, including: the primitive hybodont genus *Hybodus* and the shell crushing *Lissodus*; the orectolobiform carpet sharks *Brachaelurus* and *Squatirhina*; the sclerorhynchid sawfish *Ischyrhiza*; and the rhinobatid guitarfish *Myledaphu*s. Relatively primitive (basal) bony fishes are represented by the sturgeon *Acipenser*, the primitive gar *Lepisosteus*, and the bowfin *Amia*, whereas more advanced bony fishes (teleosts) include *Astractosteus*, *Paralbula*, and *Plactacodon*.

Amphibians

Amphibians are represented by a variety of lissamphibians, the group that includes frogs and salamanders. A total of ten genera and species of amphibians are known from the Wahweap and Kaiparowits formations. The two most abundant genera are *Albanerpeton* and *Habrosaurus* (Eaton et al., 1999; Gardner, 1999, 2000a, b). *Habrosaurus* is known from the Kaiparowits Formation and more northern formations within the WIB, as is at least one species of *Albanerpeton* (*A. gracilis*).

Squamates

Recent work on squamates (lizards) from the Kaiparowits and Wahweap formations has revised the generic diversity to 14 taxa, with 8 identified species (McCord, 1997; Eaton et al., 1999; Voci and Nydam, 2003; Nydam et al., in press). Surprisingly, only one genus (*Odaxosaurus*) is known from the Wahweap Formation, whereas the Kaiparowits Formation has yielded remains of scincids, xenosaurids, helodermatids, anguids, and varanids (McCord, 1997, 1998; Eaton et al., 1999a; Nydam, pers. comm., 2004).

Turtles

Turtle fossils are common throughout the Wahweap and Kaiparowits formations. The most common genera are *Basilemys*, *Adocus*, *Denazinemys, Aspideretoides*, and *Compsemys* (Hutchison et al., 1997; Eaton et al., 1999). The Kaiparowits Formation has been the subject of the majority of turtle research; however, the Wahweap Formation has also yielded several nearly complete specimens. Trionychids are the most common turtles found in the Kaiparowits Formation (Fig. 3). Other components of the turtle fauna include a small, undescribed mud turtle and Cretaceous members of the Chelydridae, or snapping turtles.

Crocodilians

Crocodilian remains in the Wahweap and Kaiparowits formations are abundant; yet this group remains poorly understood because of the fragmentary nature of most specimens (Eaton et al., 1999). The Wahweap Formation includes an undescribed large-bodied goniopholid over 7 m in length, as well as several smaller taxa. Crocodilians are better known from the Kaiparowits Formation, which possesses the most diverse crocodilian fauna in the entire WIB, with five identified taxa; these include an undescribed goniopholid, an undescribed species of *Brachychampsa*, and a putative new genus of caiman, the oldest occurrence of this group discovered to date (Wiersma et al., 2004). The diverse morphologies of these apparently coeval Kaiparowits taxa suggest equally diverse lifestyles (Wiersma et al., 2004; in preparation).

Figure 3. Dorsal view of a nearly complete trionychid turtle carapace (UMNH unnumbered) recovered from the Kaiparowits Formation. Scale bar equals 10 cm.

Dinosaurs

Perhaps the most significant contributions of the KBP to date have been those relating to dinosaurs. Although several important specimens have been recovered from the Wahweap Formation (see below), and the potential for further significant finds in this unit appears excellent, the most significant dinosaur discoveries have thus far come from the Kaiparowits Formation. A 1997 review of fossil vertebrates from the Kaiparowits Formation (Hutchison et al., 1997) listed the confirmed presence of eight different dinosaur taxa. Today we can document the occurrence of 16 taxa of nonavian dinosaurs in this unit, a doubling of the previous estimate in less than a decade. Perhaps more significantly, whereas all dinosaurs in 1997 study were known only from fragmentary remains, the KBP has resulted in the collection of the associated (and, in many cases, articulated) remains of approximately 40 dinosaur skeletons, including several partial to nearly complete specimens. Some spectacular examples include nearly complete skulls for several of the duck-billed and horned dinosaur taxa, as well as for a new species of tyrannosaurid theropod. Thus, whereas the 1997 study identified four of the eight dinosaur species to the genus level or below, we currently have sufficient materials in hand to establish the generic taxonomy of 10 of the 16 taxa (with many of these specimens currently under study). Moreover, the Kaiparowits sample is now sufficient to question or refute three of the four genera identifications made in the study by Hutchison et. al. (1997). Below is a brief review of the dinosaur fauna of the Wahweap and Kaiparowits formations. See also Zanno et al. (this volume) and Gates et al. (this volume) for more detailed discussions of the theropod and ornithopods, respectively.

Ornithopods

Ornithopods were a group of highly successful, plant-eating dinosaurs that played a major role within Late Cretaceous ecosystems on many continents around the globe. North American representatives of this widely distributed group include the relatively small-bodied hypsilophodonts and the giant-sized hadrosaurs (duck-billed dinosaurs). Within GSENM, hypsilophodont-grade ornithopods are thus far known only from the Kaiparowits Formation, and multiple specimens indicate the presence of a relatively large-bodied, undescribed taxon (Gates et al., this volume).

Hadrosaurids are divided into two groups: the crested lambeosaurines, which possess hollow, bony crests incorporating the nasal cavity; and the non-crested hadrosaurines, which either lack crests altogether or possess a solid, bony crest that does not incorporate the nasal cavity. As in most other terrestrial ecosystems from the Late Cretaceous of North America, hadrosaurid remains are the most common dinosaur fossils collected from the Wahweap and Kaiparowits formations. To date, two duck-billed dinosaur taxa, both hadrosaurines, are known from the Wahweap Formation: one form shares close affinities with *Brachylophosaurus*, whereas the second is closely related to an undescribed taxon from Montana (Gates et al., this volume). Three hadrosaur taxa are currently recognized from the Kaiparowits Formation. One of these is a lambeosaurine of the genus *Parasaurolophus* that is closely related to (if not conspecific with) *P. cyrtocristatus*. The remaining two taxa are both extremely large-bodied hadrosaurines from the genus *Gryposaurus*; one of these forms closely resembles *G. notabilis*, whereas the second represents a new, highly robust, species, *Gryposaurus monumentensis* (Fig. 4; Gates and Sampson, 2007; Gates et al., this volume). Multiple *Gryposaurus* specimens are known from the Kaiparowits Formation, a number of which exhibit exceptional preservation, including skulls with associated articulated postcrania and relatively common occurrences of fossilized skin impressions.

Marginocephalians

Marginocephalians are a group of "margin-headed," plant-eating dinosaurs generally divided into two groups—the dome-headed pachycephalosaurs, with a short bony shelf projecting from the rear of the skull; and the ceratopsians, or horned dinosaurs, many of which have elongate cranial shelves extending rearward to form expansive bony "frills." Pachycephalosaurid remains in the Kaiparowits Basin are rare, as is typical of all North American formations that have produced fossils of this group. However, since 2000, the KBP has recovered a number of specimens, including a frontoparietal dome from the Wahweap Formation that resembles *Stegoceras*, but appears to represent a new taxon (Kirkland and DeBlieux, in prep.). The Kaiparowits Formation has yielded two isolated, highly ornamented squamosals from a small-bodied taxon, once again morphologically similar to *Stegoceras*.

In contrast, the KBP has collected exceptional remains of three new taxa of ceratopsid (horned) dinosaurs within the middle unit of the Kaiparowits Formation, all represented by reasonably complete partial skulls. Two of these taxa pertain to the long-frilled clade Chasmosaurinae, whereas the third is a representative of the short-frilled Centrosaurinae; all three appear to pertain to new genera and species (Sampson and Loewen, in press). With regard to the Wahweap Formation, two partial skulls of a centrosaurine ceratopsian have been collected by the Utah Geologic Survey; one of these is a superbly preserved specimen with long supraorbital horns that represents another new genus and species (Kirkland et al., 2002; Kirkland and DeBlieux, in press). Preliminary study suggests that, considered in unison, these specimens will cause us to reconsider several aspects of the evolution of horned dinosaurs (Sampson and Loewen, in press).

Thyreophorans

Thyreophorans are a group of armored, herbivorous ornithischian dinosaurs that include stegosaurs (with plates and spikes arrayed along the axial column) and ankylosaurs (with dermal ossifications of armor covering most of the body). The tank-like ankylosaurs are further subdivided into nodosaurids, which lack bony tail clubs, and ankylosaurids, which possess tail clubs. As a group, ankylosaurs comprise a tiny portion of the

Figure 4. Left lateral view of a nearly complete hadrosaurid (duck-billed dinosaur) skull (RAM 6797) pertaining to *Gryposaurus monumentensis* (Gates and Sampson, 2007; Gates et al., this volume). The specimen was discovered by a crew from the Alf Museum and collected by RAM and UMNH crews. Scale bar equals 10 cm.

Kaiparowits Basin dinosaur fossil assemblage, as is true of virtually all Late Cretaceous terrestrial ecosystems in North America for which samples exist. Nevertheless, ankylosaur remains have been recovered from both of the target formations (Eaton et al., 1999). By far the best record of the group has been recovered from the Kaiparowits Formation, including several associated specimens found in the last five years. One locality has yielded more than 40 associated osteoderms (bony pieces of armor) of varying sizes from a nodosaurid. Another site includes associated cranial and postcranial elements of an ankylosaurid; preliminary examination of the latter materials suggests that assignment to *Euoplocephalus* (Hutchison et al., 1997) is unwarranted at this time.

Theropods

Theropod dinosaurs were a highly diverse, widespread group of bipedal, predominantly carnivorous animals that filled most of the large-bodied, meat-eating niches in Mesozoic terrestrial ecosystems. Little is known of the diversity of theropods from the Wahweap Formation, with the majority of fossils consisting of isolated teeth. In contrast, with a minimum of six taxa currently recognized (Zanno et al., this volume), it is becoming apparent that the Kaiparowits Formation possessed a relatively diverse non-avian theropod fauna similar to those described from geologic formations from the northern region of the WIB (e.g., Dinosaur Park and Two Medicine formations). All are members of a highly diverse clade known as Coelurosauria, which underwent a major radiation during the Cretaceous, and can be found on almost every continent during this time. As in other WIB formations, the top predator role was filled by a tyrannosaur. The Kaiparowits tyrannosaur, now known from multiple specimens, appears to represent a new genus and species. Like other Campanian-aged tyrannosaurs, the Utah taxon was significantly smaller than its larger cousin *Tyrannosaurus rex*, likely with an adult body mass in the range of 1-2 tonnes (versus 5-6 tonnes in *T. rex*). Rather than being closely allied with *Albertosaurus*, as postulated by Hutchison et al. (1997), preliminary study suggests that the Kaiparowits tyrannosaur is a near relative of *Daspletosaurus* within the clade Tyrannosaurinae.

All other theropod dinosaurs from the Kaiparowits are much smaller-bodied coelurosaurs. They include four "raptor"-like maniraptorans that were likely feathered: two dromaeosaurids, a troodontid, and an oviraptorosaur. The two species of dromaeosaur and the troodontid are recognized predominantly on the basis of isolated elements. Oviraptorosaurs are a group of toothless theropods best known from the Late Cretaceous of Asia; the Kaiparowits taxon consists of a nearly complete articulated hand and partial foot (Fig. 5), representing the holotype of the recently named species, *Hagryphus giganteus* (Zanno and Sampson, 2005). The fifth small-bodied coelurosaurian from the Kaiparowits Formation is an ostrich-mimic dinosaur, or ornithomimid, known from numerous (though predominantly isolated) specimens. This animal was previously identified as belonging to the species *Ornithomimus velox* (Decourten and Russell, 1985; Hutchison et al., 1997), but a reconsideration of the materials indicates that this assignment may be incorrect (Zanno et al., this volume). The Kaiparowits ornithomimid materials are currently under study.

Mammals

Although known mostly from teeth, mammals are without doubt the best understood microvertebrate group found within the formations, at least in terms of taxonomic diversity. Some 19 mammal genera have been identified from this interval, including marsupials, multituberculates, and insectivores (Cifelli, 1990a, 1990b, 1990d; Eaton, 1995; Eaton et al., 1999). Of these, five genera—two multituberculates (*Cedaromys* and *Kaiparomys*), two marsupials (*Varalphodon* and *Aenigmadelphys*), and one placental (*Avitotherium*)—are thus far endemic to the Kaiparowits Formation.

Invertebrates

Freshwater invertebrates from Upper Cretaceous strata in the WIB have received sparse attention (Russell, 1964; Hartman, 1976, 1981, 1984). Based on preliminary assessments, the Late Cretaceous freshwater invertebrate fauna of the Kaiparowits Basin contains one of the most complete records of Cenomanian through late Campanian molluscs in North America (J. Eaton, pers. comm., 2002). Assemblages are dominated by several genera of unionid bivalves and a diverse mesogastropod fauna (DeCourten, 1978). Non-molluscan taxa are also known, and include decapods and small arthropods. The molluscan record is especially impressive, including some of the thickest and most extensive freshwater shell beds (unionid bivalves) yet described (Roberts et al., 2005b). Systematic and taphonomic study of molluscs promises to provide answers relating to ecologic context (i.e. depositional environment and paleoclimatic data), as well as data for comparing biogeographic trends observed in vertebrates. In addition, these formations also preserve evidence of terrestrial insects, including a recently described social insect nest trace, *Socialites tumulus* (Roberts and Tapanila, 2006), and an insect-generated boring trace, *Osteocallis mandibulus* (Roberts et al., 2007). Moreover, many of the fossilized leaf specimens preserve characteristic insect damage (Fig. 6), which can be used to assess aspects of insect biology and diversity (Labandeira, 1997).

Fossil Plants

Late Cretaceous floras are common in the intermontane basins of the Rockies, but very few have been studied with modern techniques. With the exception of the Cenomanian Dakota flora of Kansas and Nebraska (Upchurch & Dilcher, 1990) and the Maastrichtian Hell Creek flora of the Dakotas (Johnson, 2002), Late Cretaceous fossil megafloras of North America are known almost exclusively from isolated fossil localities recorded in historical references or unpublished theses (McClammer and Crabtree, 1989). To date, only the Hell Creek flora comprises a dataset of densely sampled floral localities in a temporally-constrained stratigraphic framework integrated with other fossil data (Hartman et al., 2002, Wilf & Johnson, 2004). Ongoing projects in the Maastrichtian Laramie and Denver formations of the Denver Basin (Johnson et al., 2003) and the Campanian Fruitland and Kirtland formations of the San Juan Basin (Boucher et al., 1997; Boucher, 2001; Vogt & Boucher, 2002; Davies-Vollum and Boucher, 2003) are beginning to produce significant data on the paleofloras of these formations. However, a nearly complete literature gap exists for post-Cenomanian and pre-Maastrichtian megafloras. GSENM has tremendous unrealized

Figure 5. Oblique ventral view of an articulated hand from the holotype specimen of *Hagryphus giganteus* (UMNH VP 12765) a caenignathid (oviraptorosaur) theropod dinosaur from the Kaiparowits Formation (Zanno and Sampson, 2005; Zanno et al., this volume).

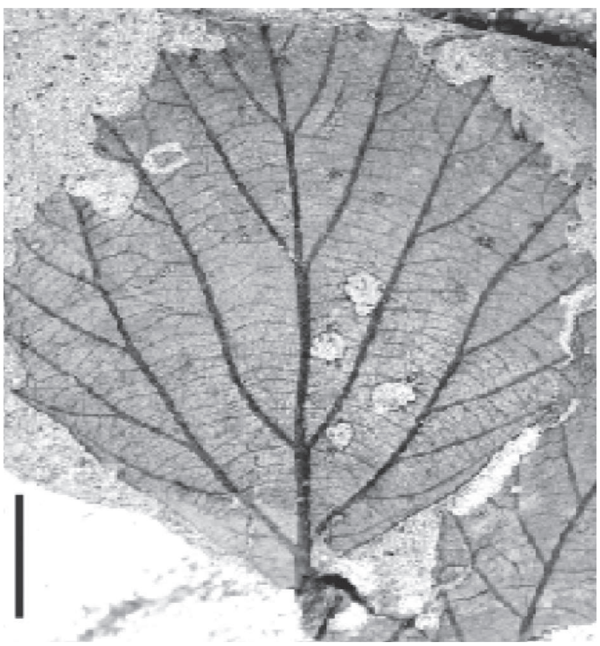

Figure 6. Fossilized angiosperm leaf (DMNS unnumbered) recovered from the Kaiparowits Formation and pertaining to the clade Plantanaceae. Note the insect feeding traces on the leaf margin and within the body of the leaf. Scale bar equals 1 cm.

potential for the study of Late Cretaceous vegetation (Gillette & Hayden, 1997; Foster et al., 2001). Reconnaissance by the Denver Museum of Nature and Science (DMNS) resulted in the discovery of numerous megafloral sites in the Kaiparowits Formation in 2002 and 2003. Fossil pollen remains have also been reported in abundance (Lohrengel, 1969; Nichols, 1995). Preliminary analysis of four Kaiparowits megafloral sites yielded 51 morphotypes (morphospecies) (Fig. 6). The flora is overwhelmingly dominated by angiosperms (84%), but also contains ferns (8%) and conifers (6%). One site contained 36 different morphotypes from only 80 specimens. Leaf margin analysis (Wilf, 1997) based on 39 dicot morphotypes indicates a mean annual temperature of 21.3 ± 2.27˚C. This evidence suggests that more extensive sampling will be richly rewarded. Ultimately, paleobotanical evidence from the Kaiparowits Basin could be used to assess floral composition, paleoenvironment, paleoclimate, and vegetation in the central portion of the WIB for much of the Late Cretaceous.

Discussion and Conclusion

Biogeographic Implications

The Late Cretaceous was an interval of warm climates and elevated global sea levels, resulting in the formation of persistent inland seaways on a number of continents. One of these, the KWIS, flooded the central portion of North America for ~35 million years, forming discrete eastern and western landmasses. A series of fossiliferous formations deposited east of a chain of mountains (the Sevier orogenic belt) in the WIB preserve evidence of a variety of terrestrial and nearshore marine settings (Fig. 2). Terrestrial ecosystems in the WIB were sandwiched between the fluctuating seaway to the east and rising mountains to the west. Although Asia and western North America were periodically connected via a northern land corridor (Russell, 1995), the lack of species common to both areas suggests that the link acted largely as a sweepstakes filter, allowing limited faunal exchange and effectively isolating the western part of North America (Farlow et al., 1995; Godefroit, 2001). The margins of the seaway were not static but rather underwent large-scale transgressions and regressions. As a result, the available habitat for terrestrial biotas alternately shrank and expanded. Although variable during the Campanian, the total combined area of these dinosaur-rich habitats encompassed approximately 4 million km^2, on the order of 16% of the present day area of North America (Lehman, 1987; Scotese, 2001). After more than a century of intense sampling and study, we now know more about Campanian–Maastrichtian terrestrial vertebrates from the WIB than from any other continent-scale region of Mesozoic age. As a result, latest Cretaceous dinosaurs from the Western Interior of North America have been pivotal in the formation and assessment of many hypotheses relating to dinosaur physiology and behavior, from metabolic and growth rates to reproductive and social behaviors (e.g., see references in Farlow et al., 1995).

To date, Mesozoic biogeography has generally been limited to biotic comparisons among continental landmasses. However, the highly fossiliferous and well-sampled Upper Cretaceous formations of the WIB offer a unique opportunity to examine finer-scale, subcontinental biogeographic patterns. With this growing North American database, we can now begin testing fundamental evolutionary and ecological ideas that were previously inaccessible. One major hypothesis is that WIB floras and faunas of the Campanian and Maastrichtian exhibited pronounced provincialism, with separation into distinct northern and southern biomes marked by a boundary approximately at the latitude of Utah and Colorado (Russell, 1967; Sloan, 1969; Lehman, 1987, 1997, 2001). This putative provincialism is thought to have had profound ecological and evolutionary implications, particularly for large-bodied dinosaurs. However, the provincialism hypothesis has been challenged, most notably by those arguing that the key geologic formations represent a time-transgressive sequence, and thus that their constituent faunas were not coeval (Sullivan, 2003; Sullivan and Lucas, 2004). Clearly, testing of such large-scale hypotheses requires detailed knowledge of floras and faunas from multiple formations of comparable age. At present, only a handful of Upper Cretaceous WIB formations preserve well-sampled terrestrial biotas in a detailed stratigraphic framework: the Hell Creek Formation of the Williston Basin (Hartman et al., 2002), the Laramie and Denver formations of the Denver Basin (Johnson et al., 2003), and the Dinosaur Park Formation of Alberta (Currie and Koppelhus, 2005). Particularly problematic is that the best-known formations occur in the northern portion of the WIB, with no equivalent standard in the central or southern regions of the basin.

Thus far, the faunas of the Kaiparowits and Wahweap formations have not been incorporated into this debate. Although results from GSENM must be regarded as preliminary, they are nonetheless intriguing. As addressed earlier, the KBP has documented that the Kaiparowits Formation represents a roughly 2 million year window that is approximately coeval with the fossiliferous portions of several late Campanian formations north and south within the WIB: Dinosaur Park Formation, Two Medicine Formation, Judith River Formation, and Fruitland Formation (Fig. 2; Roberts et al., 2005). By addressing the criticism that the formations used in Lehman's study represent diachronous deposits, this finding underlines the potential for productive, macro-scale comparisons across the WIB.

In a preliminary test of the provincialism hypothesis, we conducted an exhaustive biogeographic study (the largest for any Mesozoic terrestrial ecosystem) of known vertebrates from the above-mentioned WIB formations (Sampson et al., 2004; Gates et al., in press). The resulting database—founded upon recent discoveries, firsthand study of museum specimens, and an extensive literature search— encompassed presence-absence data for 291 micro- and macrovertebrate taxa across fishes, amphibians, lizards, turtles, crocodilians, dinosaurs, and mammals. The resultant faunal distributions show a high degree of latitudinal variation, consistent with pronounced regional endemism. Overall, mammals and dinosaurs show the highest levels of endemism. Remarkably, not a single dinosaur species is conclusively known from more than one of the three regions. In contrast to this pattern of marked species-level endemism, the sampled formations are closely similar at the family and subfamily level. Hadrosaurids and ceratopsids are invariably the dominant megaherbivores, with other ornithisichians—pachycephalosaurs, ankylosaurids, and hypsilophodontids—present but considerably more rare. Among theropods, the top carnivore role is filled by tyrannosaurs in all three regions, and there is typically a range of smaller forms, including ornithomimids, dromaeosaurs, and troodontids.

Project Significance

The results of the KBP are significant on several levels. First, the discovery and analysis of macrofossils from the Wahweap and Kaiparowits formations within GSENM, together with an increased understanding of their geologic context, are illuminating the alpha-level diversity and evolutionary history of Campanian-aged vertebrates, invertebrates, and plants from the Kaiparowits Basin. These results are permitting reconstruction of the essential elements of several successive Late Cretaceous terrestrial ecosystems. Second, the project has established the Kaiparowits Formation as a standard-bearer for comparisons within the WIB, and the results are being used to test hypotheses relating to taphonomic controls and biotic provincialism in the WIB. Additional evidence of high levels of endemism and latitudinal variation in faunal composition between and among WIB formations has profound implications for late Campanian terrestrial ecology and evolution, particularly as it relates to dinosaurs. It suggests that the ecological roles filled by dinosaurs remained relatively unchanged for much of the Campanian, as evidenced by the consistent presence of major clades (e.g., "families") throughout the WIB. Yet behind this ecological stasis may have been relatively high rates of faunal turnover at the level of genus and species (Ryan and Evans, 2005; Sampson and Loewen, in press). This hypothesis further suggests that, despite body sizes generally exceeding those of large-bodied mammals, late Campanian dinosaur species in the North American Western Interior were neither migratory nor broadly dispersed, but rather had relatively small species ranges. Currently there is no evidence of a physical barrier that would have prohibited faunal movement between the northern and southern regions of the WIB. Inhabiting a narrow, north-south oriented belt of coastal and alluvial plains, these faunas may thus have been sensitive to latitudinal zonation of environments, despite the fact that paleo-temperature gradients were markedly reduced relative to those of the present day. This hypothesis in turn raises interesting questions relating to the physiology, ecology, and evolution of dinosaurs generally. The Late Cretaceous faunas from GSENM will undoubtedly play a pivotal role in addressing these large-scale questions.

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Late Cretaceous Ornithopod Dinosaurs from the Kaiparowits Plateau, Grand Staircase-Escalante National Monument, Utah

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ABSTRACT

Ornithopod dinosaurs were bipedal, herbivorous dinosaurs with Late Cretaceous North American representatives that included hadrosaurids and more basal "hypsilophodontid" forms. Initiation of a large-scale research project aimed at the Campanian macrovertebrates of Grand Staircase-Escalante National Monument, southern Utah, has resulted in numerous discoveries of ornithopod dinosaurs. The ornithopod fauna—dominated by hadrosaurs, but including multiple "hypsilophodontid" specimens—includes several new taxa. Isolated teeth typify the majority of "hypsilophodontid" remains currently known from the Straight Cliffs and Wahweap formations, with several skeletal specimens from the Kaiparowits Formation representing an undescribed taxon. Hadrosaurid diversity within the Wahweap and Kaiparowits formations now includes five taxa, at least three of which appear to be new species. The Wahweap Formation includes at least two taxa—one form closely related to *Brachylophosaurus* and a second, undescribed genus that appears to share closest affinities with an undescribed specimen from Montana. Hadrosaurids from the Kaiparowits Formation include one species of *Parasaurolophus* and two stratigraphically separated species of *Gryposaurus*. The recognition of two temporally distinct species of *Gryposaurus* within the Kaiparowits Formation is significant in that it represents one of the few examples of within-lineage faunal turnover for the Late Cretaceous Western Interior Basin, and the first documented occurrence of the genus south of Montana.

Keywords: Hadrosauridae, Hypsilophodontidae, Campanian, Utah, Kaiparowits, Wahweap, biostratigraphy, *Parasaurolophus*, *Gryposaurus*, Straight Cliffs

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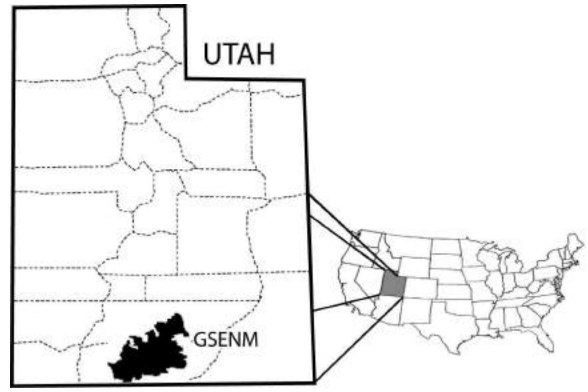

Figure 1. Location map of Grand Staircase-Escalante National Monument within Utah.

Introduction

Ornithopods are bipedal herbivorous dinosaurs that originated in the Early Jurassic and diversified through the Late Cretaceous. The group Ornithopoda was first proposed by Marsh (1881), and more recently defined in a cladistic sense by Norman et al. (2004) as "all cerapodans closer to *Edmontosaurus* than to *Triceratops.*" These dinosaurs were extremely widespread, with fossil remains discovered from every continent, including Antarctica.

In 2000, a team based out of the University of Utah launched the Kaiparowits Basin Project (KPB), with the primary goal of expanding the macrovertebrate fossil record from Upper Cretaceous (Campanian) formations exposed in Grand Staircase-Escalante National Monument (GSENM; Figure 1). This work has built upon a rich foundation of microvertebrate work spearheaded by Jeff Eaton and Rich Cifelli (Cifelli 1987; 1990; Eaton 1991; 2002). To date, two families of ornithopods, Hypsilophodontidae and Hadrosauridae, have been discovered within both micro- and macrovertebrate localities. "Hypsilophodontids" were small-bodied, cursorial ornithopods ranging from about one to three meters in length (Norman et al. 2004). They possessed relatively small heads and leaf-shaped teeth, primitive characteristics of the ornithopod clade. In contrast, virtually all hadrosaurids were large-bodied animals, and those found within GSENM were relatively giant, with some forms exceeding 10 m in length. Hadrosaurs are further distinguished from "hypsilophodontids" in possessing large, elongate heads and dense tooth batteries with more than 200 teeth in each jaw quadrant—a highly derived condition among ornithopods. The hind limbs of hadrosaurids are massively built in order to support their enormous weight, as evidenced by the inferred facultative use of the forelimbs for weight-bearing during locomotion (Horner et al. 2004). Hadrosaurids are further subdivided into two subclades, or "subfamilies," the hollow-crested Lambeosaurinae and the non-hollow-crested Hadrosaurinae. Both subfamilies possessed highly modified skulls with cranial ornamentations, although lambeosaurines are extreme in this regard, forming an elaborate extension of the nasal cavity within hollow, bony crests composed mostly of nasals and premaxillae.

Here we briefly describe the diversity of ornithopods within the Upper Cretaceous Straight Cliffs, Wahweap, and Kaiparowits formations of GSENM, focusing on recent discoveries of the KBP, and address their biostratigraphic and biogeographic significance.

Institutional abbreviations

BYU–Brigham Young University, Provo, UT; FMNH–Field Museum of Natural History, Chicago, IL; MNA–Museum of Northern Arizona, Flagstaff, AZ; RAM–Raymond M. Alf Museum, Claremont, CA; UCMP–University of California Museum of Paleontology, Berkeley, CA; UMNH–Utah Museum of Natural History, Salt Lake City, UT.

Straight Cliffs Formation

The 335 to 487 meter-thick Straight Cliffs Formation (Turonian-Santonian) consists of alternating marine and nonmarine units deposited during regression of the Cretaceous Western Interior

Seaway (Peterson 1969; Eaton 1991). During maximum transgression, the seaway extended into the middle of the Kaiparowits Plateau (Eaton 1991; Eaton et al. 1999; Peterson 1969), forming a largely north-south shoreline approximately in the center of the monument. Nonmarine strata in the Straight Cliffs Formation are found mostly in the lagoonal/ floodplain-dominated Smoky Hollow Member, the deltaic John Henry Member, and the fluvially-deposited Driptank Member. The Smoky Hollow and John Henry members produce the majority of well preserved nonmarine vertebrate taxa, whereas the Driptank contains mostly logs and scrappy bone fragments (Cobban et al. 2000; Doelling et al. 2000; Eaton et al. 1999; Peterson 1969). Most previous research has focused on screen-washing microvertebrate localities, resulting in the collection of abundant and diverse dinosaur teeth (e.g. Eaton et al., 1999). Consequently, our current understanding of the taxonomic diversity of dinosaurs within the Straight Cliffs Formation is limited largely to inferences based upon tooth morphology—a practice that generally produces only "family" grade resolution. More specific to the present review, taxonomic resolution of ornithopod diversity from the Straight Cliffs Formation, also based predominantly on dental remains, is currently constrained to Hypsilophodontidae and Hadrosauridae *incertae cedis* (Eaton et al. 1999). However, in 2006, Jeff Eaton (Weber State University) discovered the partial skeleton of a large ornithopod in the Middle Turonian Smoky Hollow Member west of the Kaiparowits Plateau and north of the town of Tropic; the specimen, subsequently excavated by the Utah Geologic Survey, consists only of vertebrae and limb elements, allowing no further taxonomic assessment. The only other large ornithopod known from the Middle Turonian of the southwestern United States is a derived iguanodontian ornithopod from the lower Moreno Hill Formation in west-central New Mexico that appears to be basal to Hadrosauridae (McDonald et al. 2006).

Wahweap Formation

Conformably overlying the Straight Cliffs Formation, the 305- to 457 meter-thick Wahweap Formation is divided into four formal members that reflect changes in either depositional regime, tectonic control, or both: the Lower Sandstone Member (LSM), the Middle Mudstone Member (MMM), the Upper Sandstone Member (USM), and finally the Capping Sandstone Member (CSM; Eaton 1991; Pollock 1999; Doelling et al. 2000). Significant ornithopod specimens have been recovered from all four members, although the MMM is currently the most productive member. As with the Straight Cliffs Formation, however, teeth comprise the only evidence of "hypsilophodontids" within the formation (Eaton et al. 1999).

Hadrosauridae

Hadrosaurids are vastly more abundant than "hypsilophodontids," with numerous macrosite localities throughout much of the stratigraphic section. Several dozen fossils have been recovered from the hadrosaurid-dominated Tibbet Springs Quarry, located in a highly indurated sandstone near the base of the LSM within a few meters of the top of the Drip Tank Member of the Straight Cliffs Formation. Multiple individuals are represented in this quarry based on numerous limb and girdle elements, vertebrae, and a poorly preserved jaw, with some material representing at least partial associated skeletons. This site has been the richest dinosaur locality found thus far in the lower member of the Wahweap Formation.

All but one of the identifiable hadrosaurid specimens recovered thus far from the Wahweap Formation pertain to the Hadrosaurinae. The single exception is an isolated lambeosaurine maxilla recovered from the USM (UCMP 152028; Figure 2), the fragmentary nature of which precludes detailed comparison to other taxa. However, the medial side of the preserved portion reveals similarities to an undescribed maxilla of *Parasaurolophus* sp. (UMNH VP 16666) from the Kaiparowits Formation (see below). These same characteristics are apparently lacking in the crested-hadrosaurs *Corythosaurus* and *Hypacrosaurus*. On the other hand, UCMP 152028 differs significantly from UMNH VP 16666, suggesting that this element may pertain to a new taxon.

Published records of dinosaur faunas contemporaneous with the Wahweap Formation do not include substantive descriptions of materials attributed to lambeosaurines, although, an undescribed lambeosaurine from the Oldman Formation of Alberta, Canada, is approximately coeval with the

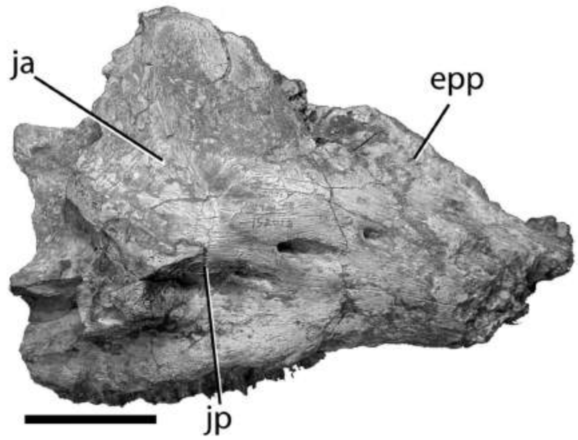

Figure 2. Unidentified lambeosaurine maxilla (UCMP 152028) from the Wahweap Formation shown in lateral view. **Abbreviations: epp**, expansion of the premaxillary process; **ja**, jugal articulation; **jp**, jugal process. Scale bar equals 5 cm.

Wahweap specimen. Future comparison of these materials will enable testing of whether or not northern and southern lambeosaurines during this interval were closely related.

A large hadrosaurine bonebed and an isolated, associated skeleton are the most significant discoveries to date within the Middle Mudstone Member. A locality known as "Jim's Hadrosaur Site" has yielded a number of juvenile postcranial elements, including a large portion of the fore and hind limbs, as well as dorsal and cervical vertebrae. This specimen was scattered amidst abundant carbonized log sections and conifer branches, as well as a disarticulated turtle, unionid clams, and freshwater crab claws. Jim's Hadrosaur Site is located near the base of the MMM and appears to preserve a single juvenile hadrosaur individual.

Another locality within the MMM producing juvenile hadrosaur material is a large bonebed near Camp Flats. Deposited in a back swamp environment, two hadrosaur individuals, an adult and juvenile, were completely disarticulated over an area of more than 18.5 m^2; additional fossils found within the site include abundant microvertebrate remains—theropod teeth, fish bones, a turtle pelvis, and large freshwater crab claws. The site also preserves abundant plant remains consisting of numerous tree stems crisscrossing both above and below the hadrosaur specimens, as well as dispersed clusters of unidentifiable leaf hash and several examples of unidentified conifer leaves. The excavation has thus far revealed approximately 70-80% of the adult postcranium and numerous elements of a much smaller juvenile specimen. Unfortunately, the only skull material collected from this locality to date consists of a juvenile jugal and dentary, which are insufficient to enable taxonomic assignment to the level of genus or species. Nevertheless, the site is extremely significant in that it has yielded the most complete dinosaur known from the Wahweap Formation. In addition, this site will provide key insights into the paleoenvironment and taphonomy of the formation. Other significant hadrosaur materials recovered from the MMM include: 1) an isolated diagnostic juvenile jugal (UMNH VP 16695; Figure 3); 2) a large partial pubis and two femora; and 3) an associated hadrosaur scapula, proximal humerus, and dentary.

The stratigraphically highest bonebed in the formation occurs near the base of the USM in the area of the monument known as "The Gut." This site is still in early stages of excavation, but already several postcranial elements have been collected from at least two individuals entombed within a silty mudstone; representative elements include a tibia, two ilia, a partial humerus, and ribs.

Currently, the most diagnostic specimen discovered from the Wahweap Formation is the partial skull of a hadrosaurine (UMNH VP 16607) that likely pertains to a new genus from Montana. Riley Nelson (Brigham Young University) discovered the specimen in a massive sandstone within the USM, just north of Right Hand Collett Canyon. The skull consists of a compete braincase and mostly complete posterior skull roof and lacrimals.

Another significant specimen, discovered within a sandstone unit of the USM on Death Ridge, includes partial limb bones and an isolated partial maxilla (UMNH VP 9548; Figure 4). This specimen is tentatively identified as cf. *Brachylophosaurus*, a close relative of the new, undescribed genus mentioned above; however, more material is required to verify the generic assignment. The maxilla more closely matches the morphology of *Brachylophosaurus* than of *Maiasaura* or the new taxon. Together, all of the above-mentioned specimens are providing a substantial foundation for the study of hadrosaurs within the Wahweap Formation.

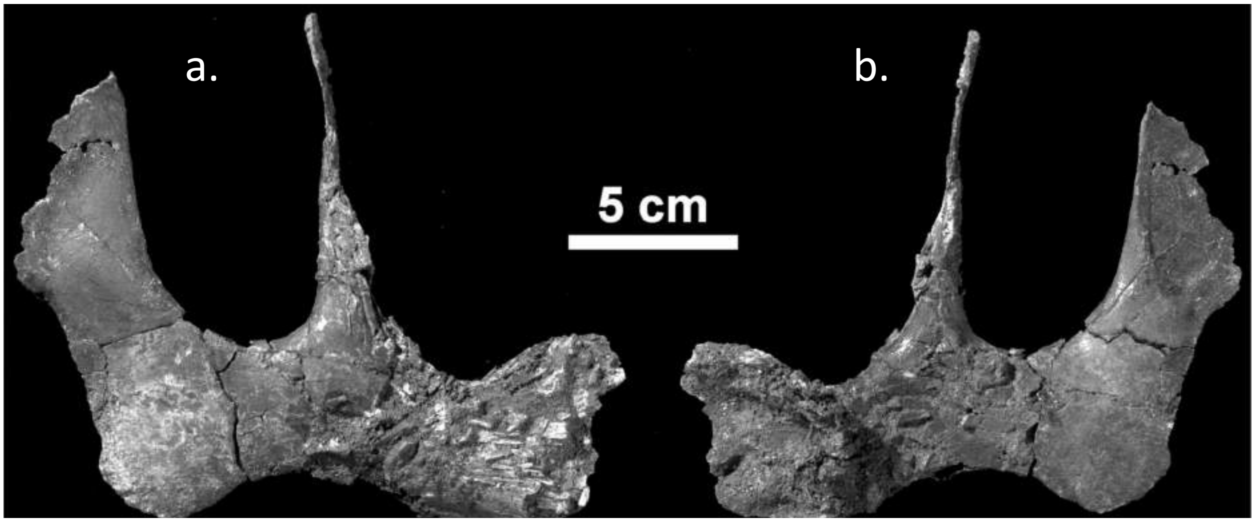

Figure 3. Right juvenile hadrosaurine jugal (UMNH VP 16695) found in the Upper Sandstone Member of the Wahweap Formation shown in **a**. lateral and **b**. medial views.

Figure 4. Right maxilla (UMNH VP 9548) recovered from the Upper Sandstone Member of the Wahweap Formation, currently attributed to cf. *Brachylophosaurus*, shown in lateral view. Scale bar equals 5 cm.

Kaiparowits Formation

The roughly 800 meter thick Kaiparowits Formation was deposited in only two million years, a remarkably rapid rate of deposition (Roberts et al. 2005). This fossiliferous formation therefore has tremendous potential to yield a high-resolution record of faunal, floral, and environmental change. In addition, the most fossiliferous portions of the Kaiparowits Formation are closely coeval with many other fossil-rich formations in the Western Interior Basin of North America, enabling comparative studies of the evolution of ornithopods and other dinosaurs within a two million year window (~76-74 Ma) in the Late Campanian (Roberts et al., 2005).

A conformable contact marks the lower boundary between the Wahweap and Kaiparowits formations (Roberts 2007). Three informal units (lower, middle, and upper) subdivide the Kaiparowits Formation based on sandstone to mudstone ratios (Roberts 2007), yet, all three units contain large channels, thick paludal and floodplain deposits, and poorly developed paleosols. The vast majority of ornithopod specimens come from the lower and middle units, the former unit being composed mostly of sandstone and the latter being mudstone-dominated. All eight articulated ornithopod specimens collected to date have been recovered from sandstone bodies within the lower and middle units.

Hypsilophodontidae

Over the past six years, six partial skeletons of "hypsilophodontids" have been recovered from the Kaiparowits Formation. The first of the specimens from the Lower Member consists of two articulated feet (UMNH VP 16281; Figure 5a) preserved in a sandy siltstone, which are large relative to those of other Late Campanian "hypsilophodontids" such as *Orodromeus* (Scheetz 1999). The right foot of the Kaiparowits specimen measures 211 mm from the proximal end of the third metatarsal to its corresponding distal ungual. Two distal tarsals are present proximal to metatarsals III, IV, and V. This specimen resembles other "hypsilophodontids" in that five metatarsals are present, with all but digit V bearing phalanges. The third metatarsal is the largest, extending well beyond the distal ends of metatarsals II and IV, which are subequal in length. This morphology differs from that of *Thescelosaurus*, for which these three metatarsals are relatively shorter, more robust, and subequal in length.

A second specimen found in the Lower Member (UMNH VP 12677) consists of a mostly complete, well-preserved, articulated hand (Figure 5b) and associated disarticulated vertebrae and limb fragments from a channel sandstone. The hand includes five carpals. However, there is no evidence of digit V, which usually consists of only a metacarpal in "hypsilophodontids" (Norman et al., 2004).

The most productive hypsilophodontid site known from the Middle Member contains two partial disarticulated juvenile skeletons composed mostly of vertebrae and fore and hindlimb elements, as well as fragments of two dentaries and a maxilla (UMNH VP 12665) preserved in a crevasse splay deposit. Preliminary examination of all the Kaiparowits "hypsilophodontid" material currently under study suggests that these materials pertain to a new taxon.

Hadrosauridae

Both lambeosaurine and hadrosaurine remains have been recovered from the Kaiparowits Formation. The lambeosaurine *Parasaurolophus* is the most distinctive hadrosaur from the formation, possessing a large, curved, hollow narial tube composed almost entirely of fused premaxillae (Figure 6a). *Parasaurolophus* was the first dinosaur to be identified from the Kaiparowits Formation, based upon a highly eroded, partial skull (BYU 2467; Weishampel and Jensen, 1979). Sullivan and Williamson (1999) identified these materials and another, more complete specimen (UCMP 143270; Figure 6a) as pertaining to *P. cyrtocristatus*, a taxon otherwise known only from the Fruitland Formation of New Mexico.

Recent work conducted by the KBP has yielded additional *Parasaurolophus* materials from this formation. Currently, the total sample consists of five partial skulls (UCMP 143270, BYU 2467, UMNH VP 16394, UMNH VP 16689, UMNH VP 16666), and associated elements within a multi-taxic bonebed, all collected from or closely associated with sandstone deposits in the Middle Member of the Kaiparowits Formation. One of the recently collected partial skulls (UMNH VP 16666.1; Figure 6b) includes a maxilla, jugal, palatine, ectopterygoid, and quadrate—elements unknown for *P. cyrtocristatus*, as well as for any other *Parasaurolophus* specimen collected from

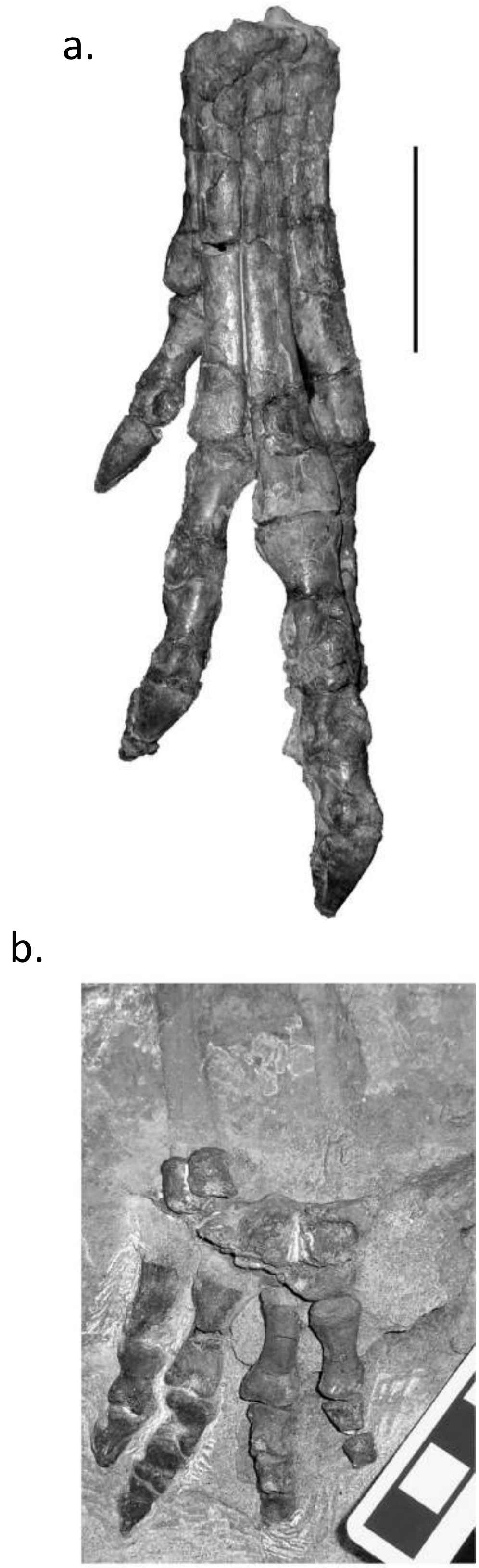

Figure 5. Examples of "hypsilophodontid" specimens from the lower unit of the Kaiparowits Formation. **a.** Articulated right foot of UMNH VP 16281; **b.** articulated left hand of UMNH VP 12677.

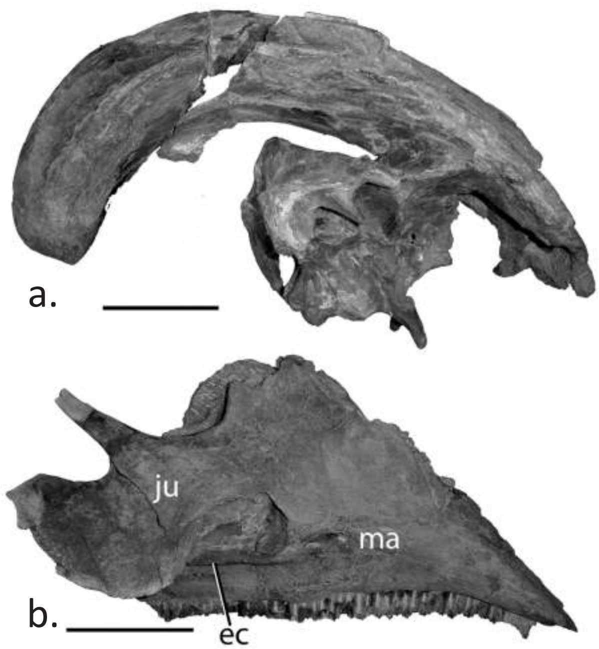

Figure 6. Examples of *Parasaurolophus* specimens recovered from the Kaiparowits Formation. **a.** Partial articulated *Parasaurolophus* skull UCMP 143270 shown in lateral view; **b.** articulated *Parasaurolophus* maxillary complex shown in lateral view. Abbreviations: et, ectopterygoid; ju, jugal; ma, maxilla. Scale bar equals 10 cm.

the Kaiparowits. The best preserved *Parasaurolophus* specimen from the Kaiparowits Formation (UCMP 143270) differs from the holotype specimen of *P. cyrtocristatus* (FMNH P27393) in the curvature of the snout and the degree of descent of the posterior portion of the crest. However, FMNH P27393 is much larger than UCMP 143270 and the observed differences may represent ontogenetic variation. All of these materials are currently under study in order to assess whether or not the Kaiparowits taxon corresponds to *P. cyrtocristatus*.

An articulated tail, partial pelvis, and left leg from a site in the lower unit was tentatively identified as a lambeosaurine hadrosaur by Titus et al. (2001). However, more recent analysis of this specimen demonstrated that it is a hadrosaurine of unknown generic affinity, leaving lambeosaurs undocumented in the lower portion of the Kaiparowits Formation.

The most common hadrosaur fossils discovered in the Kaiparowits Formation pertain to the hadrosaurine *Gryposaurus*, the remains of which—including several associated partial skulls (UMNH VP 18568, 16666, 13970, 12265, 16669, 13831 and RAM 6797), two of which are associated with partial postcranial skeletons (UMNH VP 12265 and 18568)—have been collected at seven significant localities that range from near the base of the Kaiparowits through the top of the Middle Member. Significantly, those specimens found in the Lower Member, near the base of the formation, are morphologically distinct from those found higher in the formation, indicating the presence of two successive species of *Gryposaurus*, and thus within-lineage faunal turnover, in the Kaiparowits Formation.

The lowest occurring taxon, here termed *Gryposaurus* taxon A, is represented by several specimens, including a virtually complete articulated skull (UMNH VP 18568; Figure 7) discovered by Alan Titus within a massive sandstone near Wahweap Creek. This specimen, which displays the distinctive nasal "hump" characteristic of *Gryposaurus*, is almost one meter long, substantially exceeding that of any other previously described specimens attributable to this genus. Nevertheless, another fragmentary partial skull from the Kaiparowits Formation (UMNH VP 16668), also attributable to *Gryposaurus* taxon A, is approximately 20% larger than UMNH VP 18568, suggesting that this taxon achieved body sizes well in excess of more northern congeners.

The second *Gryposaurus* species now recognized in the Kaiparowits Formation, *Gryposaurus monumentensis* (Gates and Sampson 2007), occurs higher in section and is also represented by multiple specimens, including the mostly complete type skull (RAM 6797; Figure 8) found in a muddy sand point bar deposit. *Gryposaurus monumentensis* possesses a number of unique characteristics, most related to the hyper-robust nature of the skull and lower jaws (Gates and Sampson 2007). A partial subadult skull of this taxon (UMNH VP 13970) demonstrates that the extremely robust dentary present in adults developed prior to the onset of adult size. One of the more interesting features of *G. monumentensis* is the predentary, which possesses large, clover-shaped processes along the oral margin that are unlike any structure seen on the predentaries of other hadrosaurs (Gates and Sampson 2007). While the precise function of these structures is uncertain, other hadrosaur taxa show evidence of a keratinous beak adhered to the snout via small processes on the predentary oral

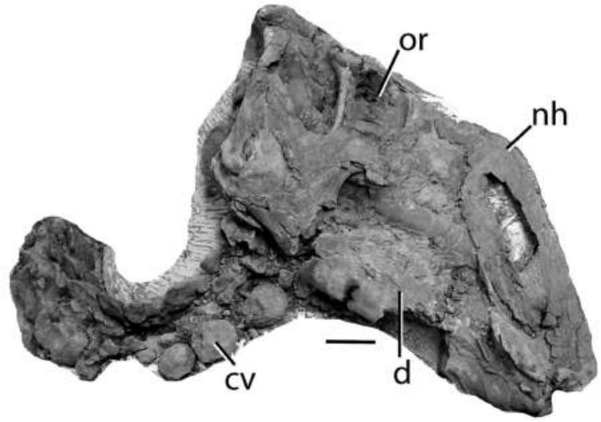

Figure 7. Lateral view of articulated skull of *Gryposaurus* sp. (UMNH VP 16667; *Gryposaurus* taxon A in text) recovered from of the Lower Member of the Kaiparowits Formation. **Abbreviations: cv**, cervical vertebrae; **d,** dentary; **nh**, nasal hump; **or**, orbit. Scale bar equals 10 cm. S

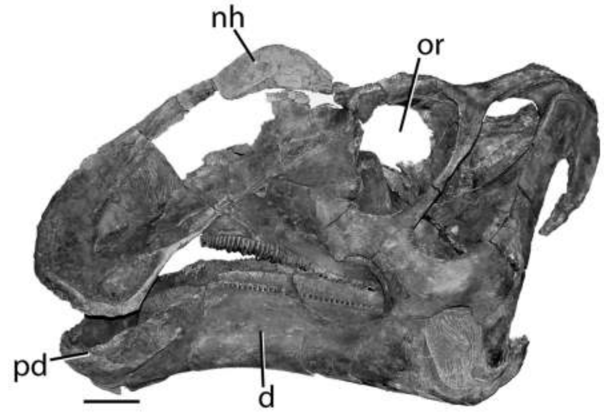

Figure 8. Lateral view of articulated skull of *Gryposaurus monumentensis*. (RAM 6797) from the Middle Member of the Kaiparowits Formation. **Abbreviations: d**, dentary; **nh**, nasal hump; **or**, orbital rim; **pd**, predentary.

margin (Morris 1970), and it is perhaps likely that these features had a similar role.

One of the most complete skeletons of *Gryposaurus monumentensis* (also the most complete adult hadrosaur skeleton discovered to date from the monument) is UMNH VP 12265 (Figure 9), an exceptionally preserved specimen recovered from the Middle Member in an expansive area of outcrop known as “The Blues.” Encased mostly in well-indurated sandstone, the associated and partially articulated skeleton includes a portion of the skull and lower jaws (maxillae, jugal, quadrate, dentary), most of the dorsal, sacral, and caudal vertebral series, fragmentary ribs, scapulae, coracoid, humerus, and the entire pelvis. Remarkably, the specimen also preserves more than 2.5 m^2 of fossilized skin impressions.

Nonmineralized vertebrate tissues tend to be rare in the fossil record, because they are a rich source of nutrients for predators, scavengers, and microbes (Lund 2006). Yet, approximately 20 vertebrate localities preserving soft-tissue forms have been recorded in the Kaiparowits Formation over the past six years, all within fine-to-coarse-grained, indurated sandstone (except one in siltstone). The majority of these localities preserve hadrosaurid skin impression in both negative and positive relief. Impressions are known from nearly every portion of the body, although the best-preserved examples to date occur in association with the head, neck, and tail (Figure 10). Tubercle density, shape, and size appear to vary along the body.

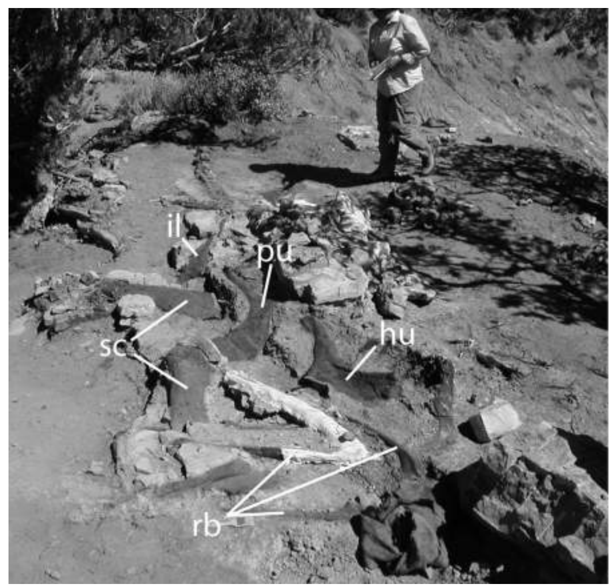

Figure 9. Skeleton of *Gryposaurus monumentensis* (UMNH VP 12265) from the Middle Member of the Kaiparowits Formation. **Abbreviations: hu**, humerus; **il**, ilium; **pu**, pubis; **rb**, ribs; **sc**, scapula.

Smaller, unornamented, circular tubercles cluster tightly around the head, whereas larger, ovoid, wider-spaced tubercles dominate along the back, tail, and limbs, many of the latter ornamented with radiating ridges and grooves that converge at their apices. Tubercle size ranges from small (< 3 mm) to large (> 10mm). The only exception is UMNH VP 12265, which preserves large, butterfly-shaped scales (~80 mm wide) and similarly-sized ovoid scales found in direct association with each of the distal neural spines along the back and tail; a similar conformation has been described for *Maiasaura* (Horner 1984). Overall, the hadrosaurid skin impressions known from Kaiparowits Formation compare favorably to others found in the Dinosaur Park Formation of Alberta, Canada, the Two Medicine and Judith River formations of Montana, and the Ringbone Formation of New Mexico (Anderson et al. 1998; Horner 1984; Lambe 1914; Negro and Prieto-Marquez 2001; Parks 1920).

Finally, the most complete hadrosaur specimen collected to date from GSENM (UMNH VP 16677; Figure 11) consists of a juvenile specimen entombed in highly cemented sandstone. Other than the skull, lower jaws, hands, feet, and distal tail, the skeleton of this specimen appears to be complete. It is approximately 88 cm long and fully articulated except for the anteriormost cervical vertebrae. Taxonomic identification is currently restricted to Hadrosaurinae, although a detailed examination has not yet been undertaken.

Biostratigraphic and Biogeographic Implications

The virtually continuous sequence of Upper Cretaceous sediments comprising the Straight Cliffs, Wahweap, and Kaiparowits formations provides an unparalleled opportunity to study temporal changes in the hadrosaurian faunas of southern Utah. Unfortunately, the fragmentary nature of remains throughout the Straight Cliffs Formation and much of the Wahweap Formation currently limits our understanding. Nevertheless, a relatively comprehensive picture of hadrosaur diversity is developing for the upper Wahweap and Kaiparowits formations. The growing picture appears to be one of relatively rapid faunal turnover and replacement. Such resolved evolutionary patterns are relatively rare, and approximately coeval examples of within-lineage turnover are otherwise documented only from geologic formations in the northern portion of the Western Interior Basin (e.g., Dinosaur Park Formation, Two Medicine Formation; Horner et al. 1992; Ryan and Evans 2005). Recognition of this pattern in the Campanian of Utah is the direct result of the large number of hadrosaur specimens collected within GSENM. To date, approximately 15 highly significant hadrosaur localities have been identified within the Monument, making these some of the most productive Campanian strata in North America for the recovery of ornithopod dinosaurs.

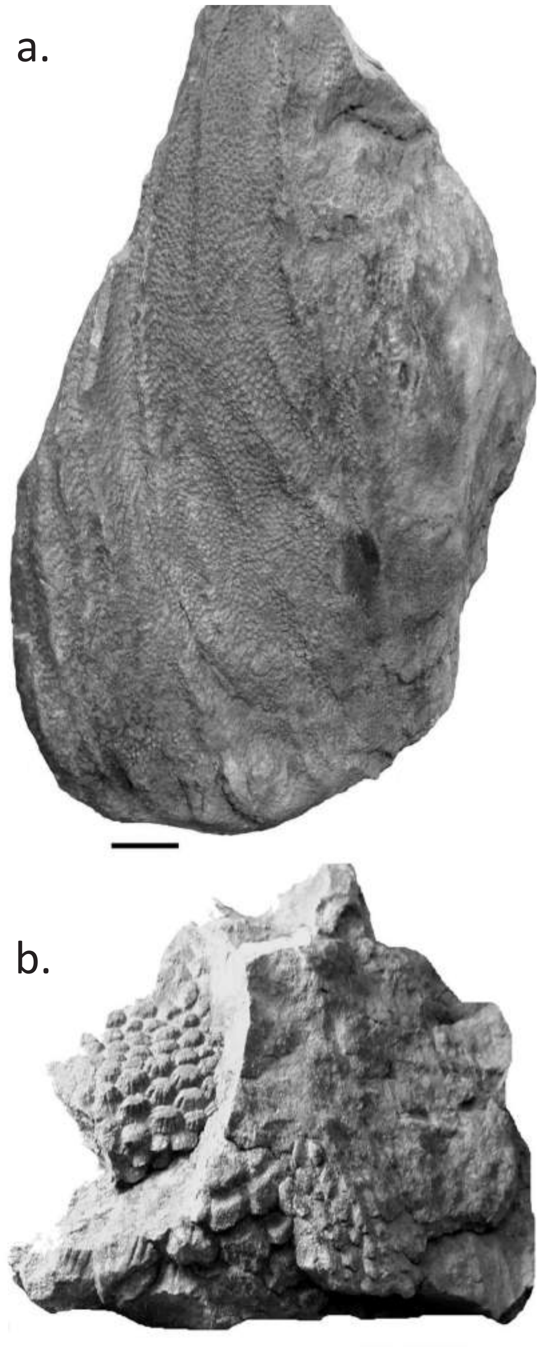

Figure 10. Specimens of hadrosaur skin impressions recovered from the Kaiparowits Formation. **a**. Sandstone block containing a large area of skin impression, from near the neck region of UMNH VP 16667. **b**. Close-up of skin impression, showing large tubercles with radiating ridges.

At present, the Wahweap and Kaiparowits formations preserve minimal evidence of faunal turnover within lambeosaurines. The only example

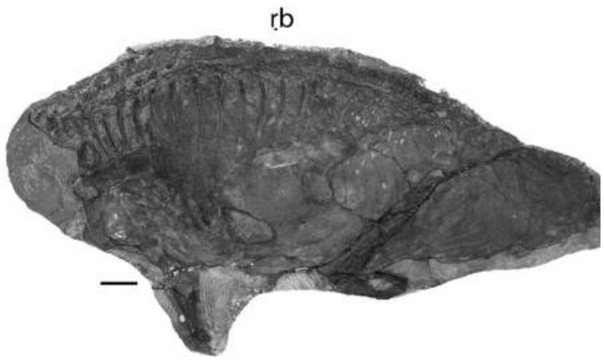

Figure 11. Articulated juvenile hadrosaur skeleton (UMNH VP 16677) found in the Middle Member of the Kaiparowits Formation. **Abbreviations: cv**, cervical vertebrae; **rb**, rib; **ru**, radius and ulna; **sc**, scapula; **tb**, tibia. Scale bar equals 10 cm.

appears to be replacement of the new taxon found in the Upper Sandstone Member of the Wahweap Formation by *Parasaurolophus*, which first occurs in the Middle Member of the Kaiparowits Formation, a separation of approximately 3-4 million years. More finely-scaled faunal turnover can be documented for hadrosaurines. Weak evidence of such turnover occurs in the Wahweap Formation, where an undescribed taxon may be replaced by cf. *Brachylophosaurus* (see above). More substantive evidence of this pattern is documented in the presence of two, stratigraphically arrayed species of *Gryposaurus* within the Kaiparowits Formation.

A series of recently obtained radiometric dates from Campanian-aged geologic formations within the Western Interior Basin (see Roberts et al., 2005 for review) now permit timeslice biogeographic comparisons (Figure 12). For example, the new, undescribed hadrosaurine in the Wahweap Formation is approximately time-correlative with a specimen from the Two Medicine Formation of Montana.

Within the Kaiparowits Formation, two main time slices are available for comparison, corresponding to the Lower and Middle members. As described above, the only hadrosaur genus in the Lower member is *Gryposaurus* taxon A. This taxon is approximately coeval with *G. notabilis* and *G. incurvimanus* in the lower Dinosaur Park Formation of Alberta, Canada (Ryan and Evans 2005).

Within the Middle Member of the Kaiparowits Formation, *G. monumentensis* is contemporaneous with two species of *Prosaurolophus* in Montana and Alberta (Gates and Evans 2005; Gates and Sampson 2007; Horner 1992; Ryan and Evans 2005).

Also within the Middle Member of the Kaiparowits Formation is *Parasaurolophus* sp., which is contemporaneous with two northern lambeosaurines, *Hypacrosaurus stebingeri* in Montana and *Lambeosaurus lambei* in Alberta (Gates and Evans 2005). The type and only confirmed specimen of *Parasaurolophus cyrtocristatus* occurs in the upper Fruitland Formation, in beds that are stratigraphically higher than all known occurrences of the Utah *Parasaurolophus*. Thus, if it turns out that the *Parasaurolophus* from the Kaiparowits Formation should be placed within *P. cyrtocristatus*, this finding would extend the stratigraphic distribution of the species in the south. The other two species of *Parasaurolophus* (*P. walkeri* and *P. tubicen*) occur in the lower Dinosaur Park Formation in Alberta (~75.5 Ma) and in the Upper Kirtland Formation (~73.5 Ma) of New Mexico, respectively (Gates and Evans 2005; Ryan and Evans 2005). Based upon current evidence, none of the *Parasaurolophus* species appear to co-occur in time. However, it is interesting to note that the geographic distribution of this genus correlates with its stratigraphic distribution, the earliest examples of *Parasaurolophus* occur in the north and the youngest occurrences are in the southern region of the Western Interior Basin.

With regard to “hypsilophodontids,” the only well known “hypsilophodontid” from the late Campanian, *Orodromeus*, occurs stratigraphically higher within the Two Medicine Formation of Montana than the earliest known “hypsilophodontid” specimen in GSENM (UMNH VP 16281), which was recovered near the base of the Kaiparowits Formation. In fact, UMNH VP 16281 has no known stratigraphic equivalent in North America. In contrast, the single “hypsilophodontid” specimen from the younger Middle Member of the Kaiparowits Formation (UMNH VP 12665) appears to have been approximately coeval with *Orodromeus* in the north.

Conclusions

In summary, Upper Cretaceous (Campanian) sediments preserved within GSENM have yielded an abundance of ornithopod specimens

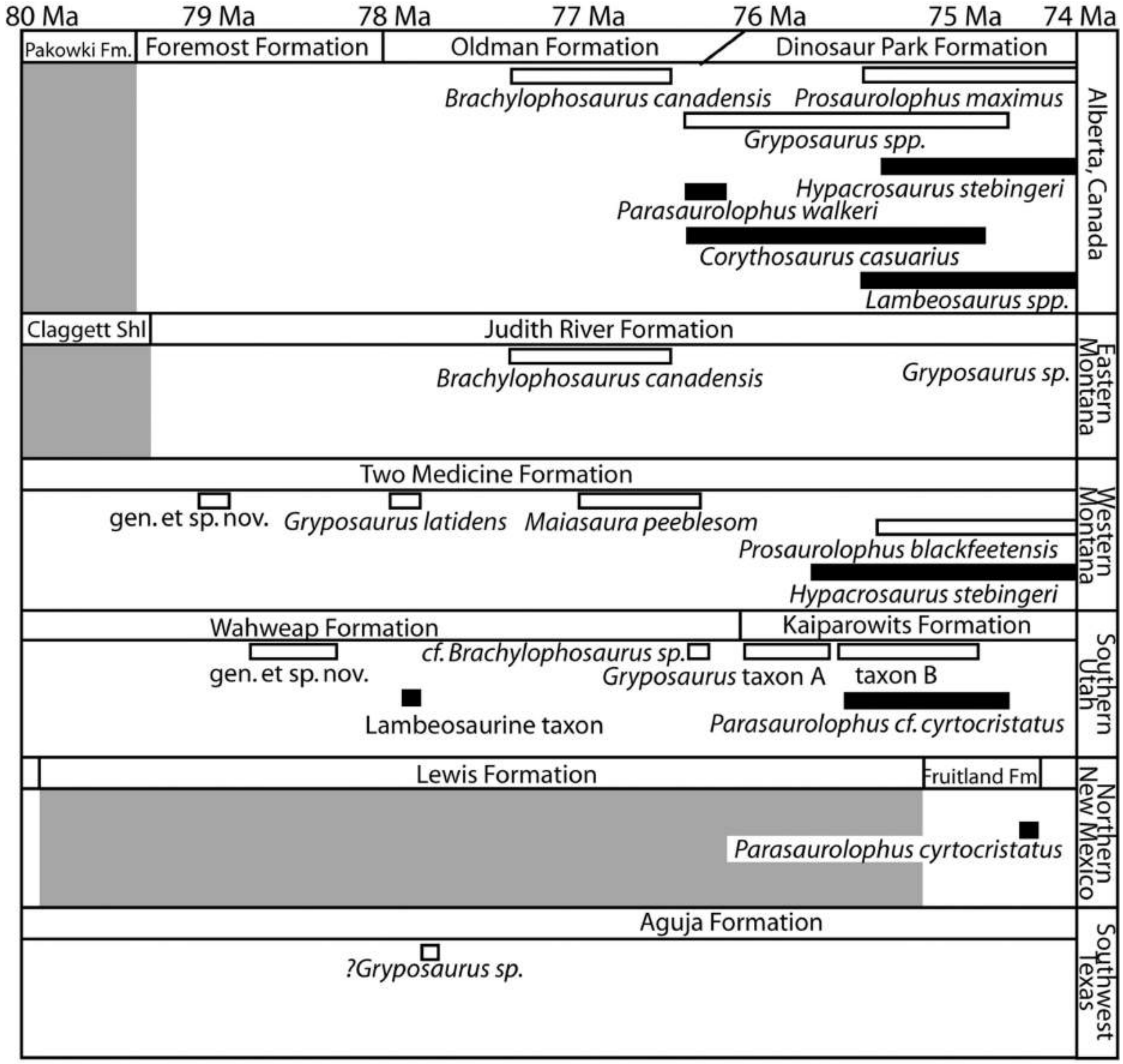

Figure 12. Stratigraphic and geographic distribution of Campanian hadrosaurs from the Western Interior Basin of North America. Age time slices are listed across the top of the diagram and six geographic regions are listed along the right. Formations present within each geographic region listed horizontally, with all hadrosaurid taxa found within each formation is listed below. Grey areas show marine sediments. White bars represent hadrosaurine hadrosaurids whereas the black bars represent lambeosaurine taxa. Bar length denotes a taxon's stratigraphic distribution. Modified from Gates and Evans (2005).

that dramatically increase our knowledge of this clade, particularly for the southwestern region of the Western Interior Basin. The bulk of these remains have been collected during the past six years through fieldwork conducted by the KBP. The majority of these specimens have been recovered from the late Campanian Kaiparowits Formation, although the underlying Wahweap Formation has also produced several significant discoveries, including hadrosaur bonebeds and the partial skull of a new hadrosaurine. Key specimens from the Kaiparowits Formation include several partial skulls of the lambeosaurine *Parasaurolophus* as well as multiple specimens (skulls and postcranial remains) pertaining to two species of *Gryposaurus*, at least one of which is a new taxon. Recent recognition of successively-occurring species of *Gryposaurus* within the Kaiparowits Formation is significant in that it represents one of the few examples of within-lineage faunal turnover of dinosaurs from a single geologic unit. Finally, several "hypsilophodontid" specimens have been recovered from the Kaiparowits Formation, the most significant of which includes manal and pedal elements. Detailed study of these materials is underway, but preliminary examination suggests that they represent an undescribed, relatively large-bodied form. The acquisition of multiple radiometric dates from the Kaiparowits Formation permits relatively high-resolution temporal comparisons within a two million year window spanning approximately 76-74 Ma. Thus, for example, the *Gryposaurus* species discovered near the base of the Kaiparowits Formation (*Gryposaurus* taxon A) appears to have been coeval with other species of *Gryposaurus* in the northern region of the Western Interior Basin. In contrast, *Gryposaurus monumentensis*, from higher in Middle Member of the Kaiparowits Formation, corresponds temporally with the northern hadrosaurine genus *Prosaurolophus*. Together, these recent discoveries establish GSENM as one of the premier localities in North America for producing remains of ornithopod dinosaurs.

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A Preliminary Report on the Theropod Dinosaur Fauna of the Late Campanian Kaiparowits Formation, Grand Staircase-Escalante National Monument, Utah

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ABSTRACT

The Kaiparowits Basin Project—a joint collaboration between the Utah Museum of Natural History and the University of Utah—has made significant additions to the previously recognized theropod dinosaur fauna of the late Campanian Kaiparowits Formation of southern Utah. Results of this project include: the discovery of *Hagryphus giganteus*, the first diagnostic North American oviraptorosaur south of Montana; a nearly complete juvenile skeleton of a new genus of tyrannosaur; the first cranial remains of a Kaiparowits troodontid from the formation; and the first diagnostic ornithomimid forelimb material from the formation. Comparison of the Kaiparowits theropod fauna with other contemporaneous formations across the Western Interior Basin reveals consistency of mid-level clade diversity among theropods, yet also demonstrates species-level endemism for those groups for which diagnostic materials have been recovered.

Keywords: Late Cretaceous, Coelurosauria, Maniraptora, biogeography, Western Interior Basin

Introduction

Seven years ago, field crews of the Utah Museum of Natural History (UMNH) and the University of Utah embarked on an exhaustive research project to survey and document the Late Cretaceous dinosaur fauna of Grand Staircase-Escalante National Monument (GSENM), southern Utah, with a focus on the poorly sampled late Campanian Kaiparowits Formation (Figure 1). To date, this collaborative effort—known as the Kaiparowits Basin Project (KBP)—has met with notable success, building substantially upon the previously recognized vertebrate fauna of the formation and highlighting its significance to our understanding of dinosaur evolution within the Western Interior Basin (WIB).

Prior to the initiation of the KBP, decades of foundational microvertebrate studies were conducted in the Kaiparowits Basin. This work was predominantly achieved by Jeffrey Eaton and

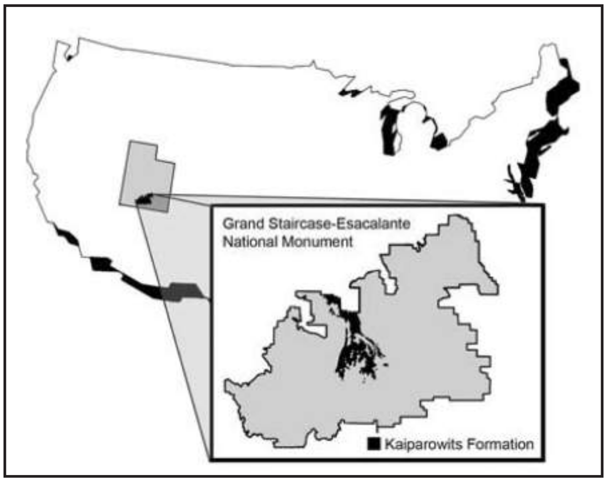

Figure 1. Map showing the location of Grand Staircase-Escalante National Monument in southern Utah, with Kaiparowits Formation outcrop illustrated in black.

Richard Cifelli, who along with their colleagues established the first comprehensive faunal list for the Kaiparowits Formation (Eaton and Cifelli 1988). Recognizing the faunal list to be an underrepresentation of all but mammalian taxa (the focus of Eaton and Cifelli's research project in the area), Howard Hutchison, Jeffrey Eaton, and Michael Parrish subsequently attempted a more thorough documentation of the lower vertebrate fauna of the Kaiparowits (Hutchison 1993; Hutchison et al. 1997; Parrish and Eaton 1991), and ultimately compiled a more comprehensive faunal list including eleven dinosaur taxa (Eaton et al. 1999). These advances notwithstanding, the recognition of dinosaurian taxa within the Kaiparowits Formation has been limited almost entirely to microvertebrate and fragmentary skeletal remains. The recent work undertaken by the UMNH and the University of Utah represents the first concerted effort to collect and research the monument's dinosaurian fauna and has already added considerably to our understanding of dinosaur diversity across the WIB during the late Campanian (Gates and Sampson 2006; Smith et al. 2004; Zanno and Sampson 2005). Through description of new taxa, taxonomic refinement of previously identified theropod materials, and collection of novel skeletal elements of enigmatic taxa, this collaborative project has resulted in a more thorough reconstruction of this unique and historically underrepresented Late Cretaceous ecosystem.

Here we review the known theropod fauna of the late Campanian Kaiparowits Formation based on materials recovered during the 2001-2006 field seasons by UMNH and University of Utah crews. For a more comprehensive review of paleontological work conducted prior to the initiation of this project, the reader is referred to Eaton and Cifelli (1988), Eaton et al. (1999), Hutchison et al. (1997), and Parrish and Eaton (1991).

Institution Abbreviations—BYU, Brigham Young University, Provo, Utah; MNA, Museum of Northern Arizona, Flagstaff, Arizona; RAM, Raymond M. Alf Museum, Claremont, California; UMNH, Utah Museum of Natural History, Salt Lake City, Utah; YPM, Yale Peabody Museum, New Haven, Connecticut.

Theropod Diversity in the Kaiparowits Formation

Tyrannosaurs

Tyrannosaurs are a group of large-bodied, highly specialized theropods that typically functioned as the top predators within Late Cretaceous ecosystems. The Maastrichtian-aged *Tyrannosaurus rex* reached body masses exceeding those of all other terrestrial carnivores (5000-6000 kg); however, tyrannosaurs from the preceding Campanian Age, although still among the largest of theropods, were typically much smaller bodied (1,000-2,500 kg).

Although late Campanian tyrannosaur diversity has been well-represented in northern WIB formations for more than a century (Lambe 1914; Osborn 1905), tyrannosaur species inhabiting southern WIB ecosystems during this interval have remained poorly understood. In fact, prior to the initiation of the KBP, the only diagnostic tyrannosaur material recovered from the Kaiparowits Formation consisted of a partial, associated skull collected by Brigham Young University in the 1970's. This specimen (BYU 9396) is currently under study by Thomas Carr, Carthage College, and is thought to represent a new genus closely related to *Daspletosaurus*, the only tyrannosaurid recognized in the late Campanian of New Mexico (Carr and Williamson 2000).

Recent field work in the Kaiparowits Formation by the UMNH has greatly expanded our knowledge of Kaiparowits tyrannosaurs, resulting in the discovery of numerous isolated elements as well as seven associated specimens. Of the latter, an exceptionally well preserved juvenile skeleton (UMNH VP 16690), discovered in 2004, represents one of the most complete and phylogenetically informative tyrannosaur individuals thus far collected from the southern WIB formations. UMNH VP 16690 is an associated juvenile skeleton that is approximately 65% complete, preserving a large portion of the skull, numerous cervical, dorsal, sacral, and caudal vertebrae, well-preserved chevrons, cervical and thoracic ribs, nearly complete illia, pubes and ischia, a complete right femur, tibia, and fibula, and a single pedal phalanx and ungual. Most of the caudal portion of the skull has been recovered, including a complete braincase, both frontals, parietals, quadratojugals, postorbitals, and lacrimals, a single maxilla, articular, angular, surangular, dentary, and multiple teeth. A number of associated but shattered elements from the rostral portion of the skull, in addition to several shattered teeth, suggest that the facial skeleton may have been trampled prior to burial. The reconstructed body size of this individual (approximately 9 m), together with the lack of neurocentral fusion in preserved dorsal and sacral vertebrae, are suggestive of a juvenile to subadult age for the animal at the time of death (Brochu 1996). Preliminary examination of these remains indicates that UMNH VP 16690 may represent a subadult individual of the same new genus as the unnamed mature BYU specimen; however, as both of these specimens are currently under study, and the BYU specimen lacks concrete stratigraphic and locality data, more research is needed to determine their individual taxonomic and phylogenetic affiliations.

While the relationship between the BYU and UMNH tyrannosaur material has not yet been established, the general morphology of UMNH VP 16690 suggests that this tyrannosaur shares a more recent common ancestry with *Daspletosaurus* than with the other late Campanian genera *Albertosaurus* and *Gorgosaurus*. This conclusion is supported by the postorbital anatomy of UMNH VP 16690, which displays a highly developed cornual boss (even at a pre-mature ontogenetic stage) and a rostrocaudally robust jugal ramus more similar to that of *Daspletosaurus* and the unnamed New Mexico genus than to the more gracile postorbital morphology of *Albertosaurus* and *Gorgosaurus* (Figure 2). Several other features present on the skeleton of UMNH VP 16690 are also indicative of a close relationship between these genera.

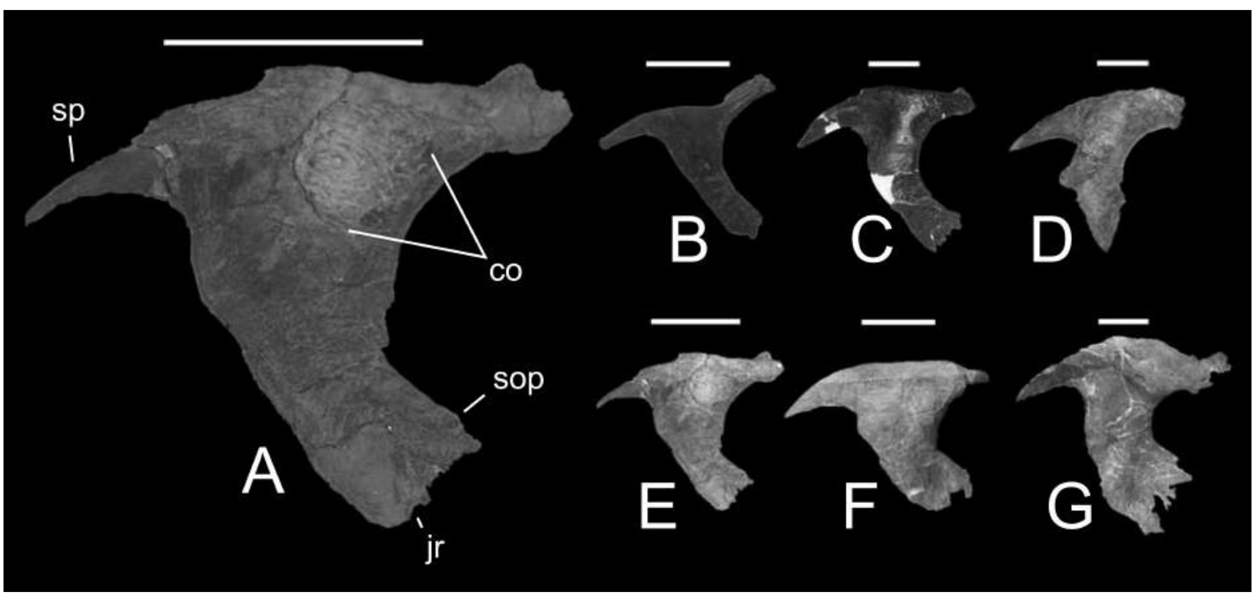

Figure 2. Morphological variation in the postorbitals of Campanian tyrannosaurs from the Western Interior of North America, all shown in right lateral view. **A** and **E**, unnamed Kaiparowits Formation tyrannosaur, UMNH VP 16690; **B**, *Gorgosaurus*, TMP 91.36.500 (reflected and modified after Currie 2003a); **C**, *Albertosaurus*, TMP 81.10.1 (reflected and modified after Currie 2003b); **D**, *Daspletosaurus*, combination of NMC 8506 and TMP 2001.36.1 (reflected and modified after Currie 2003b); **F**, New Mexico tyrannosaur NMMNH P-25049; and **G**, *Tyrannosaurus* FMNH PR 2081 (reflected and modified after Brochu 2003, image courtesy of Chris Brochu). **Abbreviations: co**, cornual boss; **jr**, jugal ramus; **sop**, suborbital process; **sp**, squamosal process. **B-G** scaled to approximately the same size. Scale bars equal 5 cm.

Additional associated but less complete tyrannosaur individuals and isolated elements recovered during the KBP include: associated juvenile cranial material, including fused parietals, a partial unfused frontal and a partial dentary (UMNH VP 12586); partial limb elements and teeth (UMNH VP 16161); fragmentary limb elements, a pedal phalanx, and ungual UMNH VP 16692; associated limb and skull fragments, including a partial dentary, pedal phalanx, and ungual (UMNH VP 16693); a tooth, caudal vertebrae, left femur, tibia, fibula, metatarsal III, a pedal phalanx, and ungual of a large adult individual (UMNH VP 16694); isolated fused parietals (UMNH VP 16225); an isolated humerus (UMNHVP 12223); and an isolated jugal from a large adult (UMNH VP 16691).

The abundance of tyrannosaur material collected during the relatively brief time span of the KBP challenges previous statements that the late Campanian formations of New Mexico exceed those of Utah with regard to tyrannosaur preservation (Carr and Williamson 2000), and highlights the importance of the KBP in understanding dinosaur evolution in the WIB. Study of the diagnostic tyrannosaur material recovered from the Kaiparowits Formation will permit a more comprehensive understanding of tyrannosaur diversity, biogeography, and evolution during the late Campanian. In addition, the juvenile specimen UMNH VP16690 will undoubtedly lend important information to the study of tyrannosaur ontogeny and life history.

Ornithomimids

Ornithomimids (ostrich mimics) were relatively medium-bodied, lightly built dinosaurs, possessing toothless beaks, elongate necks, and hindlimbs built for cursoriality (Carrano 1999; Coombs 1978; Snively et al. 2004). They are generally regarded as near relatives of tyrannosaurs, falling within coelurosaurs but outside of Maniraptora, the group that includes modern birds. Ornithomimid diets have been a matter of some debate—ranging from myrmecophagy (e.g. Russell 1972) to filter-feeding (e.g. Norell et al. 2001)—yet a few recent studies (Barrett 2005; Kobayashi et al. 1999) make a strong argument for a plant-eating habitus.

Ornithomimid skeletal remains, along with those of tyrannosaurs, represent the majority of theropod material recovered from the Kaiparowits Formation, with maniraptorans forming a much less common faunal constituent. Yet, despite their relative abundance, little progress has been made in identifying ornithomimid remains from the formation.

Thirty years ago, an ornithomimid specimen (MNA PI.1762A) consisting of a nearly complete hind limb, fragmentary pelvis, and partial axial column was collected from the Kaiparowits Formation by the Museum of Northern Arizona. This specimen was subsequently referred to the late Maastrichtian taxon *Ornithomimus velox* by DeCourten and Russell (1985). At the time, palynomorph evidence supported a Lancian age for the Kaiparowits Formation (Lohrengel 1969) making it coeval with the Denver Formation of Colorado, from which the type specimen of *O. velox* is described (Marsh 1890).

The holotype of *O. velox* is fragmentary, comprised of a distal tibia with astragalus, incomplete left metatarsus, and second pedal digit (YPM 542), together with questionably associated manual elements (YPM 548). Several authors have questioned the validity of this taxon; in their review of Ornithomimidae, Makovicky et al. (2004) noted only a single character as diagnostic for *O. velox*—metacarpal one being the longest in the metacarpus. Unfortunately, *Ornithomimus edmontonicus* also possesses this condition, rendering the trait a synapomorphy of the genus. As Russell (1972) notes, two supposedly diagnostic characteristics have been derived from the reconstructed metatarsus of *O. velox* provided by Marsh (1890): (1) shortness of the metatarsus; and (2) MT II longer than MT IV (Russell 1972). However, the length and proportion of the metatarsals of *O. velox* can not be determined from the type specimen as there are no definitive contacts preserved between proximal and distal fragments of MCII and IV.

Although the manus is generally considered diagnostic for ornithomimids, no manual elements are preserved with MNA PI.1762A. DeCourten and Russell's (1985) justification for the assignment of the Kaiparowits ornithomimid to *O. velox* lies in pedal ungual morphology (which they identify as similar in both specimens), as well as relative proportions of the pes. Although proportional characteristics have been proposed as diagnostic for individual ornithomimid taxa (Russell

1972), recent studies (e.g., Kobayashi et al. 2006) have challenged the validity of most of these differentiations. Furthermore, while Kobayashi et al. (2006) cite characteristics of the skull, forelimb, and caudal vertebrae as diagnostic for ornithomimids, they do not identify any diagnostic features of the pes among North American taxa. Finally, the specific ratio used by DeCourten and Russell (1985) to assign the Kaiparowits specimen to *O. velox* (ratio of the length of the second pedal ungual to the basal phalanx of digit two) is given by the authors as 0.61-0.64 in "pre-Lancian" North American taxa (*Struthiomimus breveteritus*, *S. currelli*, *S. ingens* [referred to *Ornithomimus edmontonicus* sensu Makovicky et al, 2004], and *S. altus*), 0.78 in MNA PI.1762A, and 0.88 in the holotype of *O. velox*; we do not find this ratio in MNA PI.1762A significantly closer to *O. velox* than to the value given for *O. edmontonicus* and *S. altus*.

An additional argument made by DeCourten and Russell (1985) merits discussion here. Following referral of the Kaiparowits ornithomimid to *O. velox*, DeCourten and Russell (1985) make note of several differences between MNA PI.1762A and *O. edmontonicus*, including a curved pubic shaft and estimated overall body size. In light of these differences, DeCourten and Russell (1985) suggest that *O. edmontonicus* can not be conspecific with *O. velox* and that the referral of *O. edmontonicus* to the genus *Ornithomimus* should be considered dubious. Removal of the Kaiparowits specimen from the *O. velox* hypodigm renders the argument that *O. edmontonicus* and *O. velox* can not be synonymous on the basis of the additional morphological information provided by that specimen fallible. Thus, the suggestion that *O. velox* may be a senior synonym of *O. edmontonicus* (Makovicky et al. 2004) remains a valid hypothesis.

In sum, we find significant problems with the assignment of MNA PI.1762A to *O. velox* including: (1) the potential synonymy of species in the *Ornithomimus* hypodigm coupled with observed differences between MNA PI.1762A and *O. edmontonicus*; (2) a lack of comparable diagnostic elements between the holotype of *O. velox* and MNA PI.1762A; and (3) the late Campanian age of the Kaiparowits Formation, which negates DeCourten and Russell's (1985) referral of MNA PI.1762A to *O. velox* on the basis of coeval occurrence.

To date, field work conducted by the KBP has added significant morphological data to the discussion of the identity of the Kaiparowits ornithomimid, including associated caudal vertebrae, metatarsal fragments, and phalanges (UMNH VP 12223), two isolated tibiae (UMNH VP 9553) and (UMNH VP 16698), as well as the first articulated forelimb material from the formation. This specimen (UMNH VP 16385) consists of an incomplete and partially crushed manus, carpus, and antebrachium. Additional material recently collected by the Raymond M. Alf Museum (RAM 6794) includes articulated sections of the sacral and caudal axial column, pelvic girdle, and nearly complete right and left hind limbs, which provide a useful comparison to MNA PI.1762A.

Preliminary examination of UMNH VP 16385 reveals similarities to *O. edmontonicus* in the relative size of metacarpal one and in ungual morphology. Additional isolated caudal vertebrae have been collected by the UMNH (UMNH VP 16260; Figure 3A-C, F, and I) and appear most similar to *Dromiceiomimus* (CMN 12228 [*Ornithomimus* sensu Makovicky et al. 2004]; Kobayashi et al. 2006) in general morphology but lack the diagnostic, deeply grooved articulation between pre- and postzygopophyses (Figure 3F-H), as well as the prezygopophyseal ventral groove (Kobayashi et al. 2006; Figure 3I-K). A more comprehensive investigation of ornithomimid materials from the Kaiparowits Formation currently being undertaken by researchers at the UMNH, the Raymond M. Alf Museum, and the College of the Holy Cross is expected to provide additional insights regarding the taxonomic and systematic relationships of North American ornithomimids.

Oviraptorosaurs

Late Cretaceous North American oviraptorosaurs (often referred to as caenagnathids, although this taxonomy is currently contentious) are an endentulous group of medium-sized, feathered maniraptoran dinosaurs possessing keratinous beaks, powerful arms with formidable claws, and often adorned with a cranial fan or crest. While the dietary preference of these unusual dinosaurs is presently unclear, other rarely elucidated aspects

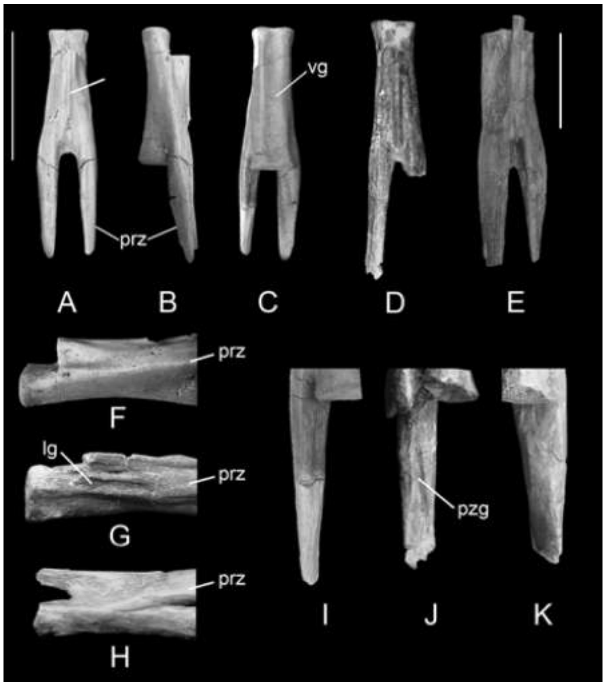

Figure 3. Morphological variation in distal caudal vertebrae of late Campanian ornithomimids from the Western Interior of North America. **A-C, F**, and **I**, Ornithomimidae incertae cedis from the Kaiparowits Formation (UMNH VP 16260); **D**, **G**, and **J**, *Dromiceiomimus* breveritus (CMN 12228, *Ornithomimus edmontonicus* sensu Makovicky et al. 2004; Kobayashi et al. 2006); and **E**, **H**, and **K**, *Struthiomimus altus* (CMN 2102/8902). Kaiparowits ornithomimid shown in **A**, dorsal; **B**, right lateral; and **C**, ventral views. Late Campanian ornithomimid caudals in right lateral views, **F**, **G**, and **H**, showing the absence of lateral groove for the prezygopophyses in all but *Dromiceiomimus*. Prezygopophyses of ornithomimid caudal vertebrae in ventral views, **I**, **J**, and **K**, showing the presence of a ventral groove in *Dromiceiomimus*. **Abbreviations: lg**, lateral groove on the centrum caused by articulation with the prezygopophyses; **prz**, prezygopophysis; **pzg**, ventral groove on the prezygopophysis; **vg**, ventral groove on centrum. Upper left scale bar equals 4mm and pertains to views **A-C**. Upper right scale bar equals 5 mm and pertains to **E**. All other views not to scale.

of oviraptorosaur paleobiology are known, including many details about egg-laying (Sato et al. 2005) and brooding behavior (Norell et al. 1994; Norell et al. 1995). Although these dinosaurs are remarkably similar to birds in both anatomy and behavior, the predominance of current analyses suggests that these similarities are the result of convergence rather than ancestry (Lu et al. 2004; Makovicky and Sues 1998; Norell et al 2001; Rauhut 2003; Sues 1997).

Unlike other theropod dinosaurs whose teeth have long been recovered from microvertebrate localities, the toothless condition of oviraptorosaurs prevented their identification in the Kaiparowits until the first diagnostic skeletal material was recovered by UMNH crews in 2002. A nearly complete left manus (missing only the second ungual), carpus, and distal antebrachium (UMNH VP 12765) of a new oviraptorosaur was recovered in articulation within a remnant of channel sandstone (Figure 4) and displays unusual soft tissue preservation. Additional elements—including fragmentary metatarsals and pedal phalanges, and a partial, articulated pedal digit with ungual—were salvaged from the surrounding hillside. The specimen, dubbed *Hagryphus giganteus*, represents the first dinosaur taxon to be named from GSENM and is notably larger than its northern cousins, with an estimated body size increase of 30-40% (Zanno and Sampson 2005). UMNH VP 12765 is also the first North American oviraptorosaur described from south of Montana and South Dakota and represents the southernmost limit yet identified for this enigmatic group of theropods within North America. *Hagryphus* represents the only published account of oviraptorosaurs in the Kaiparowits Formation, and the only unequivocal oviraptorosaur material recovered thus far during the KBP.

Dromaeosaurs

Dromaeosaurs are among the most commonly recognized dinosaurs. These lethal predators are distinctive in possessing an enlarged "sickle" claw on the second digit of their foot, as well as stiff tails reinforced by dramatically elongated bony struts. Dromaeosaurs are one of the most diverse theropod groups and are considered to be some of the closest cousins to modern birds. A surprising array of miniature, "feathered" species have been found within exceptionally prolific ancient lake beds in China (Xu et al. 1999; Xu et al. 2000), yet the largest dromaeosaur (*Utahraptor*) is known from Early Cretaceous beds in central Utah (Kirkland et al. 1993).

As a group, dromaeosaurs are known to have been widespread across the late Campanian WIB (Norell and Makovicky 2004). Collection of teeth from microvertebrate localities suggested the presence of "*Dromaeosaurus*" and "velociraptorine" dromaeosaurs in the Kaiparowits Formation over a decade ago (Hutchison et al. 1997). Subsequent collection and detailed examination has verified

Figure 4. Holotype manus of the oviraptorosaur *Hagryphus giganteus* (UMNH VP 12765) in dorsal view. **Abbreviations: DI**, digit one; **DII**, digit two; **DIII**, digit three. Scale bar equals 5 cm.

the existence of at least two dromaeosaur genera in the formation, based on isolated teeth recovered as surface float or within burial sites of herbivorous dinosaurs. In earlier publications (Sampson et al. 2004; Zanno et al. 2005; and Zanno et al. 2005) we provisionally referred these to c.f. *Dromaeosaurus* (Figure 5A) and c.f. *Saurornitholestes* (sensu Sankey 2001; Sankey et al. 2002; Figure 5B), based on comparisons with teeth from the approximately coeval Dinosaur Park and Aguja formations. Although proposals have been put forth supporting the taxonomic utility of tooth morphology in small theropods (Fiorillo and Currie 1994; Smith 2005), these studies have focused either on the intraformational identification of small theropod teeth (which can be compared to teeth associated with diagnostic skeletal materials) or on intraspecific variation in tooth morphology. Thus far, interformational and interspecific diagnostic utility have not been considered. We are unaware of any published study demonstrating that isolated dromaeosaur teeth are referable at the genus or species level; in fact, Farlow et al. (1991) demonstrated significant overlap in morphological parameters of isolated dromaeosaur teeth from different genera, and Currie and Varricchio (2004) noted that the teeth of *Saurornitholestes* are similar to those of the younger dromaeosaur *Atrociraptor* from the Horseshoe Canyon Formation. Additionally, nearly all other dinosaurs currently known from the Kaiparowits Formation represent new species or genera, including tyrannosaurs, ceratopsians, hadrosaurs, and oviraptorosaurs. Thus we regard it as unlikely that the as-yet-undescribed small-bodied theropods inhabiting the Kaiparowits ecosystem would be an exception to this pattern. Given this documented pattern of latitudinal diversity, we support a more conservative approach, instead of referring isolated teeth to known WIB genera, we identify these teeth either as "*Dromaeosaurus*-type" and "*Saurornitholestes*-type".

Postcranial materials potentially referable to Dromaeosauridae include isolated pedal phalanges and unguals. However, other than a pedal phalanx, similar to *Saurornitholestes* (PII-I; UMNH VP 12494), these elements have not yet proven to be taxonomically useful. The most complete dromaeosaur material thus far discovered was collected by Howard Hutchison of the University of California at Berkeley's Museum of Paleontology in 1994. The specimen, UCMP 149171, consists of a proximal tibia, fragmentary metatarsals, pedal phalanges, and pedal unguals, as well as some fragmentary skull material, including the basioccipital, fused parietals, and portions of the squamosals. Preliminary examination reveals differences between this specimen and northern dromaeosaurs; however, additional study is needed before it can be determined if this poorly preserved specimen represents a new taxon.

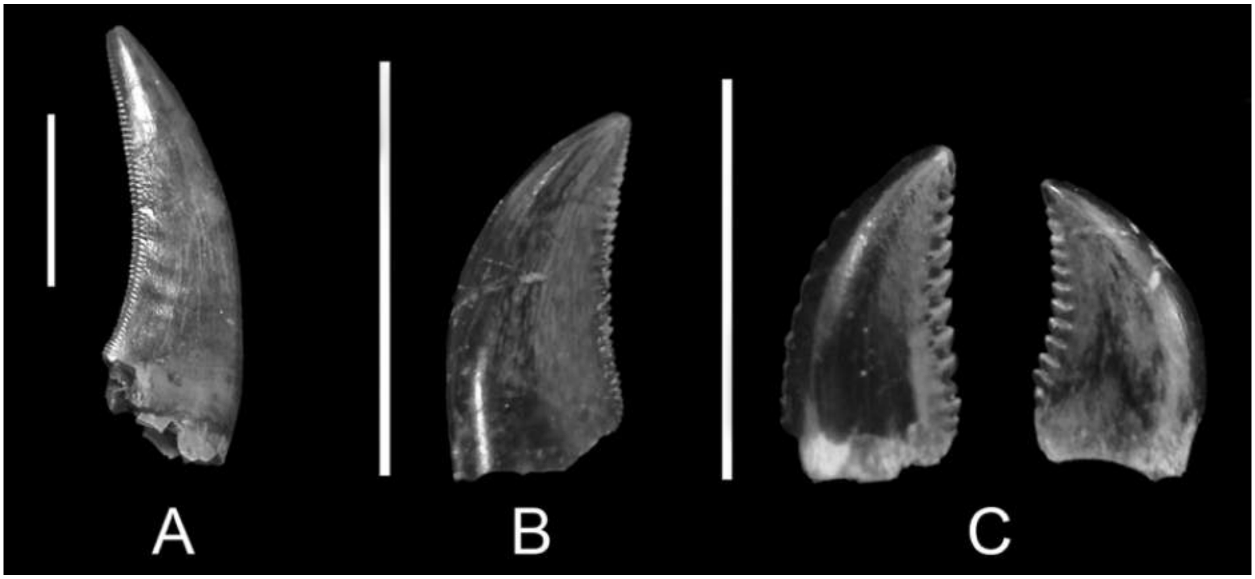

Figure 5. Maniraptoran theropod teeth from the Kaiparowits Formation. **A**, *Dromaeosaurus*-type (UMNH VP 16306); **B**, *Saurornitholestes*-type (UMNH VP 11803); and **C**, troodontid (UMNH VP 12507). Scale bar equals 1 mm.

Troodontids

Troodontids are an enigmatic group of feathered maniraptoran dinosaurs, notable for exhibiting some of the smallest body sizes and the largest relative brain sizes within Dinosauria. Only a single genus is currently recognized in North America—*Troodon* (Currie 1987a). As a result of their distinctive teeth, some authors have proposed an omnivorous diet for these theropods (Holtz 1998); however, carnivory is still the most widely regarded hypothesis for the diet of troodontids.

Previously, the presence of *Troodon* in the Kaiparowits Formation was documented entirely on the basis of isolated teeth, which are widely recognized as diagnostic for the only North American member of the group (Currie 1987a; Makovicky and Norell 2004). However, given that only a single species of troodontid is known from the Late Cretaceous WIB, it is unclear whether North American troodontid teeth are diagnostic at the genus or species level. Over half a dozen troodontid teeth have been collected by UMNH crews since 2000 (Figure 5C), adding to the numerous additional teeth collected during earlier microvertebrate surveys (Eaton et al. 1999; Hutchison et al. 1997).

During the 2005 field season, an exceptionally well preserved, isolated left frontal (UMNH VP 16303) was discovered in the Kaiparowits Formation (Figure 6A). The frontal compares closely with that of *Troodon formosus* (CMN 12340; Fig 6B), known from the contemporaneous Dinosaur Park Formation in Alberta, in possessing an elongate, triangular morphology, a extensive orbital rim, a prominent ridge defining the rostral limit of the supratemporal fenestra, and a large, laterally extensive post orbital process. However, the Kaiparowits specimen differs significantly from the Dinosaur Park specimen in a number of features including: absence of medial depression caudal to nasal contact; weakly excavated lacrimal suture on frontal; and lack of ventral overlap of the lacrimal onto the frontal. As a result of this diagnostic element, we can confidently identify a troodontid closely related to, yet likely distinct from, *Troodon formosus* in the Kaiparowits Formation.

As mentioned, additional isolated "deinonychosaurian" material, including pedal phalanges, unguals, and caudal vertebrae, have been collected by the UMNH and may be referable to this taxon. However, much of this material is damaged and more research is needed to differentiate between isolated elements referable to troodontids versus the two (at minimum) poorly known dromaeosaurs in the formation.

Aves

Today, abundant evidence exists in support of the hypothesis that birds are the direct descendants of maniraptoran theropod dinosaurs, and thus are to be considered dinosaurs themselves. Just as modern birds exist as one of the most diverse

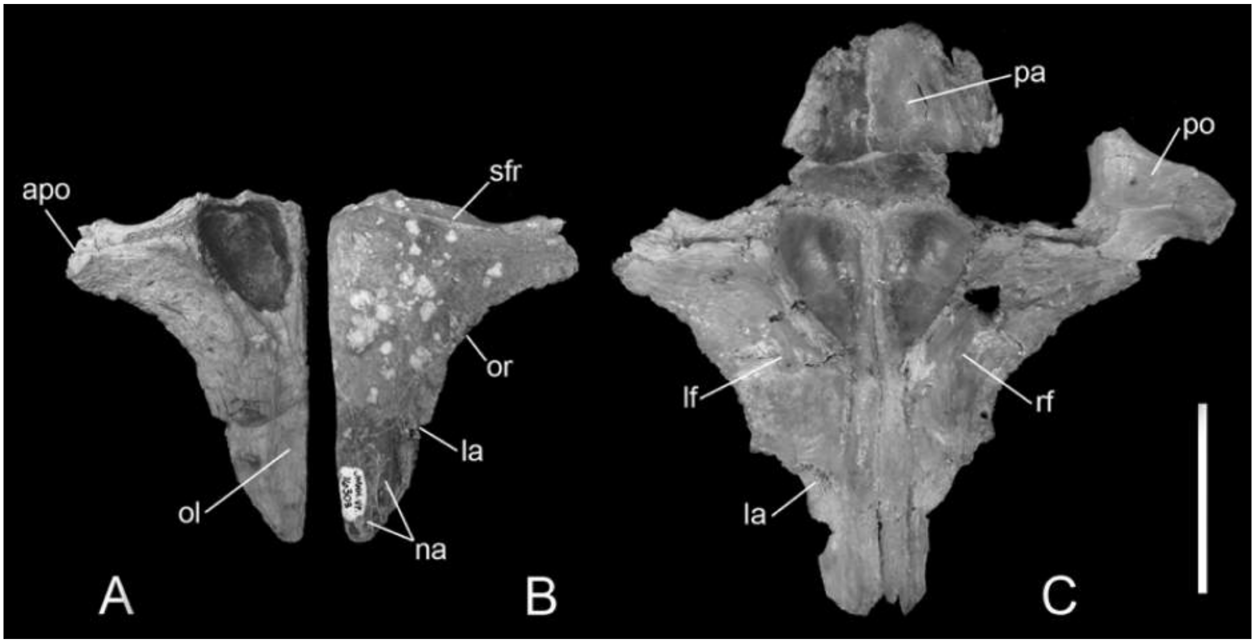

Figure 6. Morphology of troodontid frontals from the late Campanian of the Western Interior of North America. A-B UMNH VP 16303, troodontid incertae cedis from the Kaiparowits Formation of Utah in **A**, ventral; and **B**, dorsal views; **C**, CMN 12340, *Troodon formosus* cranium from the Dinosaur Park Formation, Alberta, Canada in ventral view. **Abbreviations: apo**, articular surface for the post orbital; **la**, articular surface for the lacrimal; **lf**, left frontal; **na**, articular surface for the nasal; **ol**, olfactory lobe; **or**, orbital margin; **pa**; parietal; **po**; postorbital; **rf**, right frontal; **sfr**, ridge on the rostral margin of the supratemporal fenestra. Scale bar equals 4 cm.

vertebrate groups alive today, birds are also known to have had a strong representation during the Cretaceous.

To date, a number of fragmentary avian skeletal elements have been collected during the KBP. However, thus far, the only avian taxon diagnosed from the Kaiparowits is *Avisaurus* (Hutchison 1993). Two species of *Avisaurus* are known from Late Cretaceous formations in Montana, *A. archibaldi* (Brett-Surman and Paul 1985) from the Hell Creek Formation (also known from the Lecho Formation in Argentina) and *A. gloriae* (Varricchio and Chiappe 1995) from the Upper Two Medicine Formation. Both are known solely from the tibiotarsus. By comparison, the Kaiparowits specimen represents one of the most complete Late Cretaceous enantiornithine birds, preserving a large portion of the skeleton including: partial axial column with pygostyle, well developed pectoral girdle and forelimb with a robust keel, U-shaped furcula, and papiliae remigiales, and robust tarsometatarsus with highly recurved unguals (Hutchison 1993). Preliminary study by Hutchison (1993) indicates that this specimen represents a new species of *Avisaurus*, but following publication of an abstract describing the find, no subsequent research has been undertaken to name the specimen; it therefore remains *Avisaurus* sp.

Discussion

Nearly all Late Cretaceous theropod clades known to have inhabited North America can now be documented in the Kaiparowits Formation, including tyrannosaurids, ornithomimids, oviraptorosaurs, "dromaeosaurine" and "velociraptorine" dromaeosaurs, troodontids, and avalians. Notably absent are therizinosaurs, a rare theropod clade, whose presence in the Campanian of North America is suggested from a single specimen recovered from the Dinosaur Park Formation in Alberta (Currie 1987b).

Recent radiometric dates derived from several bentonite horizons within the Kaiparowits establish the formation as coeval with fossiliferous portions of the Dinosaur Park, upper Judith River, and upper Two Medicine formations (Roberts et al. 2005). As such, the ecological diversity preserved in the Kaiparowits offers important insight into the phylogeny and biogeographic patterns of theropod dinosaurs within the WIB during the Late Cretaceous. Results of the KBP demonstrate that all major groups of theropod dinosaurs known from northern late Campanian formations contributed to the Kaiparowits ecosystem (Zanno 2005). Yet, despite the apparent ecological homogeneity among theropod groups within late Campanian WIB formations, theropod species appear to be highly endemic. During the KBP enough diagnostic material has been collected to verify that the Kaiparowits tyrannosaur and oviraptorosaur are local endemics. A potentially diagnostic troodontid frontal (UMNH VP 16303) is different enough from *Troodon formosus* to currently prevent its assignment to the northern troodontid. Similarly, the most complete dromaeosaurid specimen collected thus far from the Kaiparowits Formation (UCMP 149171) shows substantial differences relative to those species known to have inhabited northern WIB ecosystems. Thus, only a single theropod taxon from the Kaiparowits Formation is presently referred to an existing WIB genus—*Avisaurus*—and no formal study of this specimen has been conducted confirming this assignment.

Paleoenviromental interpretations of upper Campanian WIB formations suggest a span of habitats, from wet alluvial to arid coastal plain settings. Yet this substantial environmental variation appears to have had little effect upon the presence of various theropod groups within the basin (although they may be affecting local endemicity and speciation patterns). Rather than determining the diversity of theropods, paleoenvironmental conditions may have impacted the relative abundance of these clades within WIB formations, especially if the formations are sampling different primary habitat. Preliminary evidence seems to support this hypothesis, as tyrannosaurs (*Gorgosaurus*), and paravians (*Saurornitholestes* and *Troodon*) appear to be the most abundant theropods in the Dinosaur Park Formation (Currie 1987b), whereas tyrannosaurs and ornithomimids are the most commonly recovered theropods in the Kaiparowits Formation. Although we recognize that variable taphonomic factors can result in differential preservation of organisms thereby producing a difference in relative abundance values, we see no vast differences between the skeletons of Kaiparowits ornithomimids, oviraptorosaurs, and North American troodontids that would be expected to produce such biases and the former is clearly the most abundant theropod clade in the Kaiparowits Formation. While the smaller-bodied dromaeosaurs and avians may have a poorer representation in the Kaiparowits due to preservational or collection biases (small skeletons are harder to find), and the reverse conditions are undoubtedly impacting tyrannosaur abundance data, the sedimentology of the Kaiparowits and Dinosaur Park formations are sufficiently similar that invoking preservational biases as the sole explanation in this instance is likely not warranted. Ultimately, while we find these patterns of interest, a larger sample size and greater taphonomic control is needed to determine if these differences are indeed reflections of variation in regional ecology, or simply the result of skewed sampling.

Conclusions

The Kaiparowits Basin Project, spearheaded by the UMNH and the University of Utah, is currently making significant contributions to our understanding of the theropod dinosaur fauna of the Kaiparowits Formation, as well as to the taxonomy, biogeography, and phylogeny of the theropod clades that inhabited the WIB during the late Campanian. To date, the project has resulted in identification of three new theropod taxa: (1) *Hagryphus giganteus*, the first conclusive southern Cretaceous oviraptorosaur, and the first dinosaur to be named from GSENM; (2) an unnamed tyrannosaur genus, based upon a largely complete juvenile specimen; and (3) the first identifiable troodontid cranial material from the monument, which possesses a significant degree of morphological disparity from the northern *Troodon formosus*. Reinvestigation of a partial ornithomimid hindlimb and pelvis raises considerable questions about its referral to the Maastrichtian species *Ornithomimus velox*, while research in progress on the first diagnostic ornithomimid forelimb material confirms a close relationship between the Kaiparowits ornithomimid and the genus *Ornithomimus*.

Comparison of the newly revealed Kaiparowits theropod fauna with coeval late Campanian formations within the WIB demonstrates a surprising amount of homogeneity in theropod taxa at the clade ("family") level, particularly given the perceived variation in paleoenvironment between investigated formations. Yet the data also establishes a high degree of local endemicity at the genus and species levels. As a result we hypothesize that variation in paleoenvironment may be better expressed through relative abundance rather than presence/absence data for theropod clades within the WIB.

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Red Rock Sandstone Color and Concretions of Grand Staircase-Escalante National Monument: Jurassic Navajo Sandstone Examples of Groundwater Flow, Science Resource, and Analogs to Mars

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ABSTRACT

Color variations in Jurassic Navajo Sandstone are due to the presence or absence of iron and to its oxidation state. The color variations and local concentrations of iron cemented rock called concretions, are important mineralogical indicators that result from chemical interaction of pore fluids with minerals in the porous sandstone. The history of iron cycling begins with formation of the red color from breakdown of iron-bearing igneous minerals, then removal of the red color by reducing waters, and finally precipitation of the dissolved iron by oxidation to form cemented concretions.

Abundant "marble"-sized concretions (a few mms to several cms) comprise an Earth analog for recently discovered small hematite concretions ("blueberries" < 5 mm diameter) on Mars. The presence of hematite concretions on Mars implies transport of iron dissolved in water and precipitation upon oxidation.

The impressive outcrop exposure of color variations and concretions in the Navajo Sandstone in GSENM form a significant science and educational resource. These features comprise a valuable outdoor laboratory to understand the history and cycling of iron, as well as the processes of water interactions on both Earth and Mars.

Keywords: Navajo Sandstone, iron oxide, hematite, concretions, bleaching, eolian, reservoir, Mars, coloration

Introduction

Red Mesozoic sedimentary beds are widely exposed on the Colorado Plateau in Utah, Colorado, New Mexico, and Arizona. Several of these sedimentary beds were deposited by the wind (eolian), and typically comprise porous units that are good reservoirs for oil, gas, and/or water. These eolian sandstone units exhibit spectacular color variations from normally red (normal) to altered nearly white (bleached). Red sandstone rocks and their bleached equivalents dominate the landscape in southern Utah and adjacent states. Within Grand Staircase-Escalante National Monument (GSENM), the White Cliffs of the Grand Staircase, the Waterpocket Fold in Capitol Reef, Highway 12 from Escalante to Boulder, the cliffs along the Escalante and Paria rivers and the Cockscomb in Cottonwood Wash expose both bleached and red Navajo Sandstone. The varicolored sandstones are exposed on the flanks of Laramide age structures in Utah that include San Rafael Swell, Circle Cliffs uplift, Waterpocket fold, Kaibab uplift, and the Monument uplift in addition to the Uinta Mountains (Figure 1).

Color variations are the consequence of initial early reddening of sandstone during deposition or early burial (Walker, 1967), followed by later chemical bleaching and introduction of secondary iron oxides to produce the red, purple, yellow and orange hues. Reducing fluids that have interacted with hydrocarbons likely caused chemical bleaching. Although the colorful sandstone units are separated from underlying hydrocarbon source beds by thick sequences of shale, flow pathways along faults provided hydrocarbon access to the sandstone (Chan et al., 2000; Garden et al., 2001; Beitler et al., 2003).

The objectives of this paper are to describe iron cycling from initial mineral to solution and back to mineral deposition, to roughly estimate mass balance of iron, to compare iron cycling on earth and Mars, and to demonstrate how the iron cycling and formation of concretions is a valuable science resource. Examples of widespread bleaching, colors produced from introduced iron, and concretions form a fine outdoor laboratory for study in GSENM.

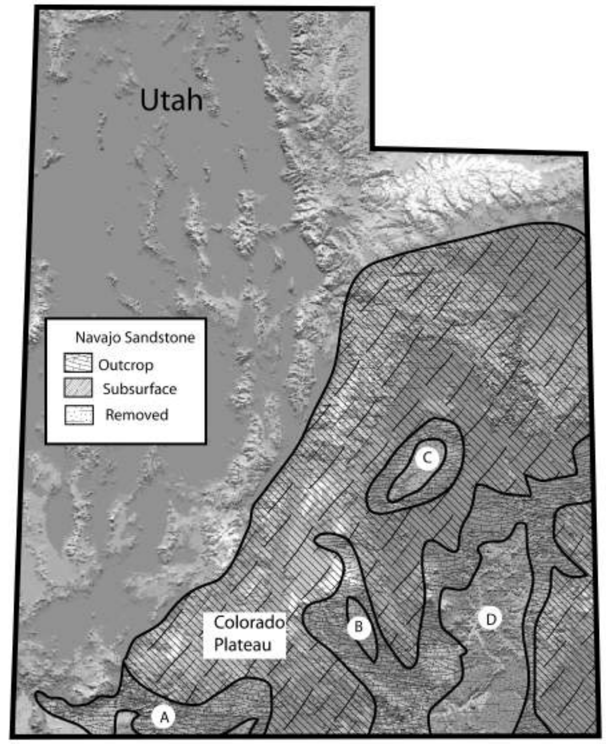

Figure 1. Shaded relief map of Utah showing areas of Navajo Sandstone outcrop, subsurface occurrence, and erosional removal on the Colorado Plateau. Major Laramide uplifts are as follows: A=Kaibab, B=Circle Cliffs, C= San Rafael Swell, D=Monument Upwarp.

Methods

Color variations in the Navajo Sandstone and concretion formation have been studied using field and laboratory methods. Field methods include observation of color variations in outcrop exposures and evaluation with multispectral Landsat 7 ETM+ imagery and hyperspectral HyMap imagery (e.g., Beitler et al., 2003; Bowen et al., 2007). Outcrop samples collected in the field were examined petrographically, and minerals were identified by X-ray diffraction. Whole-rock chemistry was analyzed by inductively coupled plasma spectrometry, and modal mineralogy was calculated using a linear, least-squares fit of whole-rock chemistry, mineral composition, and mineral abundance. Geochemical modeling calculations were accomplished using Geochemists Workbench (Bethke, 1998).

Structure

The Colorado Plateau province consists of flat-lying sedimentary rocks that are interrupted by several Laramide-age (80 to 40 million years ago, Stokes, 1986) tectonic structures. Laramide structures are broad doubly plunging anticlinal uplifts with numerous lesser structures. The East Kaibab, Waterpocket, and San Rafael anticlines are either fault-propagation folds or limb rotation folds that link to faults at depth (Davis, 1999). The faults are blind with the exception of the northern part of the East Kaibab monocline. The East Kaibab exposes a transpressive, length parallel fault that cuts Mesozoic strata (Davis, 1999). The faults that are hypothesized to provide hydrocarbon flow pathways on the Circle Cliffs, Monument, and San

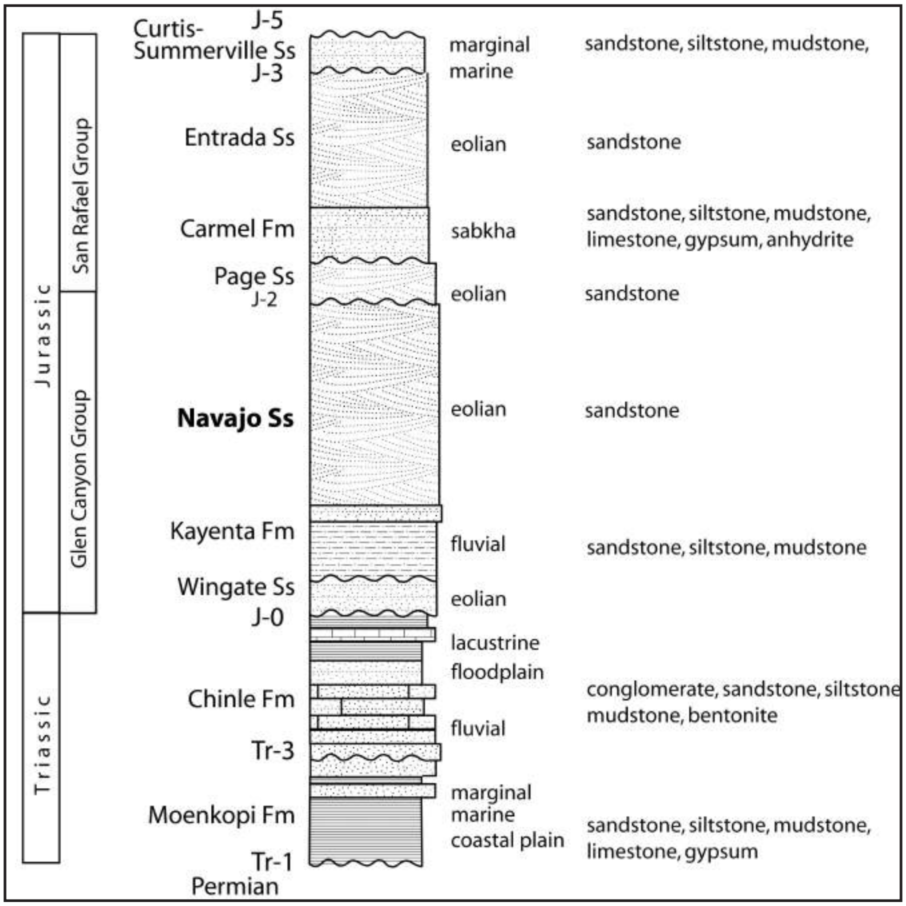

Figure 2. Stratigraphy of Triassic and Jurassic sedimentary rocks on the Colorado Plateau. Major unconformities (e.g., Tr-1, 3, and J-0 to J-5) are from Pipiringos and O'Sullivan (1978).

Rafael uplifts are blind (buried) faults that are not exposed. The Uinta Uplift was created by left-slip transpressional tectonics expressed by reverse left-slip along its northern bounding fault that is exposed as the Uinta fault (Johnston and Yin, 2001).

Stratigraphy

The spectacular red rock cliffs and slopes of southern Utah consist of Triassic and Jurassic sedimentary rocks shown in Figure 2. Three permeable eolian sandstone units of the Glen Canyon and San Rafael Groups are exposed on the flanks of the regional Laramide uplifts. The Wingate Formation, the Navajo Sandstone (the objective of this paper), and the Entrada Sandstone are wind-deposited. The Kayenta Formation that separates the Wingate Formation from the overlying Navajo Sandstone is fluvial. The true color of the Wingate is typically obscured by red clay that washes down from overlying Kayenta Formation. The slope-forming Chinle (fluvial and lacustrine) and Moenkopi (marginal marine) Formations beneath the Wingate Formation are fine-grained shales that retard movement of water. The Carmel Formation above the Navajo Sandstone represents a complex sabkha sequence of sandstone, siltstone, mudstone, limestone, anhydrite and gypsum.

Navajo Sandstone

The Lower Jurassic Navajo Sandstone is a permeable eolian sandstone member of the Glen Canyon Group, which also includes the eolian Wingate Sandstone, and the fluvial Kayenta Formation (Figure 2). The bulk of the sand grains (commonly reworked) that compose the Navajo Sandstone were originally derived from weathering and breakdown of igneous rocks in ancient mountain belts of eastern North America and the ancestral Rocky Mountains of Colorado (Reiners et al., 2005; Rahl, et al., 2003; Dickinson and Gehrels, 2003).

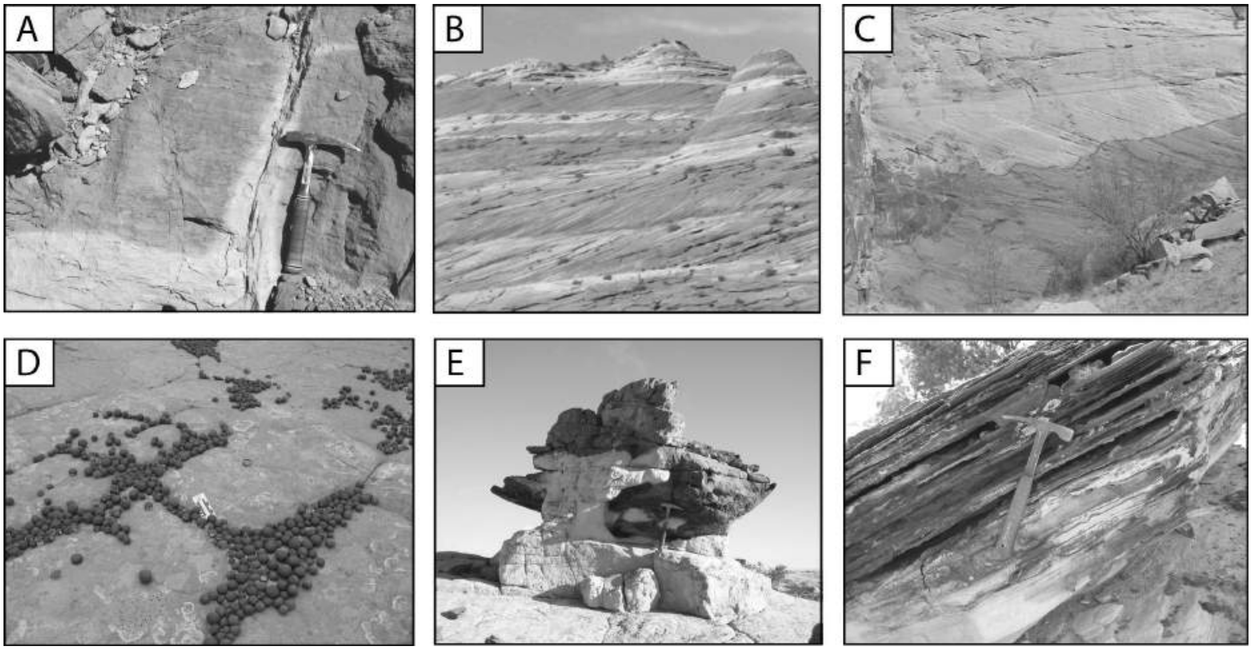

Figure 3. Examples of Navajo Sandstone outcrop expressions of sandstone coloration, bleaching, and iron oxide concretions from within Grand Staircase-Escalante National Monument. A-B) Spencer Flat, C) Escalante River, D) Spencer Flat, E) Deer Creek, F) Calf Creek.

The Navajo Sandstone varies in color (Figure 3) from an original light brown, moderate orange pink, moderate reddish brown and grayish orange pink to altered zones of diffuse reddish brown, diffuse yellowish orange and white. The Navajo Sandstone also contains a number of localized areas that contain iron oxide cemented concretions. These hard, resistant spheroidal sandstone balls weather out of the weaker eolian host rock and typically accumulate along deflation surfaces, or in small topographic lows. The concretions reflect both the movement of water that redeposited the iron oxide as a cement, as well as weathering processes that contributed to the accumulations.

The Navajo Sandstone and the equivalent Nugget Sandstone of northern Utah and Wyoming are the porous host rocks for petroleum deposits today. For example, 14 oil and gas fields occur in the Nugget Sandstone in northeast Utah and southwest Wyoming (Powers, 1995), and the recently discovered Covenant Oil Field in south-central Utah produces oil from the Navajo Sandstone (Brown, 2005).

Iron Geochemistry

Iron occurs as Fe^{+2} and Fe^{+3} oxidation states in crustal rocks. Metallic iron is present only in the core of the earth and in meteorites. The minerals hematite and goethite that form the red pigment in sedimentary rocks in southern Utah and the concretions contain Fe^{+3}. These minerals have exceedingly low solubility in water as do other minerals with iron in the +3 oxidation state. Dissolving the Fe^{+3} bearing minerals requires chemical reduction to Fe^{+2}, which also depends on acidity as shown in Figure 4.

Iron Cycling

Iron is cycled from solid minerals to solution and back to solid minerals by chemical reactions that have been described by Chan et al. (2000; 2005a; 2005b; 2006) Chan and Parry (2002), and Beitler et al. (2005). The average mineralogical composition of the Navajo Sandstone determined from whole-rock chemical analyses is 83% quartz, 6.7% potassium feldspar, 4.8% illite, and 1.0 % kaolinite. None of these minerals are colored. The mineral hematite (Fe_2O_3) comprises 0.55% of the average Navajo Sandstone and imparts the red color to the sandstone. The quartz (typically recycled), feldspar, and a few trace minerals such as zircon are derived from the breakdown of granitic rocks in the source terrain(s). Iron minerals in the granitic rocks are incorporated into the sandstone

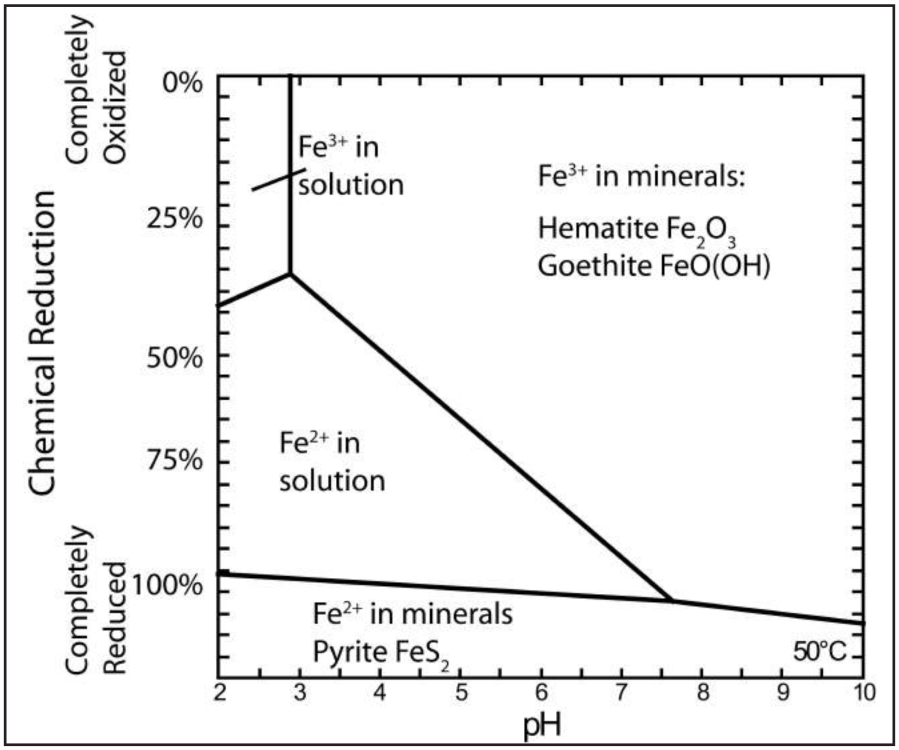

Figure 4. Iron species in solution and in minerals as a function of degree of chemical reduction and pH (acidity). Diagram was calculated using Geochemists Workbench (Bethke, 1998).

and gradually decompose during weathering and burial. Iron from these minerals is released, oxidized to Fe^{3+}, and precipitated as red coatings on the sand grains.

Following burial and formation of Laramide structures (at about 80 to 40 Mya), the Navajo Sandstone became saturated with hydrocarbons. Bleaching of red beds by hydrocarbons has been recognized by Moulton (1922), Levandowski et al. (1973), Segal et al, (1986), Surdam et al., (1993), Guscott et al., (1997), Foxford, et al., (1998), Chan et al., (2000), and Garden et al., (2001) among others. The hydrocarbons are electron donors and possibly support bacterial growth that further promotes iron reduction. The iron forming the red color is an electron acceptor. Iron is reduced from the Fe^{3+} oxidation state to Fe^{2+}, dissolved and transported in water.

Chemical analyses of red and bleached sandstones show that about 30% of the iron is removed during bleaching and transported elsewhere (Beitler, et al., 2005). Either acidic or reducing fluids enable iron mobility (Figure 4). Chemical modeling of iron reduction by hydrocarbon suggests the quantity of water required, shown on Figure 5, is dependent on the pH (a measure of the acidity) of the solution. Lower pH (i.e., more acidic) values enhance the iron solubility enormously. At a pH of 7 (neutral pH), 1 kg of water can bleach about 8 cm^3 of rock, and at the lowest pH of 3 (acidic pH), 1 kg of water can bleach about 80 cm^3 of sandstone. The pH of water that bleached the Navajo Sandstone is estimated to be near 7, because calcite that is soluble in acid is still present in the rock. Minerals that form at low pH such as jarosite are typically not present, and no source of acid for the large quantities of water has been yet identified. Therefore, the main source of iron mobilization and bleaching in the Navajo Sandstone, is likely the presence of chemically reducing, yet neutral, fluids.

The mobilized iron remains in solution and travels along preferential fluid flow paths until an oxidizing groundwater is encountered. The iron is then oxidized to Fe^{3+} and again becomes insoluble. Iron oxides and (hydr)oxides then precipitate as disseminated colorful cements and concretions that are so abundant in GSENM. The oxidation and

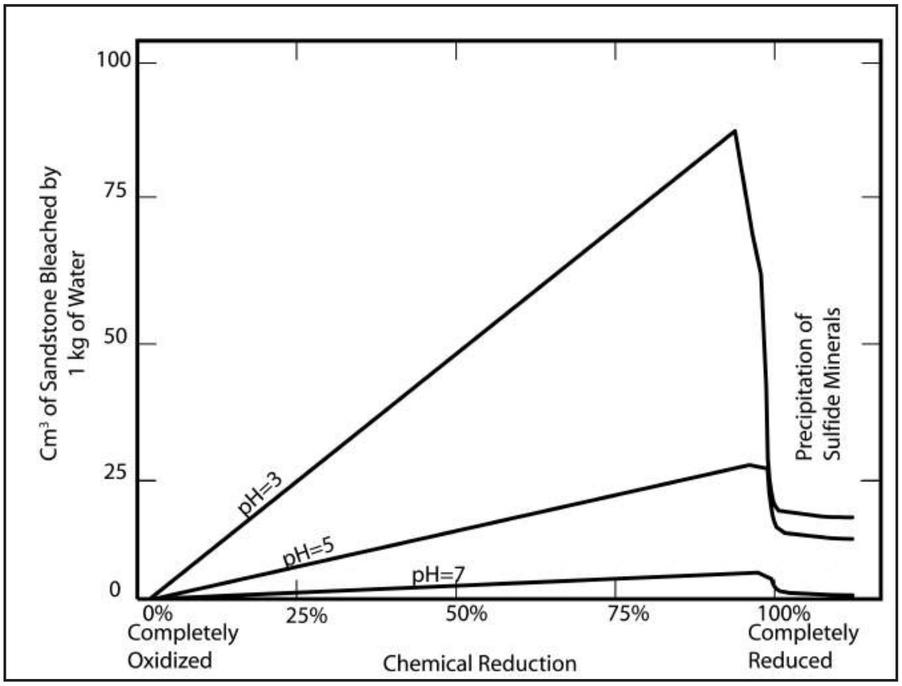

Figure 5. Iron solubility as a function of chemical reduction and cubic centimeters of red sandstone bleached by removal of 30% of the contained iron in 1 kg of water. Diagram calculated using the Geochemists Workbench (Bethke, 1998).

immobilization process is the reverse of chemical reduction and mobilization process previously described (Figure 6).

The chemical reaction front between oxidized and reduced waters can occur on a large range of scales, from small, localized "pinhead-sized" concretions to large regional zones of alteration. A wide range of shapes and sizes of concretions can precipitate at a reaction front, but spheroidal concretions are common where the host rock is homogeneous. Iron is transported to the precipitation sites by both advection (macroscopic fluid movement) and diffusion (molecular and ion movement).

Chemical reduction may also reduce sulfate to sulfide, and pyrite may precipitate. In this case, iron is immobilized as the insoluble sulfide mineral and is not removed from the rock. If reduced iron-bearing solution encounters oxidizing waters containing sulfate, the reducing waters may convert the sulfate to sulfide at the interface and precipitate iron sulfide providing the iron remains in the reduced state. These chemical reactions involving pyrite and later oxidation of pyrite to iron oxide minerals do occur in other sandstone units in GSENM such as some of the Cretaceous sandstones that are typically associated with coal and reducing conditions with high sedimentation and rapid burial rates.

Discussion

Iron cycling in the Navajo Sandstone involves transport of enormous quantities of iron. The average iron content of unaltered Navajo Sandstone is 0.55 wt. % Fe_2O_3 and bleached Navajo Sandstone averages 0.36 wt. % Fe_2O_3 (Beitler et al., 2005). The volume of bleached Navajo Sandstone on the Circle Cliffs uplift, one of the five Laramide age highs exposing bleached sandstone, is 2,100 km^3 (Beitler et al., 2003). Bleaching of this volume of rock results in mobilization of 5 billion metric tons of iron (1 metric ton=2,200 pounds). Some of this iron appears in the abundant concretions or cemented joints and other forms in GSENM, and some iron has been removed by erosion, but the fate of the remainder is unknown.

The Spencer Flats area southeast of Escalante contains particularly abundant concretions (colloquially known as Moki marbles). The area from the Straight Cliffs to the Escalante River and from State Highway 12 south to Harris Wash is 300 km^2. The thickness of the Navajo Sandstone, host for the concretions is about 300 m so the volume

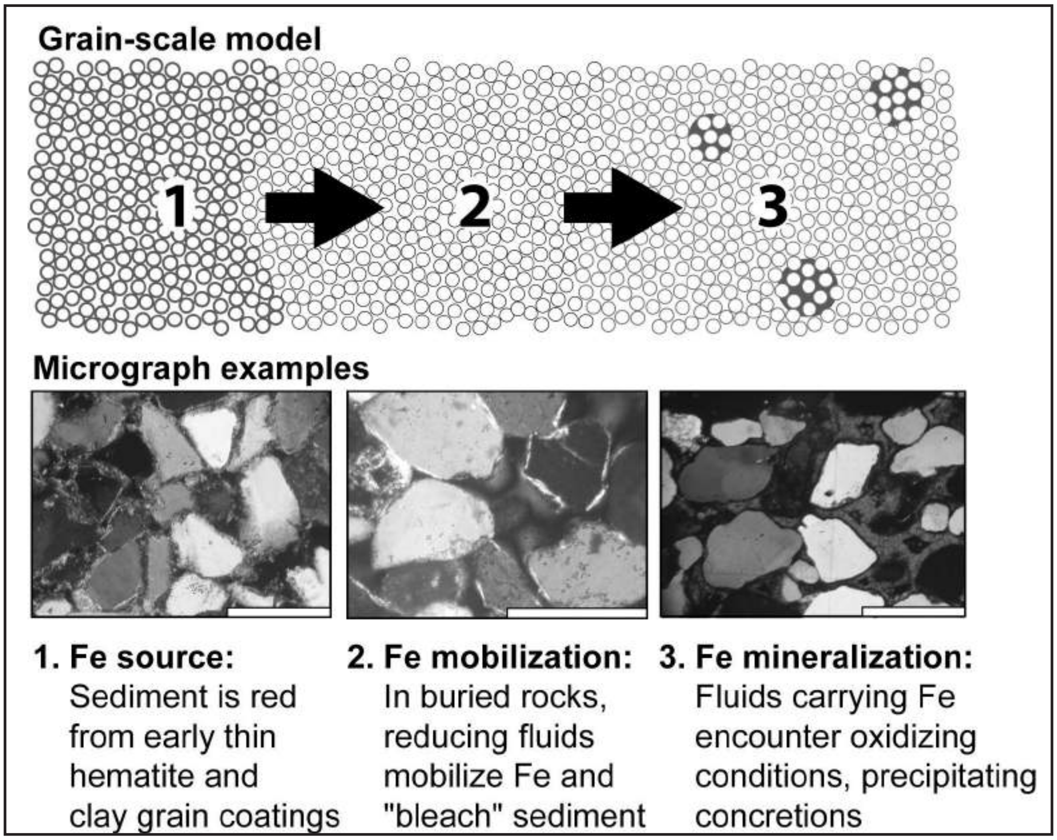

Figure 6. A sequential three-step model of Navajo Sandstone iron cycling showing various stages at the grain-scale (top row), with thin section micrograph examples beneath. Thin section micrograph scale bars = 0.25 mm.

of the Navajo containing concretions is 90 km^3. Each m^3 contains about 30 small concretions. The concretions consist of an approximate 5 mm rind (some are thinner and some are thicker) of iron oxide cemented sandstone surrounding a core of sandstone containing very little iron oxide. Each concretion contains about 10 g of iron and the total volume of Spencer Flat sandstone contains 30,000 tons of iron, thus only a tiny fraction of iron mobilized from the Circle Cliffs uplift is represented by the Spencer Flat concretions.

Although these numbers represent rough estimates, collectively they show that there is significant iron cycling that is likely facilitated by the porous nature of the Navajo Sandstone, and the likely movement of different fluids over potentially long (geologic) time spans.

Analogues with Mars

The Mars Exploration Rover (MER) Opportunity deployed by NASA sent back images of accumulations of spherules of iron oxide (Fe_2O_3) in the Meridiani Planum region of Mars, starting in 2004. The Opportunity images of the spherules dubbed "blueberries" had important implications for interpreting evidence of water on Mars (e.g., Squyres et al. 2004). The spherules physically resemble iron oxide concretions in the Navajo Sandstone in Utah (Figure 7) (Beitler et al., 2004, Ormo et al, 2004, Chan et al., 2004, 2005a, 2005b, 2006). The Mars spherules show remarkable similarities to the Navajo examples in the characteristics of in situ distributions, accumulations, geometries, joined forms, and mineralogies. Iron oxide concretions in Martian rocks suggest iron cycling involving transport and precipitation from diagenetic water similar to the Navajo analogues. There are some significant differences, however. Iron in Martian rocks is initially present as Fe^{2+} minerals in basaltic igneous rocks. Mobilization of the iron requires the breakdown of igneous minerals, likely with acid solutions from volcanic emanations as suggested by Varekamp (2004) and Ming et al. (2006). As shown in Figure 4, acid solutions are capable of mobilizing much more iron

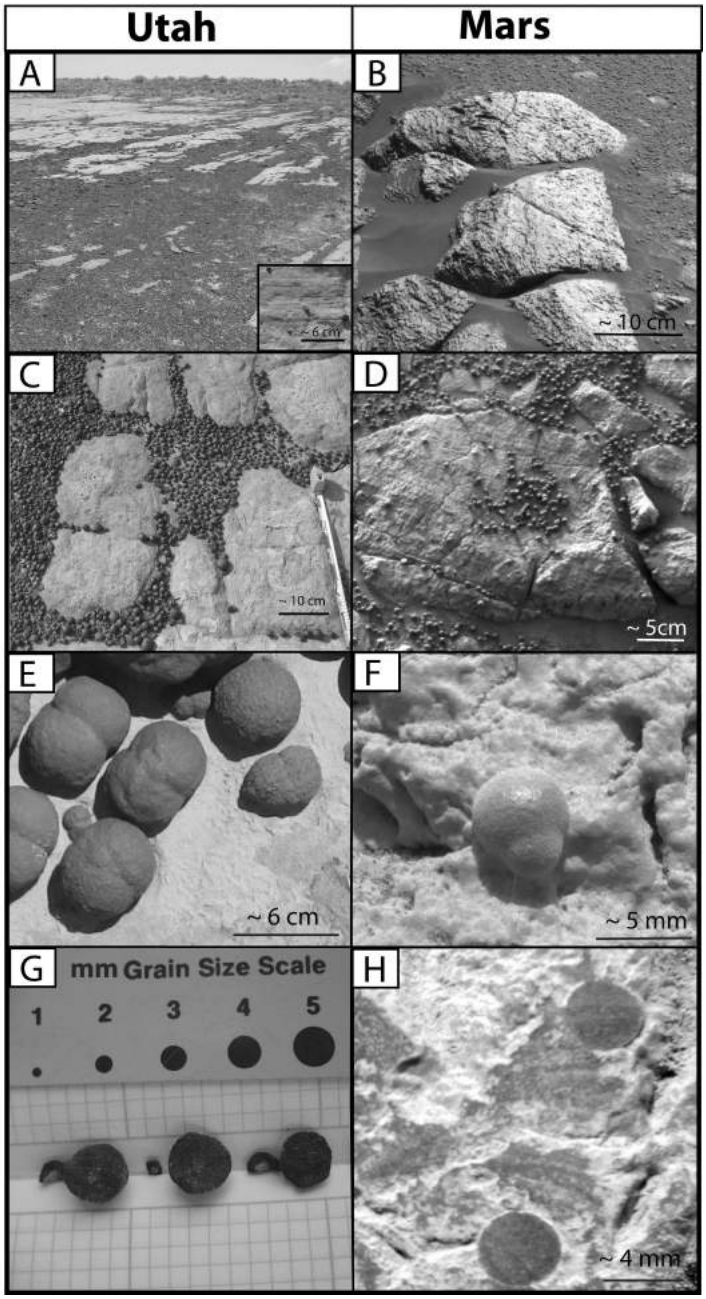

Figure 7. Comparisons of terrestrial GSENM Navajo Sandstone iron oxide concretions (left side) and Mars blueberries from Meridiani Planum (right side). Comparative features include in situ (in place) concretions (A inset and B) in the host rock, accumulations in topographic lows (C and D), joined forms (E and F) and interior forms lacking a distinct nucleus (G and H). Image H is a view of Mars host rock and a cross-sectional cut of the blueberries as exposed by the MER Rock Abrasion Tool (RAT). Mars examples from the Opportunity rover include B and D as false color pancam (panoramic camera) images. All right side Mars photo credits: NASA/JPL/Cornell.

than solutions with pH near 7. Precipitation of the iron could have occurred as a result of interaction with atmospheric oxygen coupled with chemical reaction with host rocks that consumed the acid required to maintain the iron in solution. Some modern acid lake environments have been further suggested as modern analogs to the Mars system, where acid solutions are capable of mobilizing iron, and under the right oxidizing conditions, iron precipitates as concretionary cement in porous sediment (e.g., Benison and Bowen, 2006; Bowen et al. 2008), although the modern environment lacks the comparative outcrop distributions shown in the Mars and Navajo examples cited here.

In addition to the potentially acidic conditions of the Meridiani environment of Mars, the basaltic components in the Martian host rock are more labile and potentially more involved in supplying the reactants for concretion formation (e.g., Catling, 2004; Clark et al., 2005; McLennan et al., 2005; Tosca et al., 2005) in comparison to the inert quartz arenite host of the terrestrial examples studied here. The small and relatively uniform grain sizes of the concretions along with the nearly perfect spherical geometry in the Mars example suggests that the formation of Mars blueberries were dominated by diffusion.

Although there are clearly differences between Utah and Mars concretions, the Navajo Sandstone example is important in helping establish some of the boundary conditions, and what causes or promotes different variations in concretion history, sizes, shapes, and more. The Utah examples likely contain many shapes and sizes in comparison to Mars because different tectonics, local porosity variations, and multiple fluid events have a notable effect.

Science Resource

Variable coloration coupled with exceptional exposure in the Navajo Sandstone provides an opportunity to view directly the chemical effects of groundwater movement and chemical interaction with minerals in the rocks. Precipitation of iron oxide cement to form the numerous concretions provides a record of the iron cycling and contributes to our understanding of the fluid influence on different textural characteristics of concretions. These terrestrial examples provide a comparison with Martian blueberries to understand the role of groundwater movement on other planets. It is further known that bacteria can influence both the reduction and precipitation of iron oxides, and in some instances, biomarkers can be preserved in resulting iron oxide cements (Souza-Egipsy et al., 2006). In the search for extraterrestrial life, the terrestrial analog studies of iron cycling will continue to be important for understanding the potential for preservation of life on Mars. The accessibility and fine geologic exposures of the Navajo Sandstone in GSENM comprise a valuable scientific resource to the monument. In the GSENM where there is such exceptional geology and paleontology, there are still many geologic mysteries to be unraveled and discoveries yet to come.

Conclusions

The red and varicolored Navajo Sandstone cliffs and abundant concretions of GSENM owe their coloration and formation to iron cycling. Iron from igneous minerals is first deposited as a red coating on sand grains during weathering and early burial of the sand. Later, hydrocarbon bearing and/or chemically reducing fluids dissolve the iron. Bacteria may aid the process of iron mobilization. The iron is transported in solution to an encounter with oxidizing water that cause the iron to precipitate as concretions and disseminated iron oxides.

The iron oxide concretions bear a striking physical and mineralogical resemblance to iron oxide concretions observed on Mars suggesting some similarities in formation. The Martian concretions likely formed from iron released from igneous minerals by acid solutions that derived their acidity from volcanic emanations. The concretions form when the acid solutions interact with oxygen in the atmosphere and surficial sediments.

GSENM has remarkable accumulations of concretions that comprise a terrestrial comparison for planetary geology, in addition to being a unique and valuable geologic resource for science, monument management, and educational outreach.

Acknowledgments

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Education and Adventure: High School Students and Paleontology Research Within Grand Staircase-Escalante National Monument

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ABSTRACT

The Alf Museum, located on the campus of The Webb Schools, is the only paleontology museum in the world that exposes secondary school students to all aspects of its operation, including research. The museum is named for Raymond Alf, a teacher whose student found a peccary skull in the Barstow Formation in 1936 (holotype of *Dyseohyus fricki*). This discovery inspired Alf to become a paleontologist and to launch the "Peccary Society," an innovative melding of paleontology into secondary school education where Webb students collected, prepared and studied fossils. Alf concentrated on recovery of fossil vertebrates and by 1970 had amassed a large collection, including 830 track specimens. With two large exhibit halls and over 60,000 paleo specimens, the Alf Museum is an important resource for education and research.

In the last decade, the museum has expanded its student research program in vertebrate paleontology. Current projects are centered on the Goler and Barstow formations of California and the North Horn and Kaiparowits formations of Utah. Fieldwork in the Kaiparowits Formation is within GSENM near the headwaters of Wahweap Creek. Students learn field techniques, experience the excitement of discovery while preserving the paleontology resource of the Monument, and assist in study of Kaiparowits fossils, thus making a significant contribution to scientific knowledge, unique for high school students. Rare dinosaurian specimens found by and/or collected with the help of students include a partial *Ornithomimus* skeleton, a nearly complete hadrosaur skull with articulated jaws, and part of the lower leg of a mid-sized tyrannosaur. The hadrosaur skull is presently under study at the University of Utah. A partnership of sharing information between BLM, Alf Museum, and University of Utah has expedited research within the Monument.

Keywords: Kaiparowits formation, vertebrate paleontology, dinosaurs

Collection of Vertebrate Fossils and Associated Taphonomic Data from the Late Cretaceous Kaiparowits and Wahweap Formations, Grand Staircase-Escalante National Monument, Utah

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ABSTRACT

Since 2001, the Utah Museum of Natural History (UMNH) has been working in collaboration with BLM to conduct paleontological surveys of the Upper Cretaceous Kaiparowits and Wahweap formations of Grand Staircase-Escalante National Monument (GSENM). In the course of this project, the UMNH has made field collections from more than 350 vertebrate localities and conducted extensive excavations at 10 of these sites. Vertebrate discoveries include isolated elements, associated skeletons, articulated skeletons, and even multi-individual bonebeds.

In addition to the collection of many significant fossil specimens, the field inventory of vertebrate localities involves the collection of considerable ancillary, taphonomic data that can be used to address broader paleoenvironmental and paleoecological questions. Taphonomic data most relevant in this type of survey include the sedimentologic and stratigraphic context of the locality; spatial and geographical context of the specimens obtained through excavation mapping; and categorization of localities according to their biological and preservational attributes (taphonomic modes). Additional taphonomic features observed on individual specimens following detailed preparation include: soft tissue preservation, weathering, traces of insect activity, trampling, and tooth marks.

The systematic collection of taphonomic data associated with vertebrate localities in GSENM has revealed insights into the character of the paleoenvironments and paleoecology of the formations in question. In addition to the remarkable fossils collected in the past six years of our paleontological survey, taphonomic analyses enable ecological interpretation beyond what is possible from the collection and study of the specimens alone.

Keywords: Upper Cretaceous, Wahweap Formation, vertebrates, sedimentology, stratigraphy, context

Overview of Vertebrate Taxa from the Late Cretaceous Tropic Shale, Southern Utah

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ABSTRACT

Exposed primarily along the southern escarpment of the Kaiparowits Plateau in southern Utah within boundaries of Grand Staircase-Escalante National Monument, Glen Canyon National Recreation Area, and Utah State and Institutional Trust Land, are vast outcrops of the Tropic Shale – a 200 meter thick unit of marine mudstone deposited about 93 m.y. ago along the western margin of the Cretaceous Western Interior Seaway (KWIS). Since 1999 fieldwork conducted by personnel from GSENM and the Museum of Northern Arizona has resulted in the recovery of a variety of marine vertebrates, including fish, turtles, plesiosaurs, and even a therizinosaurid dinosaur. Fish include the predatory osteichthyan *Xiphactinus* and the mollusk crushing chondrichthyan *Ptychodus*, and other selachians. Pliosaurid material includes two specimens of the large *Brachauchenius lucasi*, both of which include skull material and one of which provides the first remains of pectoral and pelvic elements known for this taxon. Three different polycotylid plesiosauroids recovered represent two new subfamilies, each with a new genus and species. Regarding the turtles, a partial carapace of the estuarine taxon *Naomichelys* was recovered, as well as a partial skeleton of what appears to be the fully marine *Desmatochelys*. These specimens provide evidence for a considerably higher level of marine diversity in the KWIS during the Late Cretaceous, early Turonian Stage, than previously realized, and ensure that continued prospecting will likely yield further surprises. The Tropic Shale affords an excellent, previously unexploited window through which this important interval of time for North American, even global, biotic diversity and evolution can be viewed.

Keywords: Tropic Shale, marine vertebrates, plesiosaurs

Discovery, Excavation, Preparation, and Preliminary Description of the Skull of a New Centrosaurine Ceratopsian from the Wahweap Formation (Upper Cretaceous) of Grand Staircase-Escalante National Monument, Utah

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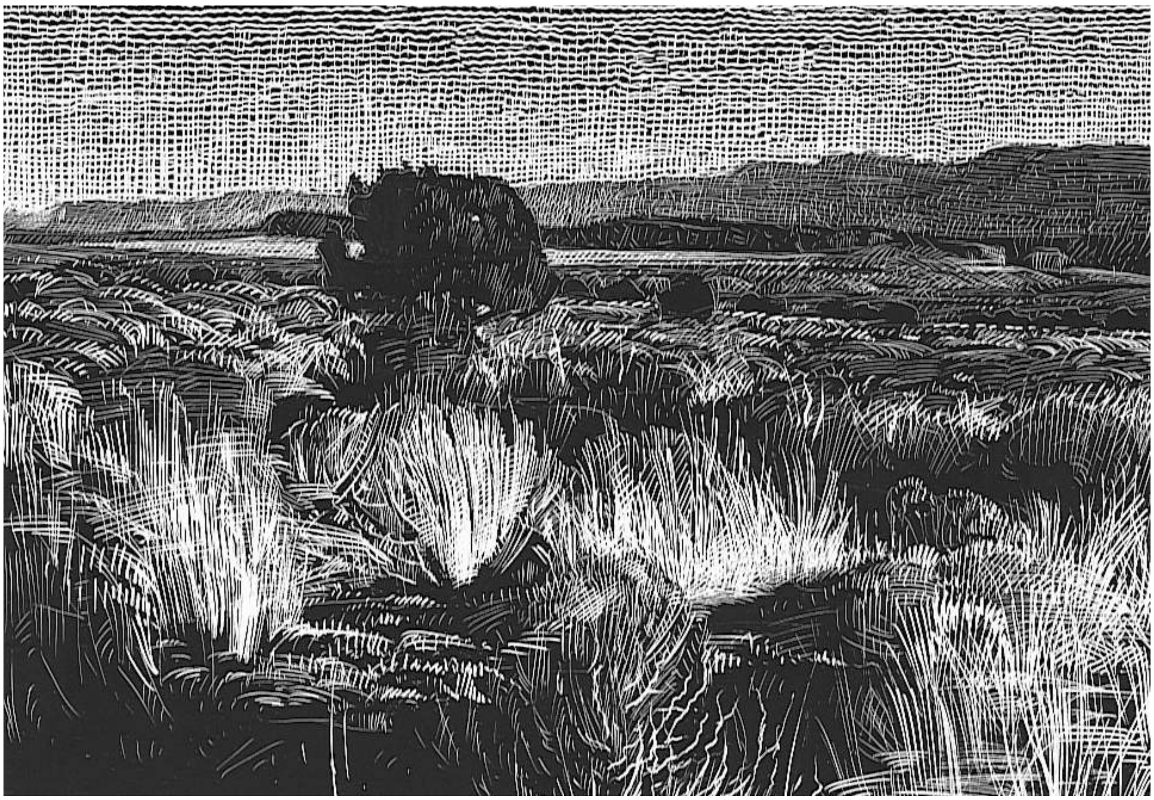
ABSTRACT

The Utah Geological Survey (UGS), in cooperation with the Bureau of Land Management (BLM), has been conducting a multi-year project to inventory the paleontological resources of the Wahweap Formation (middle Campanian) of GSENM. In 2002, the skull of a ceratopsian dinosaur was discovered eroding out of a hard sandstone ledge in the "middle mudstone member." Collection of bone on the surface and cleaning of the block revealed a nearly complete skull lying on its left side; part of the right side had eroded away with much of the skull still imbedded in the rock. We spent eight days using a gas-powered cutoff saw to separate the block containing the skull from the surrounding ledge. In September 2005, the block was transported by helicopter to a truck waiting on a nearby road and driven to the UGS preparation lab in Salt Lake City. Since then, several hundred hours of preparation have been completed on this skull.

This skull represents a new genus of long-horned centrosaurine ceratopsid. It is the first diagnosable centrosaurine recovered south of Montana and may be the oldest. It shares with more derived centrosaurines the stepped squamosal and a nasal-premaxillary process along the caudal border of the naris. Important features of the skull include a low, subconical narial horn; a smaller "epinasal" narial horn; long postorbital horns; and large, blade-like epijugals. The frill is subequal in length to the skull, and is widest at the squamosals, tapering to half its width at a pair of long caudal parietal spines separated by a medial notch. The long postorbital horns and small narial horn are primitive character states as indicated by the ceratopsid sister taxon *Zuniceratops*. Autapomorphies include "two" nasal horns, short muzzle, large blade-like epijugals, and a caudally-tapering frill with long spines.

Keywords: inventory, ceratopsid

Rangeland Ecology



"A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise."

– Aldo Leopold –

Integrating Concepts of Ecological Sites, State and Transition Models, and Indicators of Rangeland Health into Ecosystem Management Programs

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ABSTRACT

Throughout the history of rangeland use in the western United States, resource managers have been challenged to efficiently and effectively inventory and assess the condition of rangeland ecosystems, determine any management problems that may exist, implement management plans developed to correct problems and improve conditions, and monitor changes brought about by management to ensure that objectives were being met. Considerable controversy and confusion about rangeland condition and management has occurred from time to time as different inventory and assessment methods have been used to determine rangeland condition and various interest groups have interpreted available data in different ways. Ecological site descriptions, state-and-transition models, and rangeland health assessments are three powerful tools to help managers understand the current and potential condition of an area of rangeland, evaluate the seriousness of any problems that may exist, and develop management plans to correct problems and achieve desired conditions.

This paper will describe the integration of these three tools using rangelands of Grand Staircase-Escalante National Monument (GSENM) as examples.

Ecological Site Descriptions

Rangeland landscapes are classified into ecological sites for the purposes of inventory, evaluation, and management. An ecological site is an area of land with specific physical characteristics that cause it to differ from other kinds of land in its ability to produce a distinctive kind and amount of vegetation and to respond to management (USDA, NRCS 2003). An ecological site is the product of all the environmental factors responsible for its development, and it has a set of key characteristics (soils, hydrology, vegetation, and natural disturbance regimes) that have contributed to site development over time and are included in the ecological site description. Primary factors that contribute to site development are geologic parent material; long term climate patterns—particularly the annual temperature and the amount, kind, and timing of precipitation; topography or landscape position—including elevation, slope, and aspect; as well as plants and animals that occur on the site. These and other factors interact over time to create the soils, hydrology, and vegetation characteristics that differentiate one ecological site from another. The same ecological site will be found on the landscape wherever the same prevailing climate, topographic, and soil characteristics occur.

Vegetation communities believed to be most in balance with the environmental conditions of the site are referred to as the reference state. Because of naturally occurring changes in the environment (such as climate, fire, insects, and disease), this state is not defined as one mix of plants but represents the range of plant species composition and production that occurs as the plants respond to changing environmental factors.

Relationship of Soil Surveys to Ecological Sites

Because soil development integrates many other environmental factors, and soil characteristics change more slowly than vegetation, ecological sites are commonly correlated to the soils described in a published survey report. A soil survey uses field inventory and laboratory data to describe and map soils across the landscape. A soil survey map will delineate the area that has been determined to have unique and identifiable soil characteristics and a name will be given to each map unit (USDI, BLM 2001, page 15-18).

Important characteristics of soils that distinguish one ecological site from another are origin of parent materials, depth, texture, size and amount of rock fragments, and structure of the surface and subsurface horizons. Landscape position, which influences a variety of soil development processes, is also important for identifying an ecological site. These soil and topographic characteristics influence the hydrology of a site, particularly infiltration, soil water holding capacity, and runoff. Collectively, the climate, topography, and hydrology associated with soils correlated to an ecological site create the environment for a characteristic biotic community including (1) kind and/ or proportion of plant species that are adapted to seasonal moisture and temperature patterns, rooting characteristics, and dry to wetland conditions); (2) amount and timing of yearly plant production; and (3) kinds, numbers, seasons, and intensities of use by herbivores. In turn, the ecological site will develop characteristic patterns of response to naturally occurring disturbances such as wet and dry periods and the timing, frequency, and intensity of fire.

The soil survey completed in the GSENM, identified, described, and mapped 166 soil map units. These soils were correlated into 50 unique ecological sites (USDA, NRCS 2005).

Naming Ecological Sites

Ecological site names are based on physical characteristics of the site that are considered to be permanent. The USDA Natural Resources Conservation Service, which has the lead responsibility for maintaining the ecological site description database, uses an ecological descriptor followed by a surface soil descriptor as the foundation for a site name. In Utah (USDA, NRCS no date), differences in annual average precipitation and other climatic factors are used as ecological descriptors, resulting in sites receiving less than 8 inches of annual precipitation being named desert; 8 – 12 inches, semidesert; 12 – 16 inches, upland; 16 – 22 inches, mountain; and 22 – 40 inches, high mountain. Areas receiving greater than 25 inches but with a shorter growing season and lower average daily temperatures than high mountain are classified as subalpine. Areas above timberline are alpine.

A dominant surface soil texture descriptor such as sandy, sandy loam, loam, or clay will follow the climate descriptor for these sites. Site names may also include other descriptors such as steep or very steep to describe topography or gravelly, gypsum, alkaline, shallow, and stony to further define soil characteristics. Other ecological descriptors are used to name sites where average annual precipitation is not the dominant environmental factor. Examples include semiwet, streambank, bottom, or wetland descriptors for sites that receive subsurface or run-on water. In Utah, site names include the name of the dominant plant species found on the site with the plant name in parentheses.

Ecological Sites in GSENM

To better understand how environment factors are expressed on the landscape, this paper will consider four ecological sites that are common in the GSENM (USDA, NRCS 2006): (1) Desert Loam (shadscale), (2) Semidesert Loam (Wyoming big sagebrush), (3) Upland Loam (mountain big sagebrush), and (4) Loamy Bottom (basin big sagebrush). From the names alone, one knows that the soils of these four sites are dominated by loamy textured surface soil material. These soils have similar geologic parent material (water and/ or wind deposited alluvium or residual material derived from sandstone and shale). Their abilities to absorb water (permeability) are similar as are their erosion characteristics.

Soil depths vary with the Desert Loam and Semidesert Loam sites being 20 – 60 inches deep and the Upland Loam and Loamy Bottom sites being greater than 60 inches. Mean annual precipitation increases from the desert loam to the upland so that growing conditions and plant production improve as one moves from the Desert Loam, to the Semidesert Loam to the Upland Loam sites. Because the Loamy Bottom site occurs at various low lying locations in the landscape, its mean annual precipitation varies across the full range of expected precipitation occurring in the Monument. The growing conditions on the Loamy Bottom site are enhanced above what would be expected from mean annual precipitation by flooding, which the site description implies may occur four out of ten years. Flood water allows the Loamy Bottom site to support more plant production of the other three sites. Unfortunately, flood conditions can cause serious gully erosion on loamy bottom sites when protective vegetation has been removed.

Comparing reference state communities on these sites we find that:

1. Desert Loam (shadscale) Ecological Site (USDA, NRCS 2006, 035XY109UT)—Dominant plant types in the reference state for this site are 55 percent shrubs, 35 percent perennial grasses, and 10 percent forbs[1]. The dominant shrub in the reference state is shadscale but several other shrubs (winterfat, bud sagebrush, Nevada Mormontea, and broom snakeweed) are found (3 – 5 percent each) in the community. All of these shrubs are tolerant of arid conditions thus serving as indicators of a desert ecological site. The presence of shadscale indicates that there is some salt in the soil, thus shadscale serves as an indicator of an important environmental characteristic of this site. Dominant grasses in the reference state are galleta (15 – 20 percent) and Indian ricegrass (10 – 15 percent). Galleta represents a plant capable of taking advantage of rain that occurs during the warm, monsoon season (warm season plant) while Indian ricegrass is a plant that grows in the spring utilizing moisture accumulated over the winter and is considered a cool season plant. Other grasses found in the reference state are minor amounts (1 -3 percent each) of bottlebrush squirreltail, sand dropseed, and purple threeawn, the first being a cool season plant and the last two warm season plants. Many forbs grow on this site, but gooseberry globemallow is the most common forb, making up 3 – 5 percent of the plant composition. Mean annual production of the Desert Loam (shadscale) ecological site is 400 – 450 pounds per acre.

2. Semidesert Loam (Wyoming big sagebrush) Ecological Site (USDA, NRCS 2006, 035XY209UT)—Perennial grasses and shrubs each make up about 45 percent of the reference state for this site. Dominant grasses are galleta and Indian ricegrass (each 10 – 15 percent). Other grasses found in this community are bottlebrush squirreltail, needleandthread, blue grama, purple threeawn, sand dropseed, and western wheatgrass. This mix of grasses is capable of utilizing both the available cool season and warm season moisture. The dominant shrub is Wyoming big sagebrush (15 – 20 percent) which is adapted to dry conditions but requires more annual moisture than does shadscale, thus serving as an indicator of the semidesert nature of this site. Shadscale is salt tolerant but Wyoming big sagebrush is not. The presence of sagebrush indicates that the soil of the Semidesert Loam site is free of salt, an additional important difference between it and the Desert Loam site. Other shrubs found on the site are winterfat (5 – 10 percent) and lesser amounts of fourwing saltbush, yellow rabbitbrush, Nevada and green Mormonteas, and broom snakeweed. Many forbs occur on the site but individual species make up small percentages of the plant composition. Mean annual production of the Semidesert Loam (Wyoming big sagebrush) plant community is 650 – 700 pounds per acre.

3. Upland Loam (mountain big sagebrush) Ecological Site (USDA, NRCS 2006, 035XY308UT)—Mean annual production of this site is 850 – 950 pounds per acre. Perennial grasses make up 45 percent of the reference state composition and shrubs make up 50 percent. Dominant grasses are needleandthread (5 – 10 percent, Indian ricegrass (5 – 10 percent) and blue grama (5 – 10 percent). Needleandthread and Indian ricegrass are cool season plants and blue grama relies on warm season precipitation. Additional cool season grasses found in lesser amounts on the site

[1] Percentages representing composition of plants in the reference state are based on the proportional annual production (air dry weight) represented by the plant type or species.

are muttongrass, bottlebrush squirreltail, western wheatgrass, sixweeks fescue, Sandburg bluegrass, and prairie junegrass. Galleta, purple threeawn, and sand dropseed utilize warm season moisture. The dominant shrub is mountain big sagebrush (25 - 35 percent) which indicates a site receiving more annual average precipitation than does Wyoming big sagebrush. Other shrubs found on the site are antelope bitterbrush, Gambel's oak, Utah serviceberry, mountain snowberry, green Mormontea, winterfat, fourwing saltbush, rubber rabbitbrush, yellow rabbitbrush, and broom snakeweed. The first four of these indicate higher precipitation than is found on the Semidesert Loam (Wyoming big sagebrush) site. This site also supports a diverse mix of forbs, which in total make up about 5 percent of the reference state plant composition.

4. Loamy Bottom (basin big sagebrush) Ecological Site (USDA, NRCS 2006, 035XY011UT)—This site occurs at the same elevations as the Desert Loam (shadscale), Semidesert Loam (Wyoming big sagebrush), and Upland Loam (mountain big sagebrush) sites (4000 to 7500 feet). Mean annual precipitation, which drives vegetative composition and production on the other three sites, is supplemented by periodic flooding at all elevations so that this site is the most productive, with average annual production ranging from 1500 to 1700 pounds per acre. The reference state for this site is made up of approximately 55 percent grasses, 40 percent shrubs, and five percent forbs. Basin big sagebrush is the dominant shrub on this site. Rubber rabbitbrush (5 – 10 percent) and greasewood (minor amount) are also present on this site. Basin wildrye and the other grasses present in the reference state (Indian ricegrass, Nevada bluegrass, mutton grass, western wheatgrass, and needleandthread) all rely on cool season moisture. This is not surprising because the most predictable season for flooding occurs during the spring from snow melt.

The vegetation described above for the four ecological sites are the ones considered to be most in balance with the long term environmental factors of the sites and represent the reference states. Note, however, that sites that include a mixture of plants that respond to either cool or warm season precipitation may appear markedly different in a year with a dry spring and a wet summer (the herbaceous vegetation will be dominated by warm season plants) versus a year with opposite conditions (cool season herbaceous plants will be more dominant). The more years that a particular precipitation pattern continues, the more pronounced the shift between cool and warm season plants may be. Those species that have become less dominant due to an unfavorable climate pattern will normally remain in the community and my subsequently increase in dominance when the climate again shifts toward their growth requirements.

State and Transition Models

A state-and-transition model is an important part of an ecological site description. Each model depicts the different plant associations that can occur on an ecological site and provides a method to organize and communicate complex ecological information about vegetation response to disturbances (e.g., grazing, fire, lack of fire, invasive species, unusually wet or dry periods, insects, and disease) and management. We use Figure 1 from BLM Technical Reference 1734–7 as an example to explain the model components (USDI, BLM, 2001, page 20). This will be followed by a state and transition model for the Upland Loam (mountain big sagebrush) ecological site representing conditions found in the GSENM.

In Figure 1, states (large boxes bounded by solid, dark lines) are descriptions of one or more plant communities (small boxes with solid, light lines) that are collectively relatively stable and resistant to disturbances up to a threshold point (represented by the boundary of the large boxes). Changes within a state, referred to as community pathways (illustrated by dashed arrows within a state), are naturally occurring and predictable responses of the plant communities to the natural range of variability in environmental characteristics (such as drought or wet conditions) and disturbances (such as occurrence of fire) associated with the site. A state and transition model includes the reference state as a starting point for interpreting the ecological dynamics of a site (USDI, BLM 2005, page 15).

A transition (USDI, BLM 2001, page 21) is the trajectory of a change between states and is illustrated by a line leading from one state to another (*i.e.*, from State A to State B). Two por-

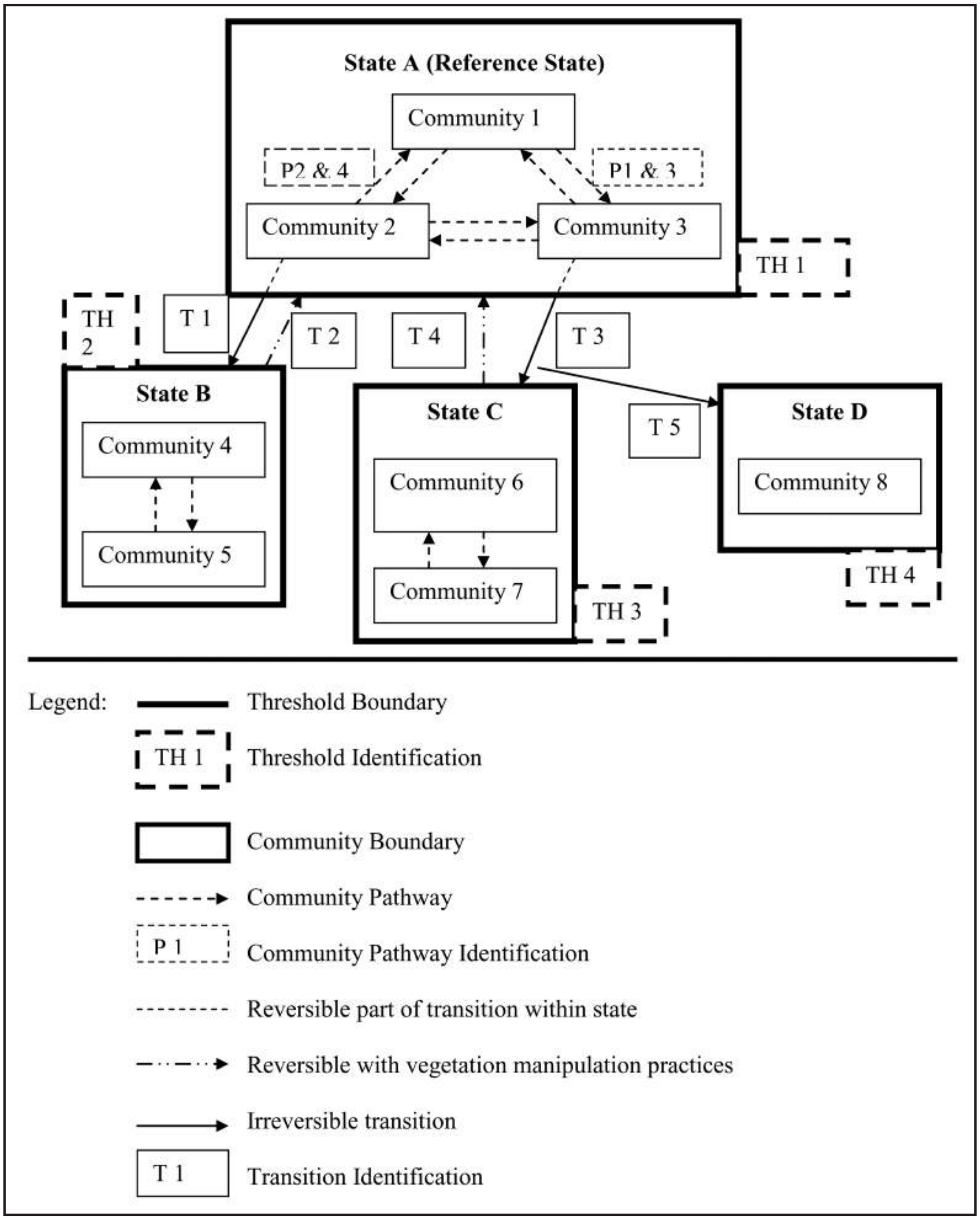

Figure 1. Generalized State and Transition Model Diagram for an Ecological Site (produced with modification from BLM Technical Reference 1734-7; USDI, BLM, 2001, page 20).

tions of a transition are recognized, reversible and irreversible, illustrated by the dashed and solid portions of the transition arrows respectively. Prior to crossing a threshold, a transition is reversible and represents an opportunity for management intervention (such as improved grazing) to reverse or arrest the change. Once a threshold is crossed, the transition is not reversible without significant inputs of management resources and energy (*i.e.* brush control and reseeding).

The discussion of a transition in the state and transition model describes the environmental or management factors that drive the change between two states including differences in vegetation (the loss of an important structural-functional group such as cool season grasses), soil properties (loss of top soil by erosion), and/or hydrologic processes (increased runoff). Transitions can be triggered by natural events, management actions, or both. Some transitions may occur very quickly and others may take a long period of time. A new stable state is formed when the system reestablishes equilibrium with the environmental and human factors acting on the site.

Understanding the ecological processes and characteristics that are associated with the transition from one state to another, particularly from a state considered to be of higher ecological or human value to a state of lower value, is one of the greatest challenges faced by resource managers and is necessary to better assess risks associated with undesirable change, targeting of high priority areas for intensive management, and planning appropriate management actions.

State and Transition Model for the Upland Loam (mountain big sagebrush) ecological site

Figure 2 represents a draft state and transition model for the Upland Loam (mountain big sagebrush) ecological site found in the GSENM. This model represents our current knowledge of the ecological dynamics of this site. As with other information contained in ecological site descriptions, state and transition models will change as additional information becomes available.

The current description of the reference state (State A) for the Upland Loam (mountain big sagebrush) site consists of three recognizable communities and the pathways of change that occur among them: (1) a mountain big sagebrush and cool and warm season grass dominated community following long periods without fire (pathway P3); (2) a cool and warm season grass dominated community following a fire or other disturbance that kills the sagebrush (pathway P1); and (3) a cool and warm season grass and mountain big sagebrush community that evolves over time as sagebrush reestablishes following fire (pathway P2). As indicated above, there are several other shrub, grass, and forb plants that will be found in the reference state, but they will occur in lesser amounts than these dominant species. The vegetation described above for the three communities are the ones considered to be most in balance with the long term environmental factors and natural disturbances associated with the Upland Loam (mountain big sagebrush) site and represent the current understanding of the reference state.

Transitions have occurred from the reference to other states on the Upland Loam (mountain big sagebrush) site due to human disturbances. Important human disturbances that have driven these changes include livestock grazing, change in wildlife populations, change in fire frequency and intensity, and introductions of exotic plant and animal species.

States where Utah Juniper and Pinyon Pine do not occur

A second state (State B) that can be described for the Upland Loam (mountain big sagebrush) site is one where long-term, light to moderate, continuous spring livestock grazing has reduced the competitive ability of the cool season grass plants and shifted the plant composition from the mixed cool and warm season grass asseblage to communities dominated by warm season plants, without sagebrush if the state has experienced recent fire (Community 4) or with sagebrush if no fire has occurred (Community 5). These two communities will change over time in response to the periodic occurrence of fire (Pathways P4 represents occurrence of fire and P5 the exclusion of fire).

The change from State A to State B involves crossing Threshold TH1 (shown as a solid arrow connecting the state boundaries), and may be caused by past spring grazing that converted the site from a mixed warm and cool season grass community to one where cool season grasses have been greatly reduced and warm season grasses are dominant. The loss of cool season grasses also represents a loss of fine fuels and the occurrence of fire is reduced. State B is enclosed in Threshold TH2 and is a new stable state. Once conditions associated with State B have reached equilibrium, this state will be resistant to change. Elimination of grazing or a change in grazing alone will not move State B back to A. Crossing the threshold from State B to A (dashed line showing Transition T2) will require significant management action (such as a change in grazing, brush control, and/or seeding) to restore the mix of warm and cool season grasses.

When cheatgrass is present, it is very unlikely that the State B (or any of the other States) can be restored to the reference state because elimination of cheatgrass from a site is seldom possible. Un-

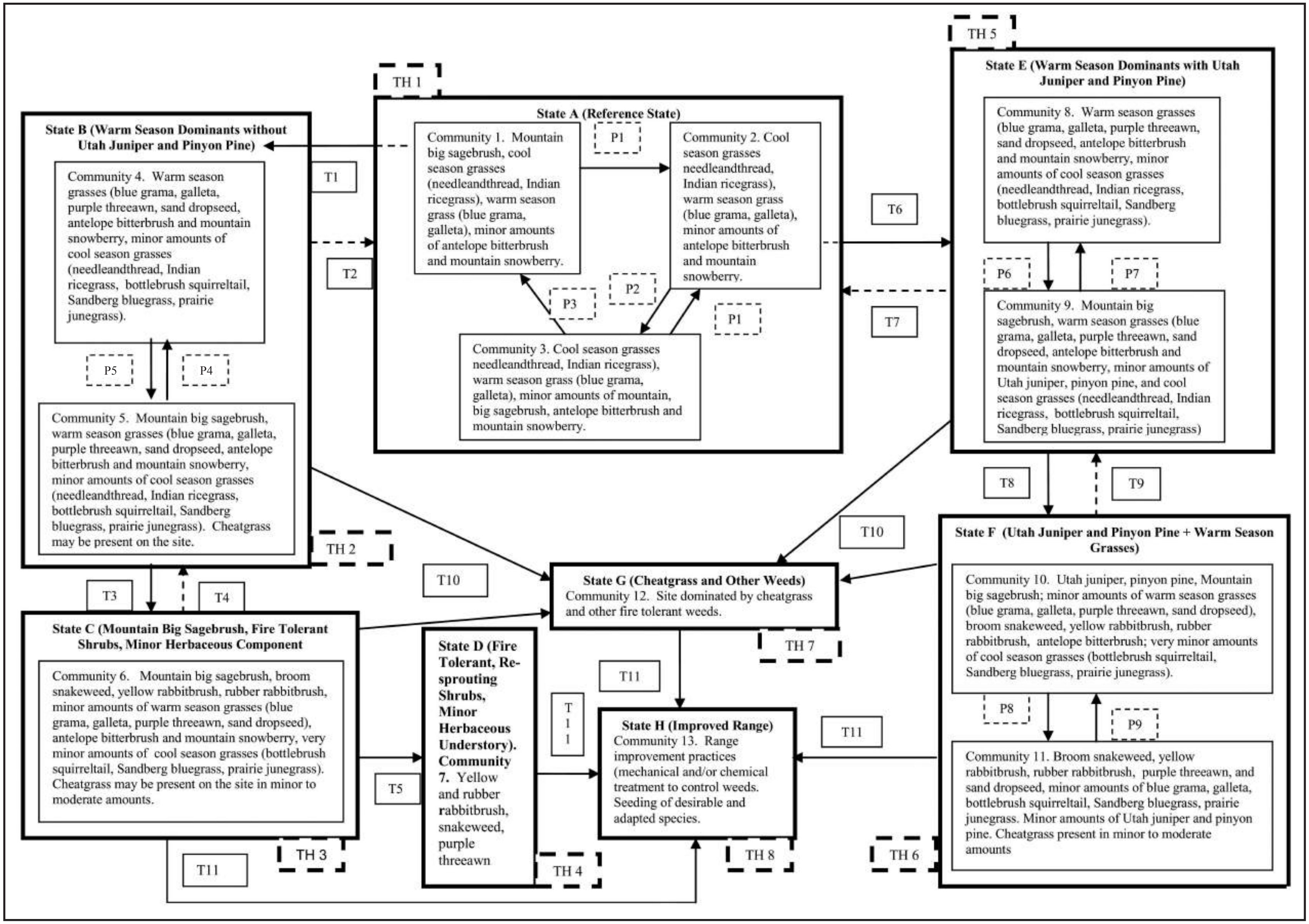

Figure 2. State and Transition Model – Vegetation Dynamics Model – Upland Loam (Mountain Big Sagebrush) Ecological Site—035XY308UT, MLRA 35 (legend shown on Figure 1).

fortunately, State B with cheatgrass is very common in the GSENM.

Long term heavy, continuous grazing in late spring and summer and the lack of fire (Transition T3) will result in both the cool and warm season grasses being reduced or eliminated from the site with mountain big sagebrush becoming dominant. This situation is illustrated in the state and transition model as Community 6 in State C. State C is a steady state that is not likely to be restored to State B without intensive management (Transition T4 represented by the dashed line). If significant amounts of cheatgrass are present in State C, the likelihood of reestablishing conditions of States B or A is very low.

States where Utah Juniper and Pinyon Pine occur

Because of the proximity of Upland Loam (mountain big sagebrush) sites to different sites where Utah juniper and pinyon pine occur[2], invasion of these trees on the Upland Loam (mountain big sagebrush) site is common, with the likelihood of invasion increasing the longer the site is protected from a fire that kills the trees. Tree invasion is illustrated as Community 9 in State E (Transition T6 crossing Threshold TH1). This community is dominated by warm season grasses because of past long-term, moderate to heavy spring grazing. Community 8 in State E is present if a fire occurs every 25 – 30 years (Pathway P7), killing the mountain big sagebrush, Utah juniper, and pinyon pine. The tree species and mountain big sagebrush will reestablish following fire (Pathway P6) and Community 9 will be present. Like State B, the cool season grasses cannot be restored without intensive management.

If Utah juniper and pinyon pine are few in number, young, and scattered, the Upland Loam (mountain big sagebrush) site can be returned (Transition T7) to the Community 2 (warm and cool season grass dominated) of the reference state with a change in grazing management, brush control, and/or reseeding of cool season grasses. If trees have become well established on the site and have produced seed for several years, this change is unlikely because the trees have probably become a permanent part of the site. Transition T7 is difficult and is shown in the state and transition model using a dashed line to emphasize the requirement of intensive management to accomplish this change.

If fire does not occur to sustain the communities associated with State E, then this site is likely to evolve into a Utah juniper and pinyon pine dominated woodland, illustrated by State F (Transition T8). This is particularly true if State E is subjected to long term, continuous spring and/or heavy summer grazing. There are two communities associated with State F: (1) Community 10, Utah juniper, pinyon pine, and mountain big sagebrush dominated community that develops with grazing as described above and long protection from fire (pathway P9) and (2) Community 11, broom snakeweek, yellow rabbitbrush, and other fire tolerant plants that develop following fire (Pathway P8). Unless other factors prevent it (such as fires recurring every 10 to 20 years), Community Pathway P9 will lead to the Utah juniper and pinyon pine becoming reestablished.

The process of Utah juniper and pinyon pine invasion is accelerated if the sagebrush – grass communities found in the reference state have been weakened by grazing, but the competitive nature of these trees when they are released from fire may lead to Community 10 in State F with or without grazing. If fire does not occur for upwards of 50 – 100 years, as is the case for many areas of the GSENM, then Utah juniper and pinyon pine may increase to such an extent that the amount of bare ground has increased and accelerated erosion has occurred, resulting in a change in the ability of the soil to support the mountain big sagebrush and grasses found in the reference state. This community may be "fire safe" if the understory plants and tree crowns are not capable of carrying a fire. Fire safe Utah juniper and pinyon pine communities represent stable communities that can exist for long periods of time.

States where fire tolerant shrubs, annual weeds, or reseeded areas occur

If the communities in States C or F, where the warm and cool season grasses have been reduced or eliminated, are burned every 3 - 10 years, thus

[2] Sites with Utah juniper and pinyon pine as part of the reference state have shallower or more rocky soils, are steeper, and historically have experienced fewer fires than the Upland Loam (mountain big sagebrush site).

killing Utah juniper, pinyon pine, and mountain big sagebrush, then State D, one that is dominated by resprouting, fire tolerant shrubs (Community 7) and/or cheatgrass (Community 12 in State G) may develop. The plant communities associated with both of these states are very competitive and will tend to prevent native grasses, shrubs, and forbs from becoming reestablished.

Community 13 in State H represents the intensive rangeland improvement activities that must be carried out to restore more desirable conditions to States C and F when the departure from the reference state is significant (loss of reference state dominant plant species, high rates of runoff and erosion, and invasion by plants not expected on the site). The treatments associated with State H are almost always needed to achieve any degree of improvement in States D and G. Treatments will include plowing or chemical control of undesirable plants, seeding of desirable plant species, and rest from grazing.

Rangeland Health

Rangeland health is a concept that was developed in the mid-1990s in response to ongoing disagreements within the rangeland management profession about how to evaluate rangeland resources (National Resources Council 1994 and USDI, BLM 2005). Rangeland health has been defined as the degree to which the integrity of the soil, vegetation, water, and air, as well as the ecological processes of the rangeland ecosystem are balanced and sustained. Integrity is defined as the maintenance of the functional attributes characteristic of a locale, including normal variability.

Rangeland Health Indicators

Rangeland health assessment is a qualitative method that considers the status of 17 soil, watershed, and plant indicators (USDI, BLM 2005). The state that best represents the balanced and sustained condition of an ecological site is used as the reference state and a reference description is developed for each of the 17 indicators. These descriptions are compiled in the rangeland health reference sheet. Once developed, reference descriptions become part of the ecological site description.

The 17 indicators are discussed in Table 1. These have several important characteristics.

1. In total, the 17 indicators consider many of the important characteristics of rangeland that are related to ecological integrity and management. It is this multiple characteristic approach to assessment that makes rangeland health a useful assessment tool.

2. None of the indicators are new to rangeland managers and scientists. All have been used from time to time to evaluate rangeland conditions. What is new is the organization of the indicators into a system so the rangeland health assessment can collectively ask many important questions about the structure and function of an ecological site.

3. Overlap in the questions asked by the indicators often helps those using qualitative indicators reach similar conclusions. For instance, it is sometimes difficult to differentiate between rills (indicator 1) and water flow patterns (indicator 2). One person conducting a rangeland health assessment on an ecological site may record more rills than would be expected for the site but fewer water flow patterns, while another person may report the opposite. When this information is interpreted, both individuals report that there is evidence of more water movement than expected for the site raising concern about the hydrologic function of the area.

4. There is redundancy built into the indicators so that the same or similar questions about rangeland health are asked in different ways. For example, bare ground (indicator 4), litter movement (indicator 7), and plant community composition and distribution related to infiltration and runoff (indicator 10) are all indicators that help determine whether an evaluation area is more susceptible to loss of soil and site stability (from runoff and soil erosion) than would be indicated by the reference conditions.

5. The assessment of rangeland health is based more on whether the ratings of the redundant indicators agree than on the rating of individual indicators. For instance, if soil cover as indicated by bare ground (indicator 4), plant composition and spatial distribution (indicator 10), and litter amount (indicator 14), suggest that there is not sufficient cover or arrangement of plants on the landscape to reduce runoff and erosion, then

Indicator	Soil and Site Stability	Hydrologic Function	Biotic Integrity
1. Rills are small erosional rivulets that are generally linear.	Yes	Yes	No
2. Water flow patterns are the naturally occurring paths that water takes as it moves across the soil surface during periods when surface water exceeds infiltration rates.	Yes	Yes	No
3. Pedestals and terracettes. Pedestals may indicate the movement by soil or wind from the base of plants or rocks, or may be the results of frost heaving. Terracettes are points of soil deposition caused by water movement (but not by wind) or by animals moving around a hill slope.	Yes	Yes	No
4. Bare ground is exposed mineral or organic soil.	Yes	Yes	No
5. Gullies are well defined channels that have been cut into the soil by moving water.	Yes	Yes	No
6. Wind-scoured, blowout, and/or depositional areas indicate occurrence of wind erosion on a site.	Yes	No	No
7. Litter movement (litter being dead plant material that is in contact with the soil surface) by wind or water.	Yes	No	No
8. Soil surface resistance to erosion is an indicator of the organic matter (roots, decomposed litter, biological crusts) contained in the soil surface and its effectiveness in forming stable soil aggregates.	Yes	Yes	Yes
9. Soil surface loss or degradation is an indication of loss of site potential since the surface soil horizon represents the highest level of soil development and significant storage of organic matter.	Yes	Yes	Yes
10. Plant community composition and distribution relative to infiltration and runoff is an indicator that evaluates the plant community's ability to mitigate the effect of raindrop splash, slow runoff, and enhance infiltration.	No	Yes	No
11. Compaction layer is a change in soil structure (such as compacting soil aggregates into a block or massive structure) and not a change in soil texture, chemical content, or water content of a subsurface horizon.	Yes	Yes	Yes
12. Functional and structural groups describes the suites of species that are grouped together because of similar life form, root structure and depth, photosynthetic pathways (cool or warm season), nitrogen fixing ability, life cycle, and response to fire (sprouting or non-sprouting).	No	No	Yes
13. Plant mortality and decadence represents the proportion of dead or decadent (e.g., moribund, dying) to young or mature plants in the community.	No	No	Yes
14. Litter amount is the dead plant material that is detached from the base of the plant (as opposed to standing dead vegetation).	No	Yes	Yes
15. Annual production represents the energy captured by plants through the process of photosynthesis given current weather conditions.	No	No	Yes
16. Invasive plants are exotic or native plants that are not part of the plant community of a site that have the potential to become dominant or co-dominant on the site if their future establishment and growth on the site is not managed.	No	No	Yes
17. Reproductive capacity of perennial plants is a measure of perennial plants in the community to reproduce sexually (seed stalks and seed) or asexually (tillers, rhizomes, stolons, and root sprouts).	No	No	Yes

Table 1. Rangeland health indicators used to interpret soil stability, hydrologic function, and biotic integrity of ecological sites.

the indicators that evaluate actual soil movement (rills, indicator 1; pedestals, 3; gullies, 5; and wind scour or blowouts, 6); will help determine the seriousness of the problem.

Rangeland Health Attributes

The rangeland health rating for an ecological site describes the departure of each of the 17 indicators from the reference condition. Once each indicator has been rated as none-to-slight, slight-to-moderate, moderate, moderate-to-extreme, or extreme-to-total departure from the reference condition, the composite is used to estimate to what degree three rangeland health attributes of an ecological site are balanced and sustainable. These attributes are (USDI, BLM, 2005):

1. Soil and Site Stability—the capacity of an area to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water.

2. Hydrologic Function—the capacity of an area to capture, store, and safely release water from rainfall, run-on, and snowmelt; to resist a reduction in this capacity; and to recover this capacity when a reduction does occur.

3. Biotic Integrity—the capacity of the biotic community to support ecological processes within the normal range of variability expected for the site, to resist loss of the capacity to support these processes, and to recover this capacity when losses do occur.

The end product of a rangeland health assessment is the evaluation of these three attributes rather than of the 17 indicators.

Some of the indicators relate to only one attribute (for example, invasive species, indicator 16, only applies to biotic integrity) but most of the indicators provide information that is useful for interpreting more than one of the attributes (soil surface loss or degradation, indicator 9, is an indicator of the health of all three attributes). Table 1 indicates which indicators are used to rate the attributes with 10 attributes being used for soil and site stability, 10 for hydrologic function, and 9 for biotic integrity.

Evaluating Rangeland Health

The evaluation process requires individuals conducting the assessment to determine for each indicator the conditions found on the evaluation area and rate the actual condition with respect to the reference condition. Once all 17 indicators have been rated the results are recorded in an evaluation sheet with the rating for each indicator associated with the appropriate attributes.

Once indicator ratings have been recorded on the evaluation sheet, individuals conducting the assessment will allocate indicators to appropriate attributes and determine a rangeland health rating for each attribute. Normally, the attribute rating will be based on which rating scales have the most attributes but may be adjusted because the evaluation team weighs one or more indicators being sufficiently important to justify a shift in attribute rating.

Possibly the most useful outcome of a rangeland health assessment is when one or more of the attribute ratings tend toward "moderate" because this indicates that problems have been found but the degree of degradation has not reached a level where improvement through management is unlikely. The moderate rating should serve as an early warning that the health of the site is at risk and needs management attention. Sites that rate moderate should be given high priority for additional study and monitoring to determine if the ranking is associated with a site recovering from a more deteriorated condition (indicating that current management may be appropriate) or if the site shows signs of active deterioration (indicating that current management may need to be changed).

It is important to note that attributes may indicate different levels of departure from reference conditions. For example, a site where the biotic integrity attribute shows significant departure from reference condition may still have healthy soil and site stability and hydrologic function. This provides very important information because it informs a manager that the soil, site, and hydrologic potential remains healthy, indicating an opportunity to improve the health of the plant community. Rangeland improvement is more difficult and costly when the soil and site stability and/or hydrologic function are rated as unhealthy because these resources may be seriously degraded.

The rangeland health ratings for soil and site stability, hydrologic function, and biologic integrity are not added together to provide a site rating. The value of rangeland health is to determine if any of the attributes indicate a problem.

An Example of Rangeland Health Assessment in GSENM

For this example, rangeland health assessments were completed for three different States found on the Upland Loam (mountain big sagebrush) ecological site in the GSENM – the reference state Communities of States A; Community 5 of State B; and Community 10 of State F. Table 2 provides a rangeland health rating for each indicator for each community.

The descriptions for each indicator suggest a range of departures from the reference condition for both Community 5 and 10 illustrating that not all characteristics of a site change at the same rate or to the same degree (Table 2). In the example, Community 5 of State B was rated as slight-to-moderate departure from the reference for the soil and site stability and hydrologic function attributes but moderate for biotic integrity. Community 10 of State F rated as extreme-to-moderate for all three attributes. Reasons for the ratings and problem identification are provided in the key indicators discussion sections of Table 2. Both areas indicate problems that require additional evaluation and monitoring to document the seriousness and causes of the problems and to develop management or improvement plans to correct the problems.

The descriptions and ratings given for Community 5 in State B and Community 10 in State F are for specific locations. Different descriptions and ratings might have occurred if rangeland health assessments had been done at other locations where the Upland Loam (mountain big sagebrush) ecological site is found. For instance, at another location, more cheatgrass might have been found on Community 5 in State B changing the rating from moderate for invasive species (indicator 16) to extreme-to-moderate, and the increased presence of cheatgrass could have lowered the rating of some of the other biotic integrity indicators.

Rangeland Health Attribute	Reference Condition Upland Loam(Mountain Big Sagebrush	Rangeland Health Rating	State B, Community 5 Upland Loam(Mountain Big Sagebrush	Rangeland Health Rating	State F, Community 10 Upland Loam(Mountain Big Sagebrush	Rangeland Health Rating
1. Rills	None to few. Any rills present should be somewhat short in length (less than 6 feet long). They are somewhat widely spaced (4 to 8 feet) and follow the surface micro-features. Old rills should be weathered and muted in appearance. An increase in rill formation may be seen after disturbance events such as recent fire or thunderstorms.	None-to-slight	Few rills, usually 3-5 feet in length	Slight-to-moderate	Rills common. 5-10 feet long, connected, often leading to a gully	Extreme-to-total
2. Water flow patterns	Flow patterns are few, short, and wind around perennial plant bases following microtopography. They are stable and there is minor evidence of deposition where water accumulates.	None-to-slight	Numerous water flow patterns, most less than 10 feet in length. Wind around perennial plants and extend into interspaces. Some connected. Very few contribute to rill formation.	Moderate	Common, 10 plus feet, connected, often leading to rills or gullies. Tend to occur in interspaces rather than be associated with plant bases.	Extreme-to-total
3. Pedestals or terracettes	Plants should show little or no pedestialing. Terracettes should be absent or few, increasing with slope.	None-to-slight	A few plants at edge of water flow patterns are pedestalled. Litter accumulating in terracettes in water flow patterns.	Slight –to-Moderate	Pedestals common around base of grasses. Roots often exposed.	Moderate-to-extreme
4. Bare ground	25 – 35%.	None-to-slight	30 – 35 %	Slight-to-Moderate	35-40 %. Most cover provided by trees.	Moderate
5. Gullies	None to few. Any gullies present should show little sign of erosion and should be stabilized with vegetation.	None-to-slight	None	None-to-slight	Occur where water has been channeled around trees. 3-4 feet deep.	Moderate-to-extreme
6. wind scoured, blowouts and/or depositional areas	Minor evidence of wind generated soil movement. Wind caused blowouts and deposition are not present.	None-to-slight	No evidence of wind scour, blowouts, or deposition of wind blown material,	None-to-slight	Evidence of wind movement of soils around base of trees in large open areas. No blowouts.	Moderate
7. Amount of litter movement	Most litter resides in place with some redistribution caused by water movement. Minor litter removal may occur in water flow channels with deposition occurring at points of obstruction.	None-to-slight	Fine litter accumulating under shrubs and around grasses. Fine litter moved interspaces.	Slight-to-Moderate	Leaves and small branches accumulate under trees. Very little litter in interspaces between trees.	Moderate-to-extreme
8. Soil surface (top few mm) resistance to erosion	80 to 90% of this site should have a soil surface resistance to erosion rating of 5 to 6 using the soil stability kit test. 10 to 20% may have a rating of 3 to 5. The average should be a 5.	None-to-slight	Soil test indicates a rating of 4 in interspaces and 5 under shrubs.	Slight-to-moderate	Soil test indicates a rating of 3 in interspaces and 4 under trees.	Moderate

Table 2. Comparison of rangeland health assessment for three communities found on Upland Loam (Mountain Big Sagebrush) Ecological Site, Grand Staircase Escalante National Monument.

9. Soil surface structure and organic matter content	Soil surface varies from 2 to 3 inches. Structure is granular to thin platy. Color is reddish brown to brown. Little difference in color of soil under vegetation. Soil organic material will be greater under shrubs and around base of grasses (as compared to interspaces) but soil has A-horizon present with some accumulation of organic matter in interspaces.	None-to-slight	Surface soil intact. Soil organic matter is high under shrubs and around grasses. Organic matter less in interspaces. Some A-horizon has been lost, particularly associated with rills.	Slight-to-Moderate	Soil organic matter high under trees but very little organic matter in interspaces. Much of soil A-horizon has been lost in interspaces, particularly associated with rills and gullies.	Moderate-to-extreme
10. Effect of plant community composition and spatial distribution on infiltration & runoff	Plants occur in sufficient cover and spatial arrangement to intercept raindrops and prevent raindrop splash erosion. Litter on soil surface and condition of soil surface also protect soil from splash erosion and encourage a high rate of infiltration. Plant spatial distribution will slow runoff allowing additional time for infiltration.	None-to-slight	Cover has been reduced so that less soil is protected from raindrop splash. Plants are arranged so that runoff occurs around shrub canopies and around clumps of grass.	Moderate	Few plants in large interspaces to intercept raindrops. Tree canopy and build up of organic matter under trees directs water into interspaces where few plants are present to slow runoff and erosion.	Moderate-to-extreme
11. Compaction layer	None. Some soils have an increase in clay content at 3 to 9 inches that could be mistaken for a compaction layer.	None-to-slight	None	None-to-slight	None	None-to-slight
12. Structural and functional plant groups	Assumed fire cycle of 30-60 years. Non-sprouting shrubs > Warm season perennial grasses = Cool season perennial grasses > rhizomatous grasses = sprouting shrubs > forbs > annuals. The perennial grass/non-sprouting shrub functional groups are expected on this site. Dominants: Mountain big sagebrush, blue grama, needleandthread, Indian ricegrass; Sub-dominants: Galleta, rabbitbrush, muttongrass, bottlebrush squirreltail Other: Antelope bitterbrush, Gambel's oak	None-to-slight	Non-sprouting shrubs>sprouting shrubs>>warm season grasses>>cool season grasses. Dominants = mountain big sagebrush Sub-dominants = yellow rabbitbrush, blue grama, galleta, purple threeawn, broom snakeweed Others = bottlebrush squirreltail, Sandburg bluegrass	Moderate	Trees>>shrubs>warm season grasses>greater than cool season grasses. Dominants = Utah juniper and pinyon pine. Subdominants = mountain big sagebrush, blue grama Others = Broom snakeweed, cheatgrass	Moderate-to-extreme
13. plant mortality and decadence	All age classes of perennial grasses should be present. Slight decadence in the principle shrubs could occur near the end of the fire cycle. Blue grama and galleta may show signs of dead or decadent centers.	None-to-slight	Some mountain big sagebrush shows decadence. Most plants appear healthy.	Slight-to-moderate	Some dead mountain big sagebrush and warm season grass plants. Numerous sagebrush plants are decadent with only one or two stems per plant showing growth.	Moderate-to-extreme

Table 2. Continued

14. Average percent litter cover and depth	Cover = 2-15 % Depth = .3 -.50 inch	None-to-slight	100 % cover under shrubs, .5-1inch deep. 10% in areas around base of grass plants. <5 % cover in interspaces with no measurable depth	Moderate	100 % litter cover under trees, 2-3 inches thick. <5% litter in interspaces between trees with no measurable depth.	Moderate-to-extreme
15. Expected annual production	850 - 950 #/acre on an average year	None-to-slight	550 – 600 pounds per acre with most production by mountain big sagebrush	Moderate	700 – 750 pounds per acre with 80 % of production by trees.	Moderate-to Extreme
16. Invasive species	Utah juniper, pinyon pine, cheatgrass, broom snakeweed, green rabbitbrush, annual forbs.	None-to-slight	Cheatgrass occurs throughout the area but does not dominate any of the site	Moderate	Utah juniper, pinyon pine, cheatgrass, broom snakeweed, green rabbitbrush.	Moderate-to-extreme
17. Perennial plant reproductive capability	All perennial plants should have the ability to reproduce in all years, except in extreme drought years. Green rabbitbrush sprouts vigorously following fire.	None-to-slight	All plants are capable of producing seed or to reproduce vegetatively	None-to-slight	Utah juniper and pinyon pine produce seed. Remaining warm season and cool season grasses produce few seed..	Moderate-to-extreme

Table 2. Continued

Collectively, these lower ratings of indicators may have resulted in the biotic integrity attribute being lowered from moderate to moderate-to-extreme. If at a different location of Community 10 in State F we had found younger Utah Juniper and pinyon pine trees that did not dominate the site, as in our example, several of the indicators may have been rated as less departure from the reference and the rating for the attributes might have been higher. For these reasons, a rangeland health assessment that has been done on one of the states and communities cannot be broadly applied to define the health of that state and community across the landscape.

Rangeland health ratings for these three situations in the GSENM are summarized for soil and site stability, hydrologic function, and biotic integrity in Figure 3a-c. In these summary charts, each indicator is recorded in the table for the attribute it represents and the rating it received. For example, in summarizing information for soil and site stability (Figure 3a) for Community 5, State B, Indicator 7 (Litter Movement) is recorded as being slight-to-moderate. Once the ratings have been recorded in these summary charts one can interpret the preponderance of evidence indicating a rangeland health rating for the attribute.

During a rangeland health assessment some indicators may be judged as being more important than others. The "key indicators" found for each of the attributes are identified in the "attribute rating justification" boxes included in Figure 3a-c. In the example, structural functional groups (indicator 12), litter cover/depth (14), annual production mostly from sagebrush and warm season grasses (15), and invasive plants (16) were all considered to be key indicators for biotic integrity for Community 5 in State B, that resulted in a moderate instead of a moderate to slight rating.

Summary and Management Implications

The ecological site description, state and transition model, and the rangeland health reference sheet described in this paper provide significant information about the Upland Loam (mountain big sagebrush) ecological site that can be used for inventory, planning, management, and monitoring. The site description provides information

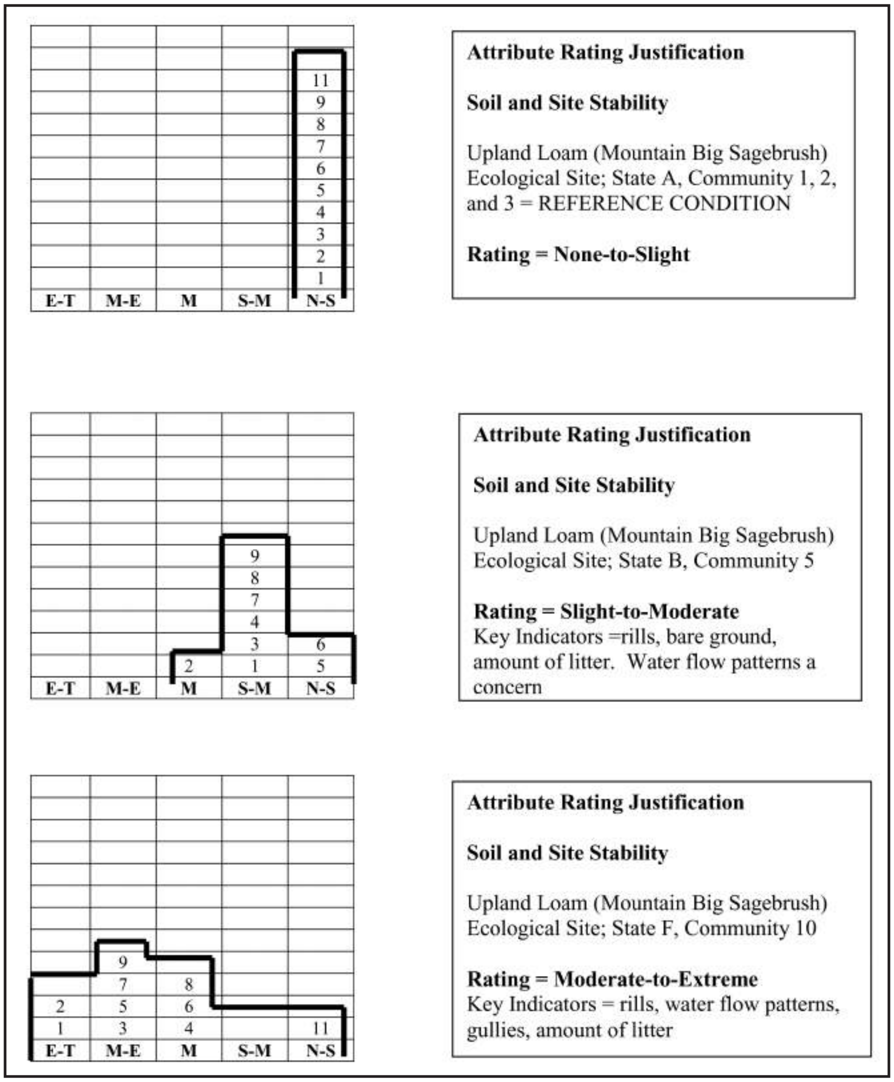

Figure 3a. Comparison of rangeland health rating for soil and site stability of three states and communities in the Upland Loam (mountain big sagebrush) ecological site.

about this unique site that separates it from other sites that may be included in a management area. Such information is necessary to interpret how this site may respond to management actions when compared to other sites in the area. It also reduces problems that may arise when one tries to assess how management may be affecting a large area that includes many sites with different soils, topography, climate, and expected plant community composition, production, and disturbance regimes. Using soil survey and other information to map the ecological sites that occur on a management area so that inventory or monitoring information can be associated with individual sites should be the first step in developing a management plan for an area of rangeland.

A state and transition model should be an important part of a site description because the model describes the different plant states and communities that have been found on a site, the ecological relationships that exist between the states and communities, the ecological and management factors associated with each state and community (including transitions and thresholds that affect management options), and the processes that cause communities to change. Currently the state, community, transition, and threshold descriptions focus on the plant community but soil, hydrology, and other information associated with a state or community are being added to the models. Knowing which states and communities are possible on a site allows a manager to set realistic objectives for the desired species composition and production.

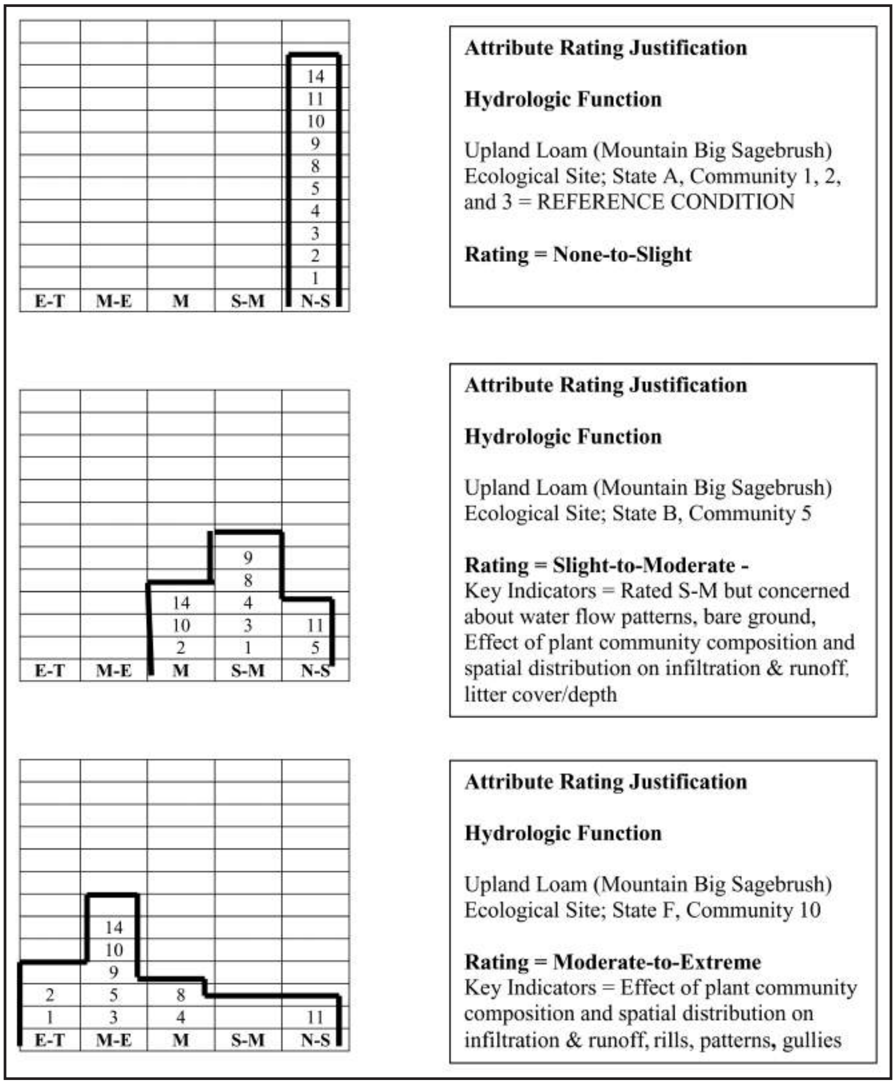

Figure 3b. Comparison of rangeland health rating for hydrologic function of three states and communities in the Upland Loam (mountain big sagebrush) ecological site.

Understanding the processes of change allows the manager to determine when current management is sustaining the site in the desired condition or when it is causing desired or undesired change. The state and transition model also provides information about changes that once initiated, are likely to continue until a new steady state is reached or management actions designed to stop or redirect the change are initiated.

From the example given in this paper, the state and transition model for the Upland Loam (mountain big sagebrush) site informs the manager that a mix of productive, cool and warm season grass plants, as well as many other species can occur on the site. Such a mix is, therefore, a possible goal. The model also informs the manager that spring and summer livestock grazing and prevention of naturally occurring fires, dominant human activities associated with use of the area since European settlement, have shifted the vegetation toward species mixes in which the cool season grasses are often minor components and other species such as Utah juniper, pinyon pine, and cheatgrass have invaded.

Field inventory, including information collected as part of the rangeland health assessment, allows the manager to determine the state and community being managed and the ecological process and disturbances (natural and human caused) that have led to the current state and community. The state and transition model also informs the manager about problems that may be encountered in achieving this goal (such as transitions that have crossed thresholds which indicate significant

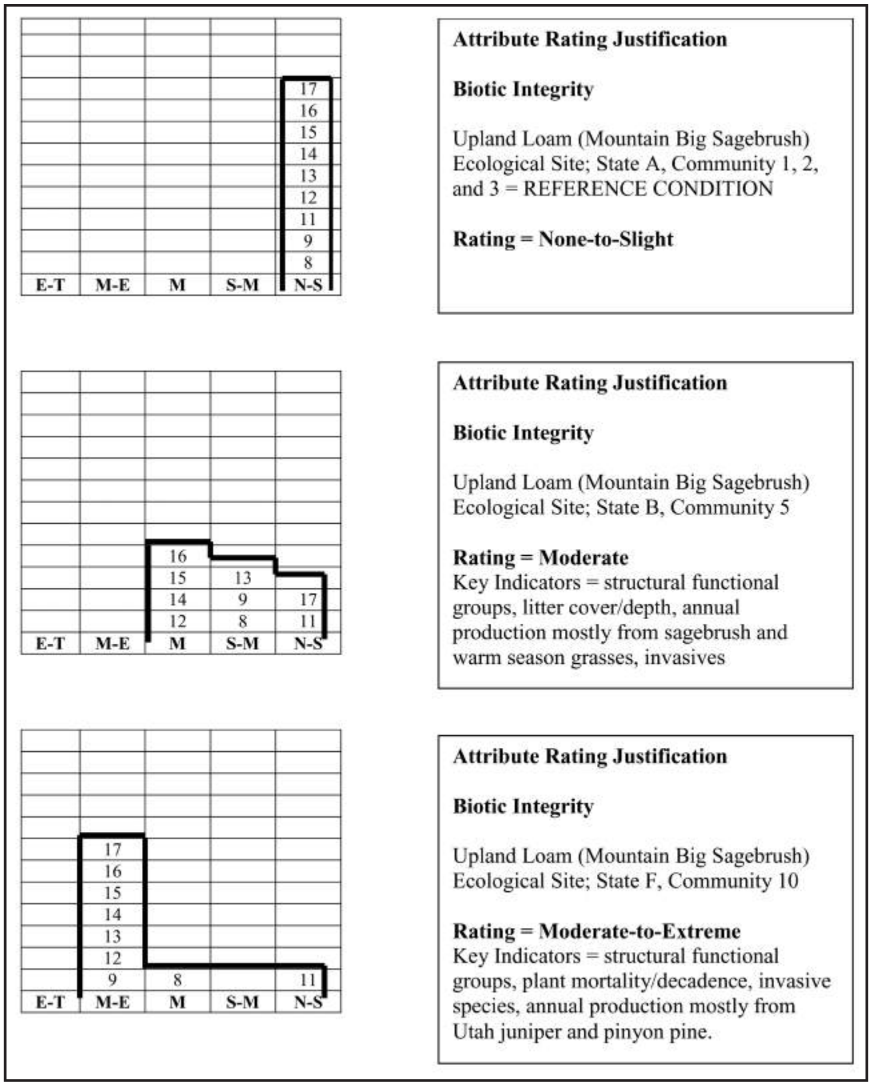

Figure 3c. Comparison of rangeland health rating for biotic integrity of three states and communities in the Upland Loam (mountain big sagebrush) ecological site.

changes in plant composition, change in fire occurrence, and invasion of exotic plants), leading the manager to understand that a mix of warm and cool season grasses may not be a realistic goal given the resources available for management. The information included in the description of transitions informs the manager of some of the management actions that may be needed to improve rangeland condition and productivity.

Rangeland health assessment identifies areas that are functioning at a level that can sustain productivity and use, areas that are at risk of changing in ways that threaten stability but that retain the potential for improvement, and areas that have reached such a level of deterioration that improvement will be difficult and costly. Such information can help the manager set priorities for treatments that will achieve the greatest benefit for investment, and to set priorities for intensive monitoring to determine if management changes are needed.

Because rangeland health is a qualitative method of evaluating rangeland condition, it cannot be used for monitoring. In the example given in this paper, it would be inappropriate to conduct rangeland health assessment on State B, Community 5 at two different time periods and conclude that the trend for biological integrity was down because the second assessment indicated a moderate departure from the reference as compared to the slight-to-moderate rating for the first assessment. These different ratings may represent deterioration in the site or represent differences in how those doing the rating viewed departure from the reference conditions. Both of the ratings indicate, however, potentially important deviation from the reference conditions and suggest that the site receive additional evaluation.

While rangeland health ratings should not be compared over time for trend monitoring, rangeland health data collected using quantitative methods can be used. For example, if the same quantitative methods have been used to gather information for indicators 4 (bare ground), 8 (soil surface resistance to erosion), 10 (plant community composition and spatial distribution related to runoff and erosion), 12 (functional and structural plant groups), 14 (litter cover and depth), 15 (annual production), and 16 (invasive species) then comparison of quantitative data over two or more time periods can be used to monitor trend. If quantitative data had been gathered during the first rangeland health assessment in the example (when the biotic integrity rating was slight-to-moderate), then data using the same method from the second assessment could be used to determine if the change to moderate was an accurate representation of change in the plant community.

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Broad-scale Assessment of Rangeland Health, Grand Staircase-Escalante National Monument, USA

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ABSTRACT

Over a 3-yr period, the qualitative assessment protocol ''Interpreting Indicators of Rangeland Health'' was used to evaluate the status of three ecosystem attributes (soil/site stability, hydrologic function, and biotic integrity) at over 500 locations in and adjacent to Grand Staircase–Escalante National Monument (Utah). Objectives were to provide data and interpretations to support the development of site-specific management strategies and to investigate broad-scale patterns in the status of different rangeland ecological sites. Quantitative data on ground cover, plant community composition, and soil stability were collected to aid the evaluation of qualitative attributes and improve consistency of the assessment process. Ecological sites with potential vegetation dominated by varieties of big sagebrush (*Artemisia tridentata* Nuttall) had the highest frequencies (46.7%–75.0%) of assessments with low ratings (moderate or greater departure from expected reference conditions) for all three ecosystem attributes. In contrast, sites with potential vegetation characterized by Utah juniper (*Juniperus osteosperma* [Torrey] Little) and/or Colorado pinyon (*Pinus edulis* Engelmann) had low frequencies (0.0%–7.8%) of assessments with low ratings for all attributes. Several interacting factors likely contributed to the development of patterns among ecological sites, including 1) potential primary production and thus long-term exposure to production-oriented land uses such as livestock grazing; 2) the presence of unpalatable woody plants capable of increasing and becoming persistent site dominants due to selective herbivory, absence of fire, or succession; 3) soil texture through effects on hydrologic responses to livestock grazing, trampling, and other disturbances; and 4) past management that resulted in high livestock use of ecological sites with sensitive fine-loamy soils following treatments designed to increase forage availability. This case study illustrates an extensive application of an assessment technique that is receiving increasing use worldwide, and results contribute to an understanding of factors contributing to patterns and processes of rangeland degradation.

RESUMEN

Durante un período de tres años, se siguió el protocolo *de interpretación de Indicadores de Salud de Pastizales*, para evaluar el estado de tres atributos del ecosistema (Suelo /Estabilidad del Sitio, función hidrológica e integridad biótica) en mas de 500 áreas del Grand Staircase–Escalante National Monument (en Utah USA) y en áreas adyacentes. Con los objetivos de proporcionar datos e interpretaciones que apoyen el desarrollo de estrategias de manejo a sitios específicos, y para investigar los patrones a gran escala del estado de diferentes sitios ecológicos de pastizal. Se recolectaron datos cuantitativos sobre cobertura de suelo, composición vegetal de la comunidad, y estabilidad del suelo para ayudar a la evaluación de los atributos cualitativos y para mejorar la consistencia en el proceso de evaluación. Sitios ecológicos con la vegetación potencial dominada por el arbusto (*Artemisia tridente* Nuttall) tuvieron las mayores frecuencias con los índices de evaluacio´n mas bajos (46.7%–75%) con una diferencia moderada a grande en relación a la esperada con las áreas de referencia, para los tres atributos del ecosistema. En contraste, sitios con vegetación potencial caracterizados por el táscate (*Juniperus osteosperma* [Torrey] Little) y/o el Piñón colorado (Pinus edulis Engelmann) presentaron bajas frecuencias (0.0%–7.8%) de evaluación con bajos índices para todos los atributos del ecosistema. La interacción de algunos factores probablemente contribuyó al desarrollo de patrones entre los sitios ecológicos, incluyendo 1) producción potencial primaria y por lo tanto largo tiempo que estas áreas estuvieron expuestas a la producción orientada del ganado en pastoreo; 2) la presencia de plantas leñ osa de baja palatabilidad capaces de incrementar su población, llegando a ser dominantes y permanentes del sitio, debido al pastoreo selectivo, ausencia de fuego, o sucesión; 3) las textura del suelo y su efecto sobre respuesta hidrológica al pastoreo, pisoteo y otros disturbios; y 4) Historial de manejo, que da como resultado un alto grado de uso por el ganado en sitios ecológicos con suelos susceptibles de textura fina, seguidos por tratamientos diseñados para incrementar la disponibilidad de forraje. Este estudio ilustra una extensiva aplicacio´n de una técnica de evaluación que estásiendo utilizada más y más en todo el mundo y cuyos resultados contribuyen a un mejor entendimiento de los factores y patrones que causan la degradación de las áreas de pastizal.

Keywords: *Artemisia tridentata* Nuttall, big sagebrush, ecological sites, ecosystem assessment, rangeland condition, soil properties

Introduction

Over the past 15 yr, there has been a focused effort to develop new methods for assessing the status of rangeland ecosystems. This effort has been driven by increased recognition that 1) the dynamics of such ecosystems often are much more complex than previously assumed and 2) sustainable management requires consideration of a broader suite of ecosystem attributes than production of key forage species and similarity of the existing plant community to a single idealized climax community (see reviews by Pyke et al. 2002; Pyke and Herrick 2003; and Briske et al. 2005 for historical perspectives). In the United States, much of this effort directly followed recommendations made by expert panels convened by the National Research Council (NRC; NRC 1994) and the Society for Range Management Task Group on Unity in Concepts and Terminology Committee (SRM Task Group; SRM Task Group 1995). The NRC panel recommended that rangeland assessments should focus on indicators of soil stability, watershed function, nutrient cycling, energy flow, and recovery mechanisms (NRC 1994). The SRM Task Group observed that because the sustainable management of rangeland ecosystems depends primarily on soil conservation, assessments should evaluate rangeland plant communities in terms of their ability to protect a site against accelerated soil erosion (SRM Task Group 1995). Both panels recommended that assessments should be conducted and interpreted on the basis of a common system for classifying land units on the basis of soil, landscape setting, and climate analogous to the ecological site concept of the US Department of Agriculture Natural Resources Conservation Service (NRCS; NRCS 2003).

Both in the United States and in Australia, there has been rapid growth in research focusing on conceptual and applied aspects of rangeland assessment and monitoring, with a strong emphasis on indicators of ecosystem or landscape capacity to capture and retain soil and water resources. The majority of this work has focused on field-based indicators (Whitford et al. 1998; de Soyza et al. 2000a; Pyke et al. 2002; Rosentreter and Eldridge 2002; Tongway and Hindley 2004; Herrick et al. 2005; Pellant et al. 2005), but the need for approaches that can be applied affordably and effectively across expansive landscapes also has led to efforts focused on the development of indicators that can be reliably detected with remotely sensed imagery (de Soyza et al. 2000b; Ludwig et al. 2002, 2007). Rather than being a stand-alone activity, assessment increasingly is recognized as a key component of an integrated framework designed to support science-based management of rangeland ecosystems (Herrick et al. 2006).

To date, the most widely adopted assessment approach in the United States has been the technique ''Interpreting Indicators of Rangeland Health'' (IIRH; Pellant et al. 2000, 2005; Pyke et al. 2002). In this technique, an interdisciplinary team of resource specialists evaluates three ecosystem attributes (soil/site stability, hydrologic function, and biotic integrity) on the basis of a suite of qualitative indicators. IIRH is widely applied by NRCS, the Bureau of Land Management (BLM), and the National Park Service (NPS), and protocols have been translated into Spanish, Chinese, and Mongolian (J. Herrick, personal communication, August 2007).

Despite its widespread adoption and increasing use worldwide, there are no published examples of how the IIRH technique has been applied to evaluate the status of rangeland ecosystems across broad spatial extents characteristic of public lands in the western United States. The purpose of this paper is to describe one such project as a case study in which the technique was applied at over 500 locations in and adjacent to Grand Staircase–Escalante National Monument, Utah (hereafter, the Monument), over a 3-yr period. Objectives of this assessment project were 1) to provide data and interpretations to support the development of site-specific management strategies for the improvement of resource conditions and 2) to investigate broad-scale patterns in the status of different rangeland ecological sites across the entire Monument. The second objective is the focus of this paper. This case study illustrates an extensive application of the IIRH technique, and results provide insights into factors affecting patterns and processes of rangeland degradation.

Methods

Study Area

The Monument covers approximately 760,000 ha in southern Utah and the west-central portion of the Colorado Plateau physiographic province (Hunt 1974) between lat 37uN, lat 38uN, long 111uW, and long 112.5uW. Elevation ranges from 1,164 to 2,625 m, and mean annual precipitation (MAP; 1961– 1990) ranges from 17 to 61 cm. (Precipitation estimates are based on the PRISM model, http://www.ocs.orst.edu/prism; Daly et al. 1994.) Approximately 90% of the Monument receives less than 36 cm MAP. As a proportion of MAP, May–September precipitation varies from 33.1% in Kanab (1,509 m elevation, 37.9 cm MAP, 16 km west of the Monument boundary) to 44.2% in Escalante (1,771 m elevation, 25.4 cm MAP, north-central edge of the Monument). Tremendous geologic and topographic heterogeneity (Doelling et al. 2000), as well as gradients in elevation and precipitation, together are responsible for generating a diversity of soils and ecological settings across the Monument. In a recent soil survey for the Monument, the NRCS described 136 distinct soil types and 50 distinct ecological sites (NRCS 2005).

Livestock grazing has been an important economic activity on lands within the Monument since the time of Euro-American settlement in the 1870s (Bradley 1999), and it remains the most extensive land use on the Monument today. Monument lands are subdivided into 91 grazing allotments, some of which extend onto adjoining public lands managed by the NPS (Glen Canyon National Recreation Area) and the US Department of Agriculture Forest Service (Dixie National Forest). Allotments are divided into two or more fenced pastures to facilitate livestock management. Pastures represent the smallest management units in the Monument, although they are typically larger than 5,000 ha and range in size up to 54,288 ha.

Sampling Design

A major objective of the assessment project was to collect data that would contribute to an evaluation of resource conditions in grazing allotments and to the development of future strategies for meeting resource-management objectives. As a consequence, assessments were conducted in all pastures and allotments across the Monument. Within these management units, it was assumed that ecosystem conditions could vary among different soils and ecological sites due to potential differences in past livestock use and in ecosystem responses to livestock use, management activities, and climate variability. Thus digital spatial data delineating soils and ecological sites were used to stratify each pasture into soil-based sampling units.

Within sampling units in pastures, specific assessment locations were identified subjectively rather than probabilistically. This approach was chosen because time and resources were judged to be inadequate for obtaining a statistically adequate number of randomly located assessments for each sampling unit in all pastures and allotments, given the overall scope of the project. For each pasture, soil map units were ranked in descending order according to their total area in the pasture, and at least one assessment was conducted in the predominant ecological site in the soil map units that cumulatively accounted for at least 75% of the pasture area. Assessments also were conducted in areas expected to receive relatively high livestock use even where these areas were associated with minor soil components or soil map units that fell below the 75% cut-off in a particular pasture. Water sources and similar areas with concentrated livestock use were excluded from sampling. The assessment team selected one or more representative assessment locations associated with each targeted ecological site, with representativeness evaluated by examining aerial photographs with superimposed soil map unit delineations and by surveying conditions on the ground prior to conducting assessments. Assessment locations were approximately 0.5–1.0 ha in size.

Field Methods

Assessments were conducted following the technique IIRH, version 3 (Pellant et al. 2000; Pyke et al. 2002). The standard technique calls for the evaluation of three ecosystem attributes (soil/site stability, hydrologic function, and biotic integrity; Table 1) on the basis of 17 qualitative indicators (Pellant et al. 2000; Pyke et al. 2002; Table 2). Indicators and attributes for a particular assessment area are evaluated and rated according to the degree to which they depart from benchmark (reference) conditions described in ecological site descriptions prepared by NRCS and/or observed at one or more ecological reference areas (Pellant et al. 2000; Pyke et al. 2002), and on the basis of the combined experience and professional judgment of the interdisciplinary assessment team. In all cases, benchmark conditions are identified and applied on an ecological-site basis, thus requiring assessment teams to properly identify soil types and ecological sites. An ordinal, five-class rating system is used, with degree of departure rated as none to slight (NS), slight to moderate (SM), moderate (M), moderate to extreme (ME), or extreme (E). In

Attribute	Definition
Soil/site stability	The capacity of a site to limit redistribution and loss of soil resources (including nutrients and organic matter by wind and water).
Hydrologic function	The capacity of a site to capture, store, and safely release water from rainfall, run-on, and snowmelt (where relevent), to resist a reduction in this capacity, and to recover this capacty following degradation.
Biotic integrity	Capacity of a site to support characteristic functional and structural communities in the context of normal variability, to resist loss of this function and structure due to a disturbance, and to recover following such disturbance.

Table 1. Three attributes of rangeland health and their definitions (from Pellant et al. 2000; Pyke et al. 2002).

Indicator and brief description	Attributes[1]			Quantitative data
	S	H	B	
1. Rills - frequency and spatial distribution of linear erosional rivulets	X	X		
2. Water flow patterns - amount and distribution of overland flow paths that are identified by litter distribution and visual evidence of soil and gravel movement	X	X		
3. Pedestals and/or terracettes - frequency and distribution of rocks or plants where soil has been eroded from their base (pedestals), and/or occurrence of erosional terracettes	X	X		
4. Bare ground - size and connectivity among areas of soil not protected by vegetation, biological soil crusts, litter, standing dead vegetation, gravel, or rocks.	X	X		Percentage of bare ground
5. Gullies - amount of channels cut into the soil and the amount and distribution of vegetation in the channel	X	X		
6. Wind-scoured areas, blowouts, and/or deposition areas - frequency of areas where soil is removed from under physical or biological soil crust or around vegetation OR frequency of accumulation areas of soil associated with large structural objects, often woody plants	X			
7. Litter movement - frequency and size of litter displaced by wind and overland flow of water	X			
8. Soil surface resistance to erosion - ability of soils to resist erosion through the incorporation of organic materal into soil aggregates	X	X	X	Soil aggregate stability
9. Soil surface loss or degredation - frequency and size of areas missing all or portions of the upper soil horizons that normally contain the majority of organic material of the site	X	X	X	
10. Plant community composition and distribution relative to infiltration and runoff - the community composition or distribution of species that restrict the infiltration of water on the site		X		Percentage of composition by functional group
11. Compaction layer - thickness and distribution of the structure of the soil near the soil surface (≤ 15 cm)	X	X	X	
12. Functional/structural groups - the number of groups, the number of species within groups, or the rank or order of dominance of groups.			X	Relative composition and dominance of functional group (based on cover)
13. Plant mortality/decadence - frequency of dead or moribund (dying) plants			X	Percentage of standing-dead cover
14. Litter amount - deviation in the amount of litter		X	X	Percentage of cover of litter
15. Annual aboveground production - amount relative to the potential for that year based upon recent climatic conditions			X	
16. Invasive plants - abundance and distribution of invasive plants regardless if they are noxious weeds, exotic species, or native plants whose dominace greatly exceeds that expected for the ecological site			X	Percentage of cover and relative composition of invasive plants
17. Reproductive capability of perennial plants - evidence of the inflorescences or of vegetative tiller production relative to the potential for that year based upon recent climatic conditions			X	
18. Biological soil crusts - amount, spatial distribution, and degree of development	X	X	X	Percentage of cover and relative composition of biological soil crusts
[1]S indicates soil/site stability; H, hydologic function; and B, biotic integrity				

Table 2. Brief description of 18 rangeland health indicators, their applicability to rangeland health attributes, and associated quantitative data collected during assessments conducted on Grand Staircase-Escalante National Monument (adapted from Pyke et al. 2002).

the project described here, assessment teams identified relatively few reference areas. Thus ratings primarily were based on NRCS ecological site descriptions for those indicators related to plant community composition, ground cover, and potential primary production. For indicators not described in existing site descriptions (e.g., frequency and spatial distribution of erosional features such as rills, pedestals, and terracettes), indicator ratings primarily were based on team members' collective field observations and experience. Interdisciplinary assessment teams ranged in size from two to five members, with botanists, ecologists, geologists, wildlife biologists, and rangeland management specialists serving as the primary team members.

The IIRH protocol allows for the use of additional indicators where necessary to meet local assessment needs (Pellant et al. 2000). For this project, the integrity of biological soil crusts (BSCs) was included as an 18th indicator applicable to all three ecosystem attributes (Table 2) because of important BSC contributions to soil stabilization (Belnap 1995; Williams et al. 1995a, 1995b), hydrologic processes (Warren 2003; Belnap et al. 2005), nutrient cycling (Evans and Lange 2003), and biological diversity (Rosentreter and Belnap 2003) in rangeland ecosystems on the Colorado Plateau. Ratings for this indicator were based on the distribution and abundance of soil lichens, soil mosses, and dark cyanobacterial crusts in comparison with reference areas and team members' collective field observations and experience (Table 3). During the 2002 field season, ratings for biological soil crusts also were informed by preliminary results from a concurrent project being conducted to develop a spatial predictive model of BSC cover, composition, and function in relation to precipitation and substrate characteristics (Bowker et al. 2006).

To inform the evaluation of qualitative indicators and increase consistency of the assessment process, quantitative data on ground cover (e.g., percentage of cover of bare ground/mineral soil, BSC, litter, plant bases, and rock), plant community composition (percentage of live and dead canopy and basal cover by species and plant functional groups), and soil stability were collected prior to evaluating indicators and attributes (Pyke et al. 2002). Data on ground cover and plant community composition were collected following the steppoint technique (Coulloudon et al. 1999). Cover data were recorded for 50–100 subsample points (approximately 1-mm diameter) placed at 4-pace intervals along a pace transect walked by one or two team members. The pace transect crossed the assessment area three to five times, with total transect length ranging from 150 to 300 m. Surface and subsurface soil stability beneath plant canopies and in interspaces among plants was measured using a soil aggregate stability field kit (Herrick et al. 2001). Nine pairs of surface and subsurface samples were collected from three to six interspace locations and three to six subcanopy locations that were selected as visually representative of conditions across the assessment area.

Assessments were conducted from July 2000 through December 2002, with about 80% of the field work conducted during April–October periods in 2001 and 2002. Amounts of precipitation received in Kanab and Escalante respectively were 32% and 43% below the 1971–2000 average during the 2000 water year, 13% and 27% above average during the 2001 water year, and 53% and 64% below average during the 2002 water year (Western Regional Climate Center 2007).

Indicator	**Degree of departure from ecological site description and/or ecological reference area(s)**				
	Extreme	Moderate to extreme	Moderate	Slight to Moderate	None to slight
Biological soil crusts	Found only in protected areas; very limited suite of functional groups	Largely absent, occurring mostly in protected areas	In protected areas and with a minor component in interspaces	Evident throughout the site, but continuity is broken	Largely intact and nearly matches site capability

Table 3. Evaluation matrix for biological soil crusts (from Pellant et al. 2000).

Data Analyses

Chi-square analysis (Zar 1999) was used to examine whether the three attributes of rangeland health had different rating distributions for all assessment locations combined (507 assessments and 1,521 attribute ratings). For ecological sites with five or more assessments, χ^2analyses also were used to determine whether some ecological sites were characterized by ecosystem conditions that were better (i.e., a greater proportion of assessments with a small degree of departure from expected reference conditions) or worse (greater proportion of assessments with a large degree of departure from expected reference conditions) than typical conditions described on the basis of the combined data set for all 507 assessment locations. For each ecological site, separate χ^2 analyses were conducted for each of the three attributes of rangeland health.

Extensive areas within the Monument were mechanically treated in the past to reduce the cover of unpalatable woody vegetation such as big sagebrush (*Artemisia tridentata* Nuttall), Utah juniper (*Juniperus osteosperma* [Torrey] Little), and Colorado pinyon (*Pinus edulis* Engelmann). In conjunction with mechanical treatments, treated areas (hereafter referred to as ''seedings'') generally were seeded with nonnative forage grasses such as crested wheatgrass (*Agropyron cristatum* [L.] Gaertner) and Russian wildrye (*Elymus junceus* Fischer). (Taxonomic nomenclature follows Welsh et al. 2003.) For ecological sites with five or more assessments in seedings and in comparable untreated areas, separate χ^2 analyses were conducted to examine whether there was a tendency for seedings or untreated areas to be characterized by better or worse ecosystem conditions in comparison with all 507 assessments combined. For all χ^2 analyses, rating classes E and ME were combined into a single class (E–ME) because of the infrequent occurrence of E ratings. Multivariate analysis of variance (MANOVA) also was used to test for differences between mean values of selected quantitative measures for seeded and comparable untreated ecological sites. Dependent variables were log-transformed [$x' = \ln(x + 1)$] prior to analysis because variances were proportional to means (Zar 1999). Stepwise multiple regression analysis was used to examine potential factors contributing to general patterns in ecosystem condition among ecological sites (Zar 1999).

Ecosystems dominated by varieties of big sagebrush are of particular interest to resource managers on the Colorado Plateau and throughout the Intermountain West because of their diversity and habitat value, and because they have been widely degraded by cumulative effects of land use, invasive exotic plants, and altered fire regimes (Knick et al. 2003; Connelly et al. 2004; Welch 2005). Five of the 50 distinct ecological sites found in the Monument are characterized by potential vegetation dominated by varieties of big sagebrush (Table 4; NRCS 2005). Of these five sites, the Semidesert Loam (Wyoming big sagebrush) site had a relatively large sample size (*n*=55) and was characterized by a wide range of rangeland health conditions. For these reasons, data for this ecological site were examined in greater detail to evaluate relationships between quantitative data and qualitative ratings of rangeland health. Principal components analysis (PCA; McCune and Grace 2002) with varimax normalized factor rotation was used to describe variability among the 55 assessments in terms of 12 quantitative variables: interspace soil aggregate stability; percentage of total live cover; total plant cover; percentage of bare ground; percentage of BSC cover; percentage of litter cover; percentage of relative cover of annual exotic plants, total exotic plants, and woody plants; functional group richness; diversity (H9); and evenness (J9; Zar 1999). Spearman's rank correlation coefficients (Zar 1999) were calculated to describe relationships between quantitative variables and ordinal qualitative ratings assigned to the three rangeland-health attributes. MANOVA was used to test whether log-transformed mean values for selected quantitative variables were significantly different among rating classes for individual rangeland health attributes. For rangeland health attributes determined to have significant effects by MANOVA, Tukey's honestly significant difference (HSD) post hoc analysis was used to test for differences between mean quantitative measures associated with different attribute rating classes (Zar 1999). With the exception of the χ^2 analyses, all statistical analyses were conducted using the software package STATISTICA™ version 6.1 on a Windows® platform (Stat-

Table 4. Soil-depth class, potential dry-weight production by ecological site, and χ^2 values by ecological site and rangeland health attribute (soil/site stability, hydrologic function, and biotic integrity) for sites with five or more rangeland health assessments (*n*), Grand Staircase–Escalante National Monument. Chi-square values were calculated to test the hypothesis that the distribution of ratings for a particular ecological site and rangeland health attribute was not different than the overall distribution of ratings for all 507 assessment locations. Values in bold type are statistically significant. Ecological sites are ranked in descending order according to the percentage of assessments that received ratings of moderate or greater departure from expected reference conditions for all three attributes of rangeland health. Palatable production includes perennial grasses and shrubs that provide livestock forage. Unpalatable production includes unpalatable woody and suffrutescent plants.

Ecological site[1]	Site no.	Soil-depth class	Potential dry-weight production ($kg \cdot ha^{-1} \cdot yr^{-1}$)[2]			*n*	Soil/site stability χ^2	Hydrologic function χ^2	Biotic integrity χ^2	Assessments with moderate or greater departure from expected for all attributes (%)
			Total	Palatable	Unpalatable					
Upland Loam (mountain big sagebrush) – seeded	035XY308UT	Deep	1009	504	403	20	**22.8*** **	**29.0*** **	**26.2*** **	75.0
Semidesert Loam (Wyoming big sagebrush) – seeded	035XY209UT	Deep	757	378	227	24	**25.5*** **	**31.3*** **	**23.7*** **	62.5
Semidesert Loam (Wyoming big sagebrush) – untreated	035XY209UT	Deep	757	378	227	31	**49.3*** **	**33.8*** **	**25.9*** **	58.1
Loamy Bottom (basin big sagebrush)	035XY011UT	Deep	1793	986	628	15	3.2	5.2	**18.2*** **	46.7
Semidesert Sandy Loam (blackbrush)	035XY218UT	Deep	532	213	266	7	**13.2** **	2.9	**11.1* **	42.9
Semidesert Sandy Loam (Wyoming big sagebrush)	035XY214UT	Deep	532	399	80	15	6.5	4.4	2.0	33.3
Upland Loam (mountain big sagebrush) – untreated	035XY308UT	Deep	1009	504	403	15	4.6	5.7	3.1	26.7
Desert Sandy Loam (fourwing saltbush)	035XY215UT	Deep	476	357	0	5	0.7	0.3	2.8	20.0
Semidesert Gravelly Shallow Breaks	—	Shallow	No data	No data	No data	5	6.9	1.3	3.5	20.0
Semidesert Shallow Sandy Loam (blackbrush)	035XY233UT	Shallow	364	73	255	5	1.7	1.9	1.2	20.0
Desert Shallow Clay (mat saltbush)	035XY223UT	Shallow	213	32	138	6	5.8	2.0	2.1	16.7
Semidesert Sandy Loam[3] (black grama)	035XY219UT	Deep	532	426	27	14	7.1	5.8	4.8	14.3
Semidesert Sand (fourwing saltbush)	035XY212UT	Deep	644	451	32	32	0.6	3.0	2.3	12.5
Semidesert Sandy Loam (fourwing saltbush)	035XY215UT	Deep	532	453	0	12	1.7	2.1	4.7	8.3
Semidesert Shallow Loam (Utah juniper–pinyon)	—	Shallow	504	151	303	64	**7.6* **	5.7	**12.8** **	7.8
Upland Sand (mountain big sagebrush)	—	Deep	672	202	336	15	1.8	3.2	4.7	6.7
Upland Shallow Dissected Slope[3] (pinyon–Utah juniper)	035XY311UT	Shallow	196	59	118	30	4.9	2.9	**11.3* **	6.7
Semidesert Steep Shallow Loam (Utah juniper–pinyon)	—	Shallow	252	88	139	16	4.9	5.2	**20.4*** **	6.3
Upland Shallow Loam (pinyon-Utah juniper)	035XY315UT	Shallow	616	216	277	34	**13.5** **	6.2	**11.2* **	2.9
Desert Shallow Sandy Loam[3] (shadscale)	035XY130UT	Shallow	252	126	101	5	2.8	2.2	0.9	0.0
Semidesert Shallow Clay (shadscale–Utah juniper)	—	Shallow	168	101	50	5	2.5	5.4	4.7	0.0
Semidesert Shallow Sand (Cutler Mormon tea)	035XY225UT	Shallow	420	273	84	15	2.6	6.0	5.5	0.0
Semidesert Shallow Sand (Utah juniper–pinyon)	035XY227UT	Shallow	252	101	113	8	1.5	1.9	1.9	0.0
Semidesert Shallow Shale (Utah juniper–pinyon)	—	Shallow	252	88	139	9	7.5	**12.7** **	**23.5*** **	0.0
Upland Loam[4] (pinyon-Utah juniper)	—	Deep	644	226	354	5	2.7	2.1	2.6	0.0
Upland Stony Loam (pinyon-Utah juniper)	035XY321UT	Deep	560	140	336	11	5.1	3.6	2.4	0.0

[1]Scientific names of associated plant species: mountain big sagebrush (*Artemisia tridentata* var. *vaseyana* [Rydberg] B. Boivin), Wyoming big sagebrush (*A. tridentata* var. *wyomingensis* [Beetle & A. Young] S. Welsh), basin big sagebrush (*A. tridentata* Nuttall), blackbrush (*Coleogyne ramosissima* Torrey), fourwing saltbush (*Atriplex canescens* [Pursh] Nuttall.), mat saltbush (*Atriplex corrugata* S. Watson), black grama (*Bouteloua eriopoda* [Torrey] Torrey), Utah juniper (*Juniperus osteosperma* [Torrey] Little), pinyon (*Pinus edulis* Engelmann), shadscale (*Atriplex confertifolia* [Torrey & Frémont] S. Watson), Cutler Mormon tea (*Ephedra viridis* var. *viscida* [Cutler] L. Benson).

[2]Potential production in normal-precipitation years, with plant community composition similar to that described by the Natural Resources Conservation Service (NRCS) as the historical climax plant community (data from NRCS 2005 unless otherwise noted).

[3]Production estimates from NRCS ecological site description.

[4]Production estimates from draft ecological site description prepared by the Bureau of Land Management.

$^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$.

soft 2004). For all analyses, results with $P \leq 0.05$ were considered statistically significant.

Results

Overall Patterns Among Ecological Sites

For all 507 assessments combined, SM was the modal rating class for each of the three rangeland health attributes (Fig. 1). The rating distributions for all three attributes were similar, but the distribution for biotic integrity was significantly different than the distribution for all 1 521 attribute ratings combined. Overall, biotic integrity tended to receive NS ratings less frequently and M and SM ratings more frequently than soil/site stability and hydrologic function attributes (Fig. 1). Of the 507 assessments, 226 (44.6%) were assigned a low rating (moderate or greater departure from expected reference conditions) for at least one of the three attributes, and 100 (19.7%) were assigned low ratings for all three attributes.

Of the 26 ecological sites with five or more assessments (including seeded and untreated areas for two ecological sites), 10 had one or more attributes with rating distributions that were significantly different than the overall distributions for all 507 assessments (Tables 4 and 5). Of the five ecological sites with significantly higher frequencies of low ratings relative to the overall distributions, four were deep-soil ecological sites with high potential production and potential vegetation dominated by varieties of big sagebrush (Tables 4 and 5). In contrast, all five ecological sites with significantly lower frequencies of low ratings relative to the overall distributions were shallow-soil ecological sites with relatively low potential production and potential vegetation characterized by the presence of juniper and/or pinyon. Only the seeded Upland Loam and seeded and untreated Semidesert Loam ecological sites had rating distributions that were significantly different from overall distributions for all three rangeland health attributes. Potential dry-weight production (Table 4; β=0.447, P=0.003) and treatment (seeded vs. untreated, from Table 4; β=0.556, P=0.0004) both were significant in a stepwise multiple regression model predicting for each ecological site the percentage of assessment locations that was assigned

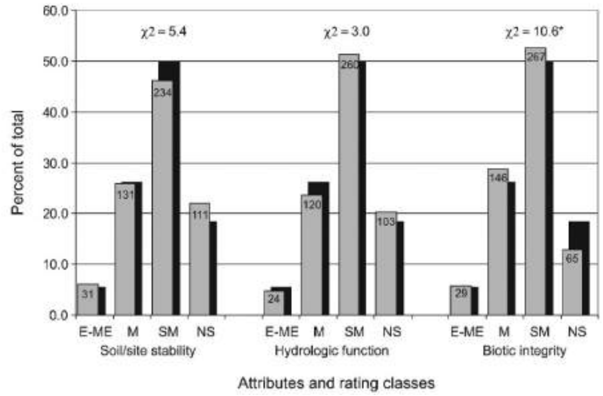

Figure 1. Overall distributions (gray bars) of ratings assigned to three rangeland-health attributes at 507 assessment locations on Grand Staircase–Escalante National Monument. Numerals in gray bars indicate numbers of assessments that received associated ratings. Black bars behind each rating distribution indicate the overall distribution of all 1 521 ratings and the null distributions that were used in χ^2 analyses for each of the three attributes (reflected by χ^2 statistics above each rating distribution; *P<0.05). For attribute ratings, E indicates extreme departure; ME, moderate to extreme departure; M, moderate departure; SM, slight to moderate departure; and NS, no departure to slight departure from expected reference conditions.

low ratings for all three attributes of rangeland health (adjusted R^2=0.62, df 2,22, F=20.34, P=0.00001). Log-transformed means for percentage of bare ground, BSC cover, and interspace soil aggregate stability were not significantly different between seeded and untreated Semidesert Loam (Wilks' λ=0.94, F=0.94, df 3,46, P=0.43) and Upland Loam (Wilks' λ =0.84, F=1.70, df 3,27, P=0.19) ecological sites.

Patterns Within the Semidesert Loam Ecological Site

Two PCA axes explain 49.3% of the variability in 12 quantitative variables sampled in conjunction with 55 assessments of the Semidesert Loam ecological site (seeded and untreated areas combined; Fig. 2). Axis 1 represents a gradient of decreasing bare ground and increasing total plant cover, total live cover, and functional group richness and diversity (Fig. 2a). Axis 2 represents a gradient of decreasing relative cover of exotic plants (including nonnative forage grasses, which accounted for 72.0% of total exotic cover, on average) and increasing interspace soil aggregate stability and cover of BSCs (Fig. 2a). Qualitative ratings assigned to the three attributes of rangeland

Ecological site	n	Soil/site stability E–ME	Soil/site stability M	Soil/site stability SM	Soil/site stability NS	Hydrologic function E–ME	Hydrologic function M	Hydrologic function SM	Hydrologic function NS	Biotic integrity E–ME	Biotic integrity M	Biotic integrity SM	Biotic integrity NS
All sites combined	507	6.1	25.8	46.2	21.9	4.7	23.7	51.3	20.3	5.7	28.8	52.7	12.8
Upland Loam (mountain big sagebrush) – seeded	20	**20.0**	**60.0**	20.0	0.0	**20.0**	**60.0**	20.0	0.0	5.0	**80.0**	15.0	0.0
Semidesert Loam (Wyoming big sagebrush) – seeded	24	**16.7**	**62.5**	20.8	0.0	**16.7**	**62.5**	16.7	4.2	**25.0**	**45.8**	29.2	0.0
Semidesert Loam (Wyoming big sagebrush) – untreated	31	**35.5**	**29.0**	19.4	16.1	**22.6**	**45.2**	22.6	9.7	**22.6**	**48.4**	22.6	6.5
Loamy Bottom (basin big sagebrush)	15	—	—	—	—	—	—	—	—	**13.3**	**73.3**	13.3	0.0
Semidesert Sandy Loam (Blackbrush)	7	0.0	**85.7**	14.3	0.0	—	—	—	—	0.0	**85.7**	14.3	0.0
Semidesert Shallow Loam (Utah juniper–pinyon)	64	1.6	17.2	**48.4**	**32.8**	—	—	—	—	0.0	14.1	**67.2**	**18.8**
Upland Shallow Dissected Slope (pinyon–Utah juniper)	30	—	—	—	—	—	—	—	—	3.3	3.3	**80.0**	**13.3**
Semidesert Steep Shallow Loam (Utah juniper–pinyon)	16	—	—	—	—	—	—	—	—	0.0	12.5	37.5	**50.0**
Upland Shallow Loam (pinyon–Utah juniper)	34	0.0	8.8	**47.1**	**44.1**	—	—	—	—	2.9	5.9	**67.6**	**23.5**
Semidesert Shallow Shale (Utah juniper–pinyon)	9	—	—	—	—	0.0	0.0	**33.3**	**66.7**	0.0	11.1	22.2	**66.7**

[1]E–ME indicates extreme or moderate-to-extreme departure; M, moderate departure; SM, slight to moderate departure; and NS, no departure to slight departure from expected reference conditions.

Table 5. Percentages of assessments by rating class[1] for three rangeland health attributes (soil/site stability, hydrologic function, and biotic integrity) at 10 rangeland ecological sites and for all sites combined, Grand Staircase–Escalante National Monument. Values are only reported for those ecological sites and attributes with rating distributions that are significantly different than the associated distribution for all sites combined (see Table 4 for significant χ^2 values). Bold, underlined print indicates percentages that exceed corresponding percentages for all sites combined.

health tended to be higher (lesser degree of departure from expected reference conditions) at assessment locations characterized by higher scores for PCA axes 1 and 2, but there was considerable variability in PCA scores among assessment locations that were assigned the same qualitative rating for a particular attribute (Figs. 2b–2d). Ratings for the three attributes of rangeland health were more strongly correlated with site scores for PCA axis 2 than with site scores for PCA axis 1 (Table 6).

Seven of twelve quantitative variables were significantly correlated with ratings assigned for one or more rangeland health attributes (Table 6). Measures of functional group richness and diversity (H′) were important in the PCA but not correlated with assigned ratings for any of the three attributes (Table 6). However, both variables were significantly correlated with assigned ratings for the individual indicator pertaining to functional and structural groups (richness: p=0.42, P<0.01; diversity: p=0.38, P<0.01). Percentage of bare ground, total live cover, BSC cover, and interspace soil aggregate stability had the highest rank correlations with assigned attribute ratings (Table 6). MANOVA results for these four variables were statistically significant for each of the three rangeland health attributes (soil/site stability: Wilks' λ=0.26, F=6.28, effect df=12, error df=114.1, P<0.001; hydrologic function: Wilks' λ=0.29, F=5.63, effect df=12, error df=114.1, P<0.001; biotic integrity: Wilks' λ=0.32, F=3.62, effect df=16, error df=128.9, P<0.001), but Tukey's HSD analyses found relatively few significant differences among log-transformed mean values for different attribute rating classes because of the high degree of variability in quantitative measures among assessments that were assigned the same rating for a particular attribute (Fig. 3). Mean quantitative measures for assessment locations that were assigned NS ratings for rangeland health attributes were statistically different than means associated

Variable	S	H	B
Bare ground %	**−0.65*****	**−0.65*****	**−0.40****
Total live cover %	**0.54*****	**0.55*****	**0.48*****
Total plant cover %	**0.35****	**0.38****	**0.31***
Biological soil crust cover %	**0.52*****	**0.47*****	**0.57*****
Litter cover %	0.16	0.19	0.15
Interspace soil aggregate stability	**0.50*****	**0.40****	**0.50*****
Functional group richness	0.09	0.19	0.19
Functional group diversity (H′)	0.15	0.24	0.17
Functional group evenness (J′)	0.05	0.02	−0.15
Relative annual exotic cover %	0.01	−0.10	**−0.42****
Relative total exotic cover %	−0.18	−0.20	**−0.31***
Relative woody plant cover %	−0.05	−0.06	−0.11
PCA axis 1 site scores	**0.33***	**0.33***	0.13
PCA axis 2 site scores	**0.38****	**0.42****	**0.58*****

[1]S indicates soil/site stability; H, hydrologic function; and B, biotic integrity.
*$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$.

Table 6. Spearman rank correlations between 12 quantitative variables included in the principal components analysis (PCA; Fig. 2), site scores for PCA axes 1 and 2, and ordinal qualitative ratings (extreme, moderate-to-extreme, moderate, slight-to-moderate, and none-to-slight departure from expected reference conditions ranked 1–5, respectively) for rangeland health attributes soil/site stability, hydrologic function, and biotic integrity at 55 Semidesert Loam assessment locations on Grand Staircase– Escalante National Monument (n=50 for interspace soil aggregate stability). Bold type indicates statistically significant relationships.

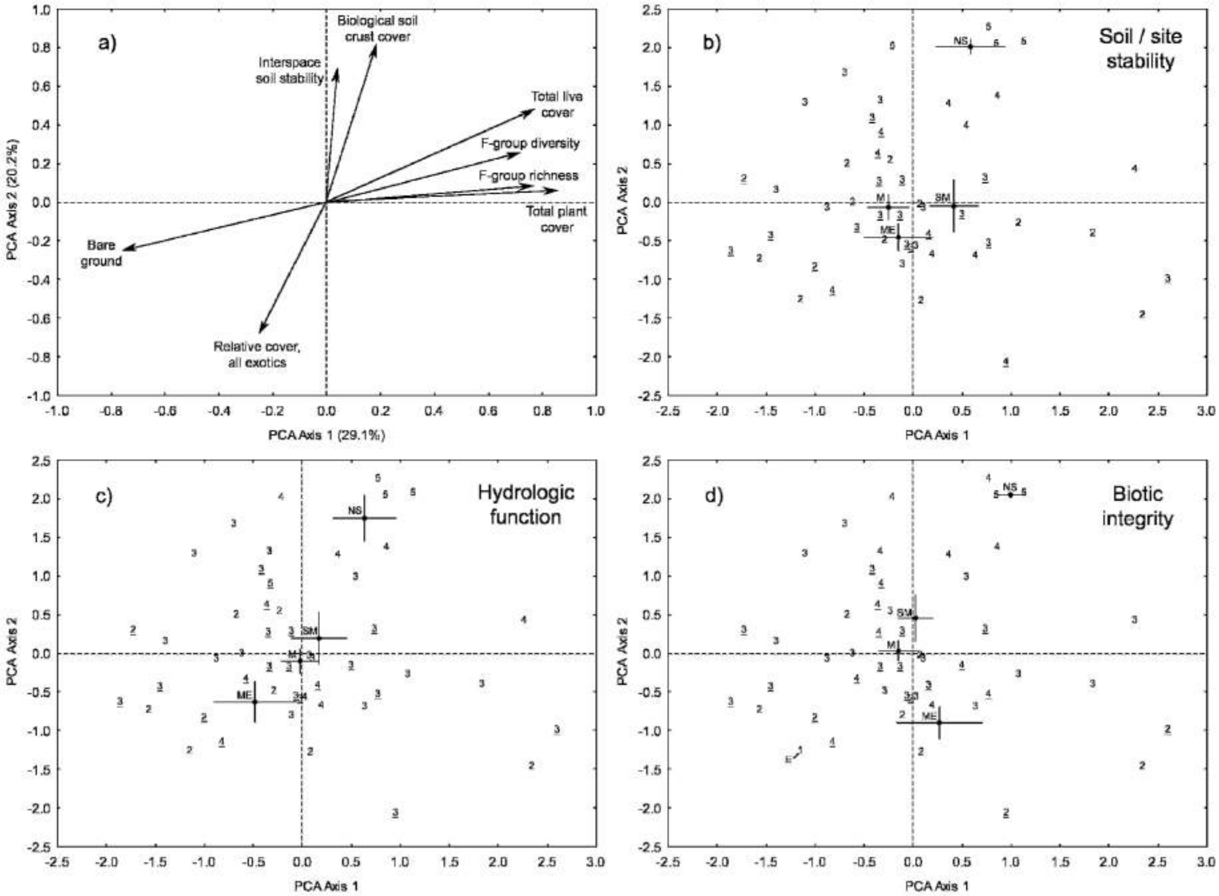

Figure 2. Principal components analysis (PCA) results for data associated with 12 quantitative variables measured at 55 Semidesert Loam assessment locations, Grand Staircase–Escalante National Monument. a, vectors indicate loadings (Pearson correlation coefficients, r) of eight variables on axes 1 and 2 (only those variables with $r \geq 0.60$ are shown; F-group indicates functional group). In the remaining panels, numbers 1–5 indicate attribute ratings (1 and E indicate extreme departure; 2 and ME, moderate to extreme departure; 3 and M, moderate departure; 4 and SM, slight to moderate departure; and 5 and NS, no departure to slight departure from expected reference conditions) assigned for b, soil/site stability; c, hydrologic function; and d, biotic integrity at each of the assessment locations. Underlined ratings are for assessments associated with seedings. Coordinates of the attribute ratings in ordination space indicate PCA scores associated with the corresponding assessment location. Points indicate centroids (mean PCA scores ± 1 SE) for each set of assessment locations receiving the same attribute rating.

with locations that were assigned lower rangeland health ratings in most cases, whereas means for locations that were assigned ME, M, or SM ratings were statistically different from one another less frequently (Fig. 3). This finding is consistent with PCA results showing that centroids for locations that were assigned ME, M, or SM ratings tended to be clustered together in the center of the ordination space defined by the quantitative variables, whereas the centroids for locations assigned NS ratings were relatively distinct in ordination space (Fig. 2).

Discussion

Results of this broad-scale assessment project indicate patterns in qualitative attributes and quantitative measures of rangeland health across a 760 000-ha landscape that represents a significant proportion of the Colorado Plateau physiographic province. Because of the large numbers of assessment locations and ecological sites included in the project, data resulting from this effort represent a valuable resource for examining general patterns in ecosystem condition among and within different ecological sites, and for developing hypotheses about factors that may have contributed to the development of these patterns.

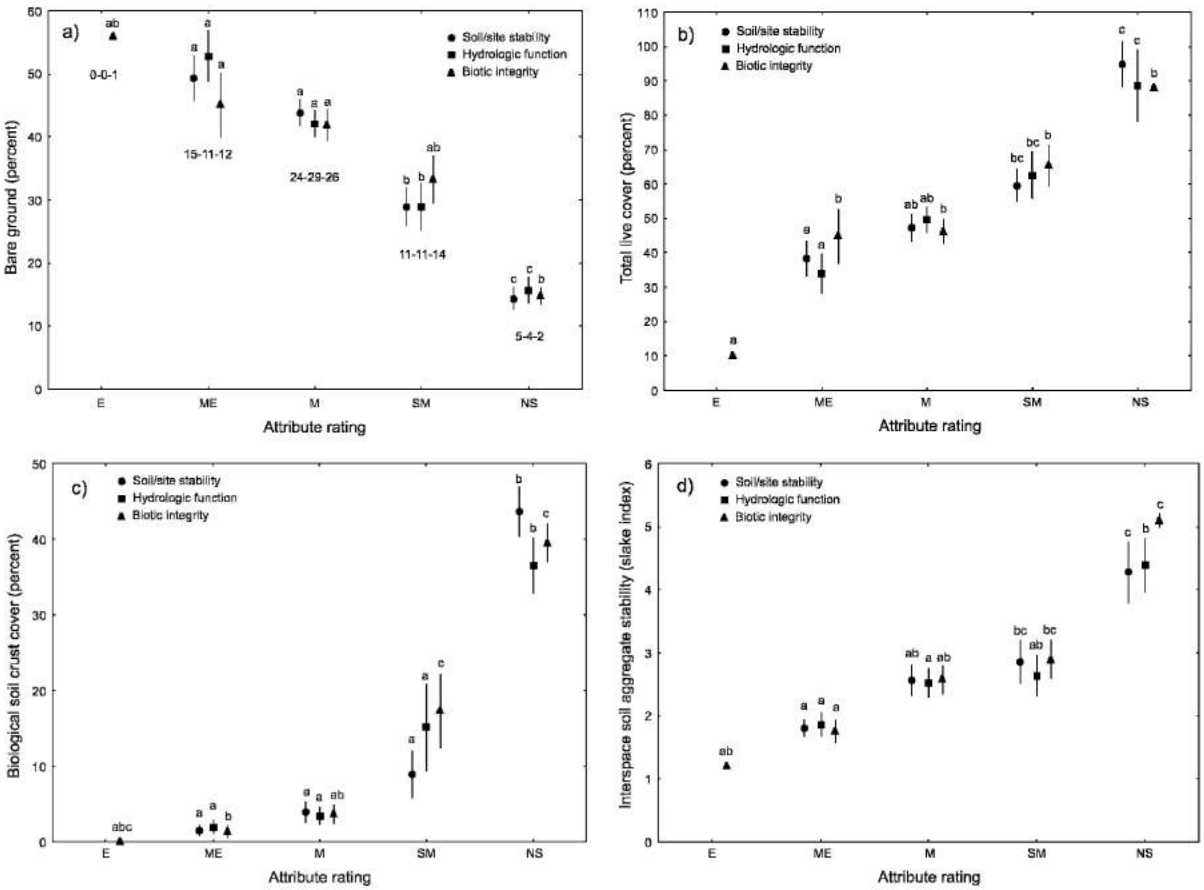

Figure 3. Relations between qualitative ratings assigned for rangeland health attributes (soil/site stability, hydrologic function, and biotic integrity) and quantitative measures (means ± 1 SE) of a, percent bare ground; b, percent total live cover; c, percent biological soil crust cover; and d, interspace soil aggregate stability for 55 Semidesert Loam rangeland health assessments, Grand Staircase–Escalante National Monument. In a, numbers indicate sample sizes for multivariate analysis of variance and numbers of assessments that received particular ratings for particular attributes. For each quantitative measure and rangeland health attribute, means annotated with the same letter (a–d) are not significantly different. (Attribute ratings: E indicates extreme departure; ME, moderate to extreme departure; M, moderate departure; SM, slight to moderate departure; and NS, no departure to slight departure from expected reference conditions.)

Factors Contributing to Patterns Among Ecological Sites

Production Potential and Relative Use

At the scale of the entire Monument, upland ecological sites with the greatest production potential tended to be the most degraded, as measured by percentages of assessment locations that were assigned low ratings for all three attributes of rangeland health. Productivity has been widely cited as a factor affecting ecosystem responses to grazing by large herbivores (Milchunas et al. 1988; Cingolani et al. 2005; Lunt et al. 2007) and to disturbance in general (Huston 1979). In the Monument, production potential likely was an indirect factor contributing to general patterns of ecosystem status among different ecological sites because of correlations with land use and plant community composition.

In this rocky dryland environment characteristic of much of the Colorado Plateau, ecological sites with the greatest production potential account for a relatively small proportion of the landscape and thus have tended to receive a disproportionate level of use for livestock grazing—the predominant production-oriented land-use activity on the Monument. For example, estimates based on soil-survey data (NRCS 2005) indicate that productive Upland Loam, Semidesert Loam, and Loamy Bottom ecological sites cumulatively account for approximately 7.4% (56 461 ha) of the total Monument area. In contrast, relatively unproductive ecological sites with low frequencies of low rangeland health ratings (those with signficant χ^2 values in Table 4) account for approximately 33.8% (257 378 ha) of the total Monument area. Relative to the productive big sagebrush ecological sites, the unproductive ecological sites typically have received low levels of use for livestock grazing or other land-use activities except on a very localized basis. On the basis of existing data, it is difficult to quantify differences in livestock use among ecological sites because use is recorded by allotment and allotment boundaries do not correspond with ecological site boundaries.

Plant Community Composition

The relative abundance of different plant functional types is an important factor that affects ecosystem responses to drivers such as livestock grazing (Dı´az et al. 2002; Lunt et al. 2007). In the Monument, rangeland ecological sites with the greatest production potential are characterized by the presence of big sagebrush, with that species accounting for a significant proportion of standing biomass and annual production (20%–30%) in historic climax plant communities described by NRCS (2005). Except for some formerly grazed reference areas and seedings where sagebrush was removed or thinned in the past, most assessments conducted in big sagebrush ecological sites found much higher ratios of sagebrush to perennial grasses than expected on the basis of NRCS ecological site descriptions—a factor that contributed to the assignment of low ratings for biotic integrity at such locations.

Big sagebrush is relatively unpalatable to livestock, and livestock grazing (selective herbivory) has long been cited as a process that has facilitated increases in shrub:grass ratios in sagebrush ecological sites throughout the Intermountain West due to effects of grass removal on competitive relations and fire frequency (USDA Forest Service 1937; Miller et al. 1994). But successional trends resulting in increasing shrub:grass ratios have been reported for ungrazed sagebrush ecosystems in some settings, a pattern that may be attributable to landscape characteristics that naturally protect such sites from fire (West and Yorks 2006). Baker (2006) reviewed the evidence for natural fire regimes in sagebrush ecosystems and concluded that fire exclusion (whether due to grazing or fire suppression) probably has had little effect on vegetation trends in most sagebrush systems because of natural fire-return intervals that are likely to be much longer than commonly assumed. In a study conducted on the Monument, Harris et al. (2003) found significantly higher sagebrush:grass ratios in a grazed area relative to a comparable area on an ungrazed mesa top (both associated with the Upland Loam [mountain big sagebrush] ecological site), suggesting that livestock grazing has played a role in increasing shrub:grass ratios in some settings.

No matter the cause, increases in shrub density can be accompanied by a greater concentration of soil impacts in interspaces among shrubs if such areas are used by livestock and/or large numbers of mule deer (*Odocoileus hemionus*). In many sagebrush-dominated areas associated with the Semidesert Loam ecological site in the Monument, trampling of interspaces has resulted in erosion and the loss of relatively sandy surface horizons, the exposure of relatively fine-textured subsurface horizons, and the subsequent development of ‘‘playettes’’ (Eckert et al. 1986) with vesicular structure (M. Miller, personal observation, August 2001). Interspace playettes have been reported for sagebrush settings elsewhere (Eckert et al. 1986; Pierson et al. 1994), and their presence can indicate altered hydrologic functioning (i.e., transition from infiltration to runoff generation; Pierson et al. 1994), accelerated erosion, and diminished potential for seedling establishment (Eckert et al. 1986). All of these were factors that contributed to low ratings for the three attributes of rangeland health.

Assessment results for big sagebrush ecological sites contrast with those for several ecological sites characterized by grassland physiognomic structure (Desert Sandy Loam [fourwing saltbush], Semidesert Sand [fourwing saltbush], Semidesert Sandy Loam [black grama], and Semidesert Sandy Loam [fourwing saltbush]). These grassland sites also tend to receive preferential use by livestock in the Monument because of high levels of forage production relative to production of unpalatable woody plants, but they all had lower frequencies of low rangeland health ratings than all of the big sagebrush ecological sites except the Upland Sand site (Table 4). This result may be due to the fact that these grassland ecological sites differ from many other semiarid grasslands (e.g., Van Auken

2000) in that they generally lack unpalatable, long-lived woody plants that have the capacity to increase and become persistent site dominants due to succession, absence of fire, or selective herbivory by livestock. In some settings where palatable shrubs such as winterfat (*Ceratoides lanata* [Pursh] J.T. Howell) and fourwing saltbush (*Atriplex canescens* [Pursh] Nuttall) are major components in these ecological sites, moderate livestock grazing actually tends to maintain grassland physiognomic structure whereas release from grazing can result in conversion to shrubland structure (Rasmussen and Brotherson 1986; Floyd et al. 2003).

Soil Texture

Among the five big sagebrush ecological sites, assessment results varied systematically in relation to soil texture. Sagebrush sites primarily associated with fine-loamy soils (seeded Upland Loam and seeded and untreated Semidesert Loam) had higher frequencies of assessments with low ratings for all rangeland health attributes than sites primarily associated with coarse-loamy (Loamy Bottom and Semidesert Sandy Loam [Wyoming big sagebrush]) or sandy (Upland Sand) soils (Table 4; soil textural family classes from NRCS 2005). Livestock grazing and trampling can have adverse impacts on rangeland hydrologic processes and erosion where they cause reductions in ground cover, soil aggregate stability, soil structure, and soil-surface roughness (Thurow 1991; Spaeth et al. 1996; Ward and Trimble 2004). Assessment results reported here for sagebrush ecological sites are consistent with Walker's (2002) proposition that relatively sandy soils are inherently more resistant to livestock impacts on hydrologic processes than soils with lots of silt and clay because infiltration rates are inherently greater in relatively sandy soils. Grassland ecological sites in the Monument also are characterized by coarse-loamy or sandy soils, thus this same soil-hydrologic principle may have contributed to the finding that these sites had relatively low frequencies of low ratings for all three attributes of rangeland health.

Management

Seeded areas associated with the two sagebrush ecological sites on fine-loamy soils had the highest frequencies of low ratings for all three attributes of rangeland health (Table 4). This suggests that past vegetation treatments associated with these two ecological sites generally have not provided long-term ecological benefits compared with untreated areas, although without further research it is difficult to know the relative degree to which degraded conditions in seedings are attributable to pretreatment land uses, long-term effects of mechanical treatments themselves, or post–treatment management. However, it is likely that interactions between soil properties and post–treatment management played a role in the development of poor rangeland-health conditions documented in Semidesert Loam and Upland Loam seedings on the Monument.

Allotment management plans in the past typically have allowed higher levels of forage utilization by livestock in seedings than in comparable untreated areas (P. Chapman, personal communication, June 2007), largely because nonnative forage grasses such as *A. cristatum* are more tolerant of heavy grazing than some native grasses (e.g., Richards and Caldwell 1985). This high-use management strategy inadvertently may have contributed to the relatively degraded conditions found in seedings because of the inherent sensitivity of fine-loamy soils to adverse hydrologic changes, as well as their susceptibility to compaction caused by trampling or other compressive forces (Hillel 1998). Of the ecological sites in Table 4, the seeded Upland Loam, untreated Semidesert Loam, and seeded Semidesert Loam sites had the highest frequencies of assessments with low ratings (moderate or greater departure from reference conditions) for soil compaction (35.0%, 22.5%, and 20.8%, respectively), which is one of the four qualitative indicators that applies to all three attributes of rangeland health (Pellant et al. 2000; Pyke et al. 2002). On the Monument, the typical seasons of livestock use are winter and spring (when soils are most likely to be moist and thus most susceptible to compaction) for the Semidesert Loam site and summer and fall for the Upland Loam site. Because of elevational differences, winter mule deer use of the Semidesert Loam ecological site also tends to be greater than that of the Upland Loam ecological site. Drier soils during summer and fall use may explain why low ratings for soil compaction were less frequent (13.3%) for untreated Upland Loam assessments than for untreated Semidesert Loam assessments.

Patterns Within the Semidesert Loam Ecological Site

Multivariate Gradients in Ecosystem Condition

Analyses of quantitative data collected during assessments of the Semidesert Loam (Wyoming big sagebrush) ecological site describe two multivariate gradients in ecosystem condition (Fig. 2a). Interspace soil aggregate stability and BSC cover tended to vary independently of total plant cover, functional-group richness and diversity, and percentage of bare ground (Fig. 2a). These results support approaches to rangeland assessment and monitoring that focus on multiple indicators of soil stability, hydrologic function, and biotic integrity rather than on plant community composition alone (Pellant et al. 2000, 2005; Herrick et al. 2005). Soil aggregate stability is related to several ecosystem processes associated with concepts of soil quality and rangeland health including erosion resistance, infiltration capacity, and soil biotic activity (Herrick et al. 1999, 2001). Likewise, BSCs are important contributors to soil stability (Belnap 1995; Williams et al. 1995a, 1995b), nutrient cycling (Evans and Lange 2003), and biological diversity (Rosentreter and Belnap 2003). Because soil-surface roughness increases residence time of runoff on hillslopes (Ward and Trimble 2004), roughness attributable to well-developed BSCs also has been cited as a factor that can enhance runoff retention and infiltration relative to comparable soils without well-developed BSCs (Belnap 2003; Warren 2003). This provides strong rationale for including BSCs (abundance, spatial continuity, and degree of roughness) as indicators of hydrologic functioning for ecological sites with high BSC potential.

Consistent with results of Bowker et al. (2006), data reported here (Fig. 3c) indicate the high BSC potential of soils associated with the Semidesert Loam ecological site. Three distinct soils (Barx series; Progresso series, cool phase; and Ruinpoint series) were found to have BSC cover greater than 40%, with maximum BSC cover of 56% on the Barx series, which is the dominant soil associated with this ecological site in the Monument. Because of the hydrologic sensitivity and high BSC potential of fine-loamy soils associated with this ecological site, the functional significance of BSCs for runoff retention and erosion resistance is particularly high. The steep decline in mean BSC cover between assessment locations assigned NS ratings and those assigned SM ratings for the three attributes of rangeland health (Fig. 3c) also indicates the low resistance and resilience of well-developed BSCs to disturbance (Belnap and Eldridge 2003). In combination, these factors suggest that BSC loss and the degradation of hydrologic and soil-stabilization functions performed by BSCs on fine-loamy soils likely played a role in the development of poor rangeland-health conditions documented for this ecological site.

Relations Between Quantitative and Qualitative Data

Quantitative data exhibited a large degree of variability among Semidesert Loam locations that were assigned the same qualitative ratings by assessment teams (Figs. 2b–2d). Some of this variability probably reflects the fact that ratings for the three qualitative attributes were based on suites of multiple indicators, several of which are difficult to measure and thus were not addressed by the quantitative sampling (Pellant et al. 2000; Pyke et al. 2002). Accordingly, variations in the status of indicators that were evaluated solely on a qualitative basis could have caused variations in rangeland-health ratings among assessment locations that might have been similar with respect to the quantitative variables.

It is also probable that the assessment process was not as consistent as it might have been had qualitative ratings been linked more explicitly with the quantitative data. Although quantitative data certainly were useful during the assessment process, they would have been more effective in improving assessment consistency on a real-time basis if thresholds between rating classes (NS, SM, M, ME, and E) were defined by ranges in values for one or more quantitative variables. The reference worksheet included in version 4 of the IIRH technique (Pellant et al. 2005) is a significant improvement that seeks to establish such a quantitative framework for rating indicators. This approach will work well for indicators that are easily quantified (e.g., percentage of bare ground) but will be less effective for indicators that are difficult to quantify (e.g., amount and distribution of overland flow paths; Table 2). Ideally, quantitative rating frameworks would be developed through process-based studies conducted on an ecological-site basis, but resources are insufficient to support this work for more than a small number of rangeland ecological sites. An alternative is to develop quantitative rating frameworks for specific ecological sites on the basis of existing, published research and through the use of standardized sampling techniques (e.g., Herrick et al. 2005) to acquire regional data sets describing ranges of variability across gradients of land use and condition, including sites heavily impacted by human activities as well as relatively unimpacted reference sites (Whitford 1998; Tongway and Hindley 2004). Quantitative data describing ecosystem-specific condition gradients (e.g., Figs. 2a and 3; Bosch and Kellner 1991) would be of utility to a wide range of institutions and stakeholders involved in assessment, monitoring, and sustainable management of rangeland ecosystems (e.g., Parrish et al. 2003), as well as to scientists engaged in related research activities (Herrick et al. 2006; Vavra and Brown 2006). The absence of such contextual data sets constrains the interpretation of data from moment-in-time ecological assessments, whether based on qualitative or quantitative techniques.

Additional Lessons Learned From Application of the Technique

As applied in this project, the IIRH technique had two important and related strengths. First, it was effective in broadening many practitioners' perspectives concerning the number and types of ecological attributes encompassed by the notion of "rangeland health." Staff who had previously focused primarily on key forage species or measures of plant community composition became attuned to soil and hydrologic processes and their importance for evaluating the status of rangeland ecosystems. Second, the technique proved valuable as a tool for facilitating discussion among diverse practitioners and stakeholders about ecological processes in rangelands.

Four factors would improve application of the IIRH technique relative to its application in this project. As discussed above, consistency would be improved by greater integration of quantitative data in the assessment technique. Second, a probabilistic sampling design (e.g., Theobald et al. 2007) would enable spatial analyses and inferences not possible with the judgment-based design used in this project. Third, the prominence of soil and hydrologic indicators in the IIRH technique calls for practitioners to have greater professional knowledge of these topics. Soil expertise is lacking in most BLM field offices (B. Ypsilantis, personal communication, July 2007), and a trained soil scientist participated in only 7 of 507 assessments in this project. As a consequence, it is probable that there was a tendency for assessment teams to understate the degree to which particular soil indicators (e.g., soil instability, soil surface degradation, and compaction) were expressed across the project area. Finally, conceptual models of ecosystem dynamics (e.g., Bestelmeyer et al. 2004) need to play a stronger, more explicit role in the assessment process to enhance the information content of assessment results and thus their value for informing the development of effective strategies for management and restoration (Briske et al. 2005; Herrick et al. 2006; Hobbs 2007).

Management Implications

The qualitative IIRH technique used in this project yielded meaningful data regarding the status of three ecosystem attributes (soil/site stability, hydrologic function, and biotic integrity) and how the status of these attributes varied among and within a large number of ecological sites across a 760 000- ha landscape. Patterns among ecological sites in terms of the frequency of assessments with low ratings for all three attributes appear attributable to several interacting factors including 1) potential primary production and long-term exposure to production-dependent land-use activities such as livestock grazing; 2) the presence of unpalatable woody plants that have the capacity to increase and become persistent site dominants due to selective herbivory, absence of fire, or succession; 3) soil texture through effects on hydrologic responses to grazing, trampling, and other disturbances; and 4) past management that resulted in high livestock use of ecological sites with sensitive fine-loamy soils following treatments designed to increase forage availability. In particular, results indicate that big sagebrush ecological sites with relatively high production potential had high frequencies of assessments with low ratings for all three ecosystem attributes, whereas shallow-soil ecological sites with relatively low production potential and the presence of Utah juniper and/or Colorado pinyon had low frequencies of assessments with low ratings for all three attributes. Areas where fine-loamy big sagebrush ecological sites were seeded in the past to increase livestock forage were characterized by frequencies of low rangeland health ratings that were higher than or similar to comparable untreated areas, suggesting that these treatments have not provided long-term ecological benefits relative to untreated areas. For seeded areas, it is likely that interactions between soil properties and post–treatment management played a role in the development of poor rangeland-health conditions documented by assessments. These results—that sites with the greatest production potential tended to be the most degraded, and that net effects of past management treatments have not been ecologically beneficial—suggest that ongoing management, restoration treatments, and post–treatment management of these ecological sites should be tailored to account for their sensitivity to degradation.

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Untangling the Biological Contributions to Soil Stability in Semiarid Shrublands

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ABSTRACT

Communities of plants, biological soil crusts (BSCs), and arbuscular mycorrhizal (AM) fungi are known to influence soil stability individually, but their relative contributions, interactions, and combined effects are not well understood, particularly in arid and semiarid ecosystems. In a landscape-scale field study we quantified plant, BSC, and AM fungal communities at 216 locations along a gradient of soil stability levels in southern Utah, USA. We used multivariate modeling to examine the relative influences of plants, BSCs, and AM fungi on surface and subsurface stability in a semiarid shrubland landscape. Models were found to be congruent with the data and explained 35% of the variation in surface stability and 54% of the variation in subsurface stability. The results support several tentative conclusions. While BSCs, plants, and AM fungi all contribute to surface stability, only plants and AM fungi contribute to subsurface stability. In both surface and subsurface models, the strongest contributions to soil stability are made by biological components of the system. Biological soil crust cover was found to have the strongest direct effect on surface soil stability (0.60; controlling for other factors). Surprisingly, AM fungi appeared to influence surface soil stability (0.37), even though they are not generally considered to exist in the top few millimeters of the soil. In the subsurface model, plant cover appeared to have the strongest direct influence on soil stability (0.42); in both models, results indicate that plant cover influences soil stability both directly (controlling for other factors) and indirectly through influences on other organisms. Soil organic matter was not found to have a direct contribution to surface or subsurface stability in this system. The relative influence of AM fungi on soil stability in these semiarid shrublands was similar to that reported for a mesic tallgrass prairie. Estimates of effects that BSCs, plants, and AM fungi have on soil stability in these models are used to suggest the relative amounts of resources that erosion control practitioners should devote to promoting these communities. This study highlights the need for system approaches in combating erosion, soil degradation, and arid-land desertification.

Keywords: arbuscular mycorrhizal fungi; arid ecosystems; biological soil crusts; erosion control; soil stability; structural equation modeling (SEM)

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Introduction

Organisms that inhabit the soils of all ecosystems, such as plants, invertebrates, fungi, and bacteria, mediate the formation and maintenance of soil structure and stability. Christensen et al. (1996) highlight the maintenance of soils as an important ecosystem service and emphasize the need to understand the processes behind such services in order to manage sustainable ecosystems. We define soil structure as the spatial arrangement of soil particles (i.e., aggregation) and soil stability as the ability of soils to resist erosive forces. Soil structure and stability are ecosystem properties, while their formation and maintenance can be considered to be ecosystem services. A substantial body of literature shows that, individually, soil organisms strongly influence soil structure and stability (Belnap and Gardner 1993, Angers and Caron 1998, Miller and Jastrow 2000, Rillig 2004). However, the myriad of interactions among soil biota, and the corresponding net effects of these interactions on soil stability, represent a level of complexity that soil ecologists are only beginning to understand. In arid and semiarid ecosystems, where soils are particularly fragile and susceptible to erosion (Dregne 1983), the interactions of soil organisms and their effects on soil stability are poorly understood. Yet, soil erosion and loss are implicated as both symptoms and causes of desertification (Schlesinger et al. 1990, UNCCD 1994, Reynolds et al. 2007) and the eventual ‘‘collapse’’ of functioning ecosystems and human societies (Diamond 2005). The scientific and ecological challenge lies in understanding how soil organisms interact in natural ecosystems to influence soil stability. Understanding the major mechanisms that generate and maintain soil stability in arid lands will help ecosystem managers improve efforts to control erosion and combat desertification.

In this study, we examined the combined effects of plants, biological soil crusts (BSCs), and arbuscular mycorrhizal (AM) fungi as major drivers of soil stability in dryland ecosystems. These different communities of organisms can strongly influence soil stability, but likely function in different ways and on different scales. Plant roots and root exudates bind soil microaggregates (<250 μ) together, forming macroaggregates (>250 μ) and stabilizing rhizosphere soil. In addition, above-ground and below-ground plant litter contributes to soil organic matter pools, which promote soil structure and stability (Tisdall and Oades 1982). In many semiarid shrublands, dominant shrub species occur in ‘‘fertility islands’’ (Fig. 1) that are separated by a matrix of comparatively unfertile soil (Schlesinger et al. 1996, Schlesinger and Pilmanis 1998). Shrub islands and their associated litter resist physical erosive forces from raindrops and surface runoff, while unvegetated interspaces have been found to be particularly susceptible to wind and water erosion (Abrahams et al. 1995.)

Biological soil crusts, communities of primarily mosses, lichens, and cyanobacteria, inhabit soil surfaces in the unvegetated matrix of undisturbed landscapes and promote soil stability in arid and semiarid ecosystems (reviewed in Belnap et al. 2001). Cyanobacterial filaments help bind soil particles together to form microaggregates (Belnap and Gardner 1993). BSC communities have

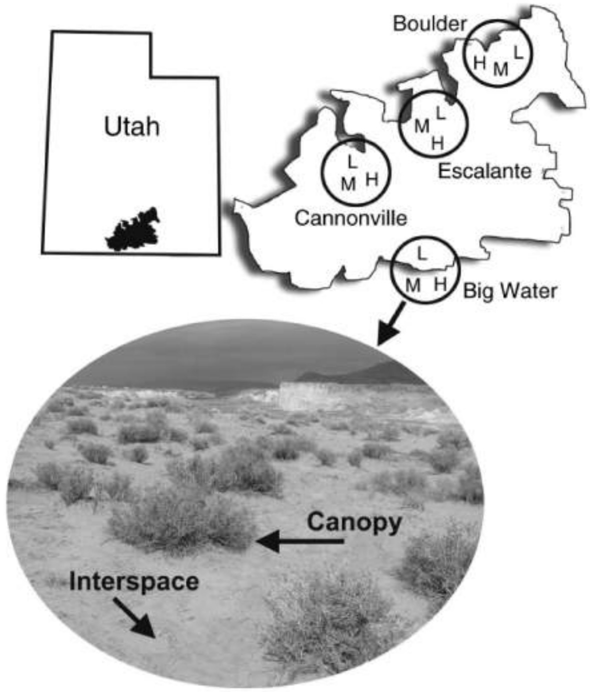

Figure 1. Location of the Grand Staircase-Escalante National Monument (GSENM) in southern Utah, USA, and the four sampling regions, each containing a low (L), medium (M), and high (H) stability site. The inset photograph typifies a single site, illustrating ''shrub islands'' and microsite heterogeneity across the landscape.

the potential to reduce soil erosion by increasing water infiltration rates, decreasing raindrop impact, and decreasing surface runoff (reviewed in Warren 2001). These communities also reduce wind erosion because soil aggregates linked by cyanobacterial polysaccharides require greater wind velocity to move compared to single grains (Marticorena et al. 1997). In addition, BSCs contribute to surface organic matter pools and alter soil fertility by N fixation. These soil surface communities are a dominant component of many arid ecosystems and, in undisturbed areas, can make up >70% of living cover across the landscape (Belnap et al. 2003).

Another major component of arid ecosystems, AM fungi, have a strong potential role in soil stability. The majority of plants in arid ecosystems associate with AM fungi and support diverse communities of these ubiquitous root symbionts (Stutz et al. 2000, Chaudhary 2006). These fungi deliver a variety of benefits to plants (e.g., increased nutrient uptake, improved water relations, protection from pathogens) in exchange for photosynthates (Newsham et al. 1995). Arbuscular mycorrhizal fungi have been found to physically stabilize soil through the enmeshment of soil particles by filamentous hyphal networks and the production of glomalin, a putative heat-shock protein homolog (Gadkar and Rillig 2006), quantified in soils as operationally defined glomalin-related soil protein (GRSP; Wright and Upadhyaya 1996, Miller and Jastrow 2000, Rillig 2004). Glomalin is a component of the hyphal walls of AM fungi, which likely remains recalcitrant in soils following hyphal decomposition (Driver et al. 2005, Gadkar and Rillig 2006). Both hyphal density and GRSP concentration in soils have been found to be strongly correlated with aggregate stability in mesic soils (Wright and Upadhyaya 1998). In a tallgrass prairie, AM fungal hyphal density was found to have a stronger direct effect on percent macroaggregation than fine roots (0.2–1.0 mm diameter), very fine roots (<0.2 mm diameter), organic carbon, microbial biomass, or inorganic carbonates (Jastrow et al. 1998). Arbuscular mycorrhizal fungi may play an important role in generating and maintaining soil stability in arid ecosystems, though our knowledge of their contribution compared to other biotic and abiotic components of the system remains speculative.

Understanding the contributions to soil stability of biotic components of arid ecosystems is important for a number of reasons. First, drylands make up roughly 41% of terrestrial ecosystems (Reynolds et al. 2007), yet the majority of erosion models have been developed in mesic agroecosystems, and their application in natural dryland ecosystems has proved inappropriate (Pierson 2000). Second, severe soil erosion results in desertification, which the United Nations recognizes as a major economic, social and environmental problem facing societies – even designating 17 June as the World Day to Combat Desertification (UNCCD 1994, Cardy 2000). Desertification results in a decline in the quality and quantity of natural assets such as soil, water, and biodiversity (Narjisse 2000). Drylands are home to two billion people, one-third of the global population, and nearly $65.5 billion is lost annually due to forgone income from desertified cropland and rangelands (Dregne and Chou 1992, Arnalds and Archer 2000, Millenium Ecosystem Assessment 2005). And third, understanding the biological mechanisms that generate and maintain soil stability will aid in the prioritization of soil conservation and restoration efforts. For example, the majority of biological erosion control efforts stress the incorporation of plants (Toy et al. 2002). But in dryland ecosystems, measures to promote other organisms could also be beneficial. Untangling the contributions of soil organisms to soil stability is prerequisite to the preservation and restoration of soil resources.

We studied plant, BSC, and AM fungal communities of semiarid *Artemisia* shrubland ecosystems of the southern Colorado Plateau in the southwestern United States. Mean annual precipitation in this region is generally <450 mm, and plant communities are categorized as part of the larger Great Basin Conifer Woodland biotic community type, one of the most extensive types of vegetation found in the southwestern United States (Brown 1994). The Colorado Plateau region contains great edaphic heterogeneity, and erodibility of these soils can vary depending on proximity to biological soil stabilizing agents. For instance, soils with an intact BSC community and no plant cover, such as those of undisturbed shrub interspaces, can have highly stable soil surfaces (the top 1 cm), but unstable soils as few as 1–2 cm below the surface. In contrast, subsurface soils that contain plant roots and AM fungal hyphae, such as those found underneath shrub canopies, can be highly resistant to erosion (V. B. Chaudhary, *personal observation*). A major source of soil disturbance in the Colorado Plateau region is livestock production; few areas have escaped cattle grazing, and it is currently permitted in numerous parks, monuments, and recreation areas. In an effort to determine early warning signs of rangeland degradation, several land management agencies initiated a program to qualitatively and quantitatively assess rangeland health using indicators of soil stability, hydrologic function, and biotic integrity (Pellant et al. 2000). Soil stability at nearly 500 sites across the southern Colorado Plateau was measured, making it an excellent region in which to study the relationships between soil stability and the dominant organisms of semiarid shrublands.

Goals and questions

The purpose of this study was to address the following overarching research question: How do plants, BSCs, and AM fungi differ in their contributions to soil stability in semiarid shrublands? To this end we utilized a multivariate modeling technique to examine plants, BSCs, and AM fungi as a system of interrelated variables. Because these major biological components of drylands likely interact in natural systems, we sought to investigate the direct and indirect effects of these interactions on soil stability as well as on each other (note that direct and indirect effects are understood with reference to direct and indirect pathways in models). We first formulated a conceptual model based on information from previous research and ecological knowledge of the system and used that to guide the specification of *a priori* structural equation models (Grace and Bollen 2008). We then evaluated the structural equation models using our empirical data. From this analysis process we obtained estimates of the strength of all hypothesized relationships present in the model.

Fig. 2 shows the *a priori* conceptual model we formulated to represent hypothesized effects of plants, BSCs, and AM fungi on soil stability. Dashed boxes represent conceptual variables without regard for precisely how they would be specified in statistical models. Arrows represent hypothesized mechanistic processes associated with various pathways (summarized in Table 1). Several causal pathways that have been shown to exist; for example, feedbacks between AM fungal abundance and plant cover and BSC cover and plant cover (Bever 1994, Belnap et al. 2001), were omitted from the conceptual model because they likely operate on different time scales than those examined in this study. Paths J1–J3 and K were included in the model to account for variation caused by abiotic differences among sites and incorporate sampling design structure.

Related to the ideas represented in our conceptual model, we sought to address two main research questions: (1) What are the direct and indirect contributions of plants, BSCs, and AM fungi to soil stability and how do they compare in strength to one another? Further, do our predictors explain a substantial proportion of the observed variation in soil stability? (2) Do the biological contributions to soil stability differ between surface and subsurface soils? Here we hypothesized that BSCs play a primary role in surface soil stability, while plants and AM fungi play a more important role in subsurface stability.

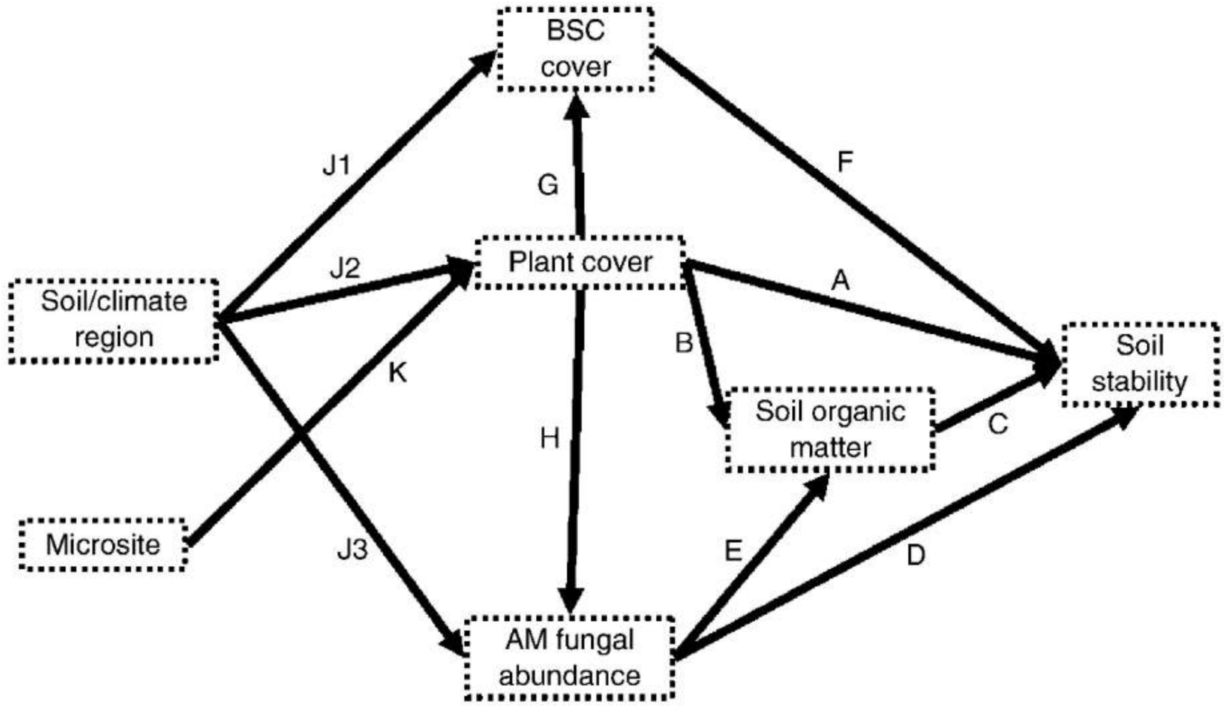

Figure 2. A priori conceptual model of hypothesized causal relationships between major biotic and abiotic components of semiarid shrublands and soil stability. Dashed boxes represent constructs of interest without regard for precisely how they are measured. Proposed mechanisms for each path (letters A–K) are described in Table 1.

Methods

Sampling design

To examine the biological contributions to soil stability in a semiarid shrubland landscape, we sampled soil across a gradient of soil stability levels within four soil (Bowker and Belnap 2008) and climatic regions in the 769 000-ha Grand Staircase-Escalante National Monument (GSENM) in southern Utah, USA (37°24' N, 111°41' W; Fig. 1). Sites representing three surface soil stability levels (low, medium, or high) were selected from within each of the four regions for a total of 12 sites. Regions were roughly 5000 ha in size, and sites were 0.5 ha in size. The four soil and climatic regions were located near the towns of Big Water, Cannonville, Escalante, and Boulder. Soil, climate, and vegetation characteristics of each region are summarized in Appendix A. The average surface (top 1 cm) and subsurface (15 cm deep) soil stability rating of each site was previously determined in the Bureau of Land Management's extensive rangeland health assessment (Pellant et al. 2000) using an in-field aggregate stability test (Herrick et al. 2001). In this procedure, soil peds are assigned a rank score between 1 (<10% structural integrity after wet sieving) and 6 (>75% structural integrity after wet sieving). These aggregate stability scores have been shown to be curvilinearly correlated to the percentage of aggregate stability traditionally measured in the laboratory with mechanical wet sieving (Herrick et al. 2001). All soil sampling sites were located using GPS coordinates, and Rangeland Health Assessment stability ratings were confirmed by conducting additional slake tests at the time of soil sampling. No difference was detected between our slake measurements and those of the earlier Rangeland Health Assessment Protocol (Wilcoxon signed-rank test, P=0.548).

To account for microsite heterogeneity commonly present in arid ecosystems, sampling was stratified to include soil from both underneath shrub islands (referred to as "canopy") and interspaces between shrub islands (referred to as "interspace"). At each site, 18 soil samples were collected at a depth of 15 cm, half from the rhizosphere of randomly selected shrubs and the other half from the adjacent interspaces. In entirety, the study contained 216 observations collected from a total of 12 sites. To hold the sampling location consistent, canopy samples were collected from the north side of the shrub and interspace samples

Pathway	Alpha code	Interpretation	Mechanistic examples
Plant cover → soil stability	A	influence of plant cover on soil stability independent of effects mediated indirectly by soil organic matter, AM fungi, or BSCs	dampening of wind and water erosive forces, root enmeshment of soil macroaggregates
Plant cover → soil organic matter	B	contribution of plants to soil organic matter accumulation independent of any influence through AM fungi	root contributions to soil organic matter
Soil organic matter → soil stability	C	contribution of soil organic matter to soil stability	organic matter binding to clay particles to produce aggregates
AM fungi → soil stability	D	separate contribution of AM fungi to soil stability	hyphal enmeshment of soil microaggregates, glomalin production
AM fungi → soil organic matter	E	contribution of AM fungi to soil organic matter accumulation	spore and hyphal contributions to soil organic matter
BSC → soil stability	F	independent contribution of biological soil crusts to soil stability	soil particle adhesion by cyanobacterial filaments, increased water infiltration
Plant cover → BSC	G	influence of plants on biological soil crusts	reduction of BSC available habitat by litterfall and shading
Plant cover → AM fungi	H	influence of plants on AM fungi	obligate biotrophy: AM fungi cannot live without plants
Region → BSC	J1	regional differences in biological soil crust cover	BSC cover varies by climate
Region → plant cover	J2	regional differences in plant cover	plant cover varies by climate
Region → AM fungi	J3	regional differences in AM fungi abundance	AM fungal abundance varies by climate
Microsite → plant cover	K	microsite differences in plant cover	more plant cover near shrub canopies than interspaces

Notes: All pathways represent the influence of a factor independent from other influences in the model.

Table 1. Pathways and presumed processes associated with a priori model (see Fig. 2).

were located at least 1 m away from any shrub. Because AM fungi have been shown to exhibit host specificity, shrub genus was held constant. *Artemisia tridentata* plants were sampled in the Boulder, Cannonville, and Escalante regions, while *Artemisia filifolia* plants were sampled in the Big Water region. *Artemisia* was chosen as the target genus because it is the dominant plant species at all sites and has a wide distribution across the western United States. Soil samples were collected in May 2004, air-dried, and stored at 4°C until processed.

Plant, BSC, and AM fungal assessment

At each sample location, plant cover and BSC cover were visually quantified within a 1-m^2 quadrat. Cover of each plant species within a plot was individually measured, but later summed for analysis of total plant cover. Roots were not present at our soil sampling depth of 15 cm; therefore, we assumed plant cover to be a reasonable proxy for root biomass. Total BSC cover was quantified by the presence of any BSC community component, including cyanobacteria, lichens, or bryophytes. Species most often encountered were the cyanobacterium *Microcoleus vaginatus* and the moss *Syntrichia caninervis*.

Because an optimal technique for measuring AM fungal abundance at the GSENM has not been determined, we quantified AM fungi using four different methods: a mycorrhizal infection potential (MIP) bioassay, hyphal density, GRSP concentration, and spore abundance. The MIP bioassay is a comparative measure of viable AM fungal propagules, where root colonization of bait plants is assessed as a measure of living, infective mycorrhizal propagules present in the soil (Moorman and Reeves 1979, Jasper et al. 1989). In July 2004, *Zea mays* bait plants were grown in 150 mL of each soil sample in 3.8 cm diameter Conetainers (Stuewe and Sons, Corvallis, Oregon, USA) in a greenhouse. After 6 weeks, plants were harvested, and a 0.25-g root subsample was cleared, stained, and examined using a compound microscope (200 X magnification) for the presence of AM fungal structures (McGonigle et al. 1990, Vierheilig et al. 1998).

Hyphal density and GRSP concentration were assessed because of their suspected physical and chemical contributions to soil structure (Miller and Jastrow 2000). Hyphal density was quantified by agitating 5 g of soil in a blender, siphoning the suspension with a pipette, and then collecting hyphal fragments on a membrane filter (modified from Jakobsen et al. 1992). Hyphae were preserved on permanent slides, examined with a compound microscope for morphology that is characteristic of AM fungi (e.g., absence of regular septae), and length per gram of soil was calculated using the grid-line intersection method (Tennant 1975). Two different fractions of GRSP, easily extractable Bradford reactive soil protein (EE-BRSP) and total BRSP, were quantified (Rillig 2004). Protein concentration of each sample was determined using the Bradford colorimetric protein assay (Bradford 1976, Wright and Upadhyaya 1996).

Spore abundance was quantified as another potential indicator of AM fungal abundance and was determined by extracting spores from a 30-g subsample of soil by wet-sieving and centrifuging through a sucrose density gradient (Gerdemann and Nicholson 1963, McKenney and Lindsey 1987). Spores were collected by suction filtration and mounted onto glass microscope slides for enumeration using a compound microscope (2003 magnification).

Soil properties

Six abiotic soil characteristics were measured primarily to explore their potential relationships with plants, BSCs, and AM fungi, and secondarily to explore their relationships with soil stability. Soil organic matter was measured by percentage of mass loss after ashing for 24 h at 550°C. Inorganic carbon was removed from soil samples prior to ashing using a method adapted from Harris et al. (2001) by washing soil samples with 6 mol/L HCl to evolve carbonates. Soil pH and electrical conductivity (EC) were determined by creating a soil–water slurry and measuring with a glass electrode pH meter (Corning Incorporated, Corning, New York, USA) and a table-top EC meter (YSI, Yellow Springs, Ohio, USA). Soil ammonium (NH_4^+) and nitrate (NO_3^-) concentrations were measured using KCl extraction, and available phosphorus (P) concentration was analyzed using the Mehlich III extraction procedure (Mehlich 1984).

Analysis of data

We examined the relationships between soil stability, plants, BSCs, AM fungi, and soil properties by conducting pairwise correlations between all response variables and comparing the strength of these relationships using Pearson's correlation coefficients (*r*). Analyses were performed for a total of 216 observations. All correlation analyses were performed using JMP 4.0 Statistical Package (SAS Institute 2000).

To analyze our data as a system of interrelated variables, we evaluated our *a priori* model of the causal relationships among agents of soil stabilization using structural equation modeling (SEM). SEM is a method of specifying and evaluating complex hypotheses involving multiple pathways of influence operating in systems (Bollen 1989, Shipley 2000, Grace 2006). It contrasts most directly with univariate models, which are primarily suited for selection of sets of predictors and for the summarization of net effects. SEM can be performed using either maximum likelihood or Bayesian methods (Lee 2007). SEM involves both the estimation of parameters and an evaluation of data–model consistency. By comparing model-implied covariance structure with the actual covariance structure in data, an evaluation of overall model fit is achieved (typically using a model χ^2 test). Such evaluations of overall model fit permit not only an assessment of specified pathways, but also detection of unanticipated relationships.

We used the following protocol: first, we created an *a priori* conceptual model of presumed causal relationships (Fig. 2). We considered surface and subsurface stability separately in two parallel models. Working in a backward direction from hypothesized effect to hypothesized cause, we constructed the model in two primary phases. The process of building models in multiple phases is a useful strategy to manage model complexity and focus on the most important relationships (Grace and Keeley 2006). In the first phase, we constructed models containing all variables proposed to have a direct influence upon soil stability and their proposed interrelationships. We evaluated the fit of these models using the maximum likelihood χ^2 goodness-of-fit test, Joreskög's goodness of fit index (GFI), and the root mean square error of approximation (RMSEA) index. Rules of thumb for desired values for these indices are high *P* values for the χ^2 test, close to 1 for Joreskög's GFI, and close to 0 for RMSEA. Using multiple goodness-of-fit indices is generally recommended in SEM, particularly when sample size is large

(>100 observations; Grace 2006). Based on the results of goodness-of-fit tests, we decided which variables were the most informative and retained them, excluding less predictive measures of our concepts. At this stage of the process we also resolved directionality of primary causal influences between pairs of variables that could conceivably have a feedback relationship by comparing alternative models involving reciprocal relationships and choosing the best-fitting model. While many parts of an *a priori* model are generally confirmed, a satisfactory goodness of fit is often not obtained initially, and rather than stop at the confirmatory stage, it is more informative to engage in exploratory analyses. Thus, after initial evaluations, we conservatively used modification indices (single algorithm-provided changes in the model that can result in better fit; Jöreskog and Sörbom 1984) when justifiable on theoretical grounds or past knowledge. Recommended changes were considered one at a time until a satisfactory overall fit was obtained. When this portion of the model had achieved a satisfactory fit, we began the second phase of model construction and introduced abiotic variables. We repeated the above protocol, discarding uninformative variables. Uninformative weak pathways were those that, when removed, did not alter the fit of the model. Again we used modification indices conservatively until we arrived at a model structure with satisfactory fit. It is important to note that in the χ^2 test, low P values indicate lack of fit and poor empirical support for the multiple causal hypotheses in the model. At this point, we grouped AM fungal variables together into a composite variable (Grace and Bollen 2008), a useful way to observe the combined effects of conceptually linked variables. Finally, we removed uninformative weak pathways for simplification and retested the resultant final model. Final models generated in this way are considered to be provisional until confirmed by being used as *a priori* models in future studies. All SEM analyses were performed using AMOS Software Version 5 (SPSS 2006).

Results

Relationships between soil stability and plants, BSCs, and AM fungi

Soil surface stability and subsurface stability were weakly correlated with each other (r=0.39) and with many biotic and abiotic variables (Table 2). Surface stability was weakly positively correlated with EE-BRSP concentration (r =0.34), spore abundance (r=0.27), plant cover (r =0.23), hyphal density (r =0.21), BSC cover (r=0.19), and percentage of MIP colonization (r=0.13). Surface stability was weakly negatively correlated with soil NH4 (r =0.19). Subsurface stability was weakly positively correlated with plant cover (r =0.47), percentage of organic matter (r =0.47), percentage of MIP colonization (r =0.45), electrical conductivity (r =0.42), hyphal density (r=0.41), EE-BRSP concentration (r =0.34), and spore abundance (r =0.18). Subsurface stability was negatively correlated with BSC cover (r =0.36) and NH4 (r =0.25). Means of all AM fungal variables, including patterns in variation at several spatial scales are presented in another manuscript (V. Bala Chaudhary, N. C. Johnson, T. E. O'Dell, and M. C. Rillig, *unpublished manuscript*).

Surface stability model

Results were found to be congruent with our hypothesized conceptual model of the biotic and abiotic factors that influence surface soil stability in semiarid shrublands. Results are summarized in Fig. 3A. Note that mention of direct and indirect effects is understood to be within the context of direct and indirect paths in the models. Thirty-five percent of the variation in soil surface stability was explained by this model. Biological soil crust cover had the strongest direct effect on surface soil stability (0.60), followed by plant cover (0.44), AM fungal abundance (0.37), and then soil/climate region (0.21). In addition to direct contributions, plant cover influenced surface soil stability indirectly in two ways. First, plant cover appeared to indirectly hinder surface soil stability by having a negative relationship with BSC cover, which in turn promotes surface stability. Second, plant cover appeared to indirectly encourage surface soil stability by having a positive relationship with AM

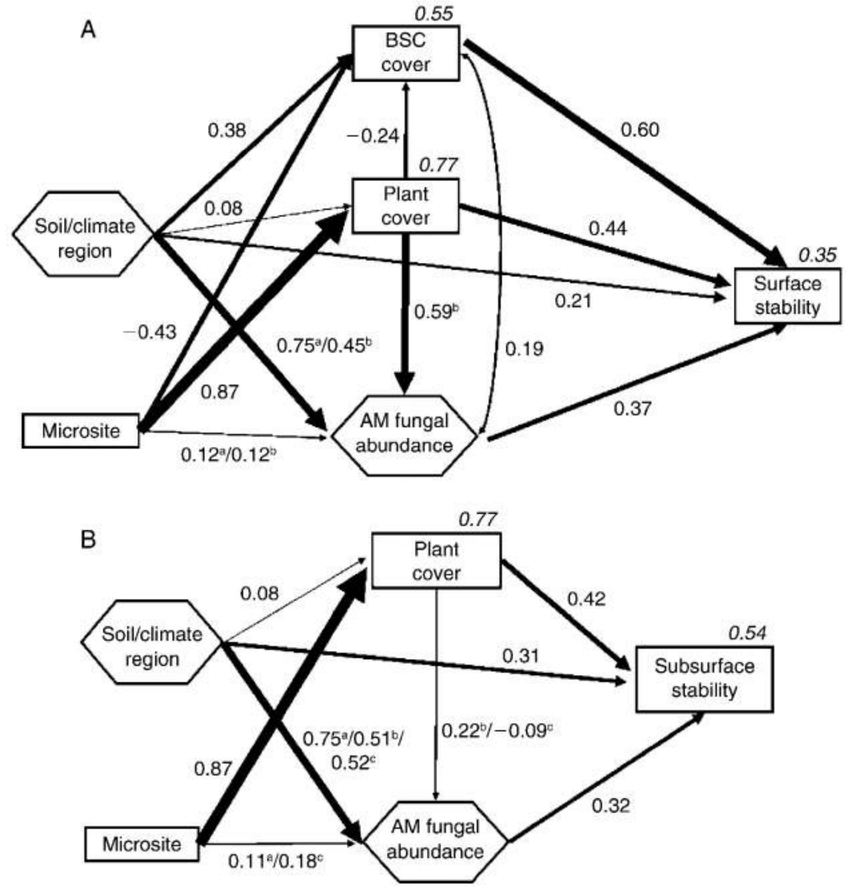

Figure 3. Final structural equation models (SEMs) of the biotic and abiotic contributions to (A) surface and (B) subsurface soil stability in semiarid shrublands. Values associated with arrows (and line width) relate to path strength. Rectangles represent individual measured variables, while hexagons represent composite effects. Values in italics above rectangles indicate the proportion of variation explained for the given measured variable. In the surface stability model (panel A), the superscript letter ''a'' refers to influences on hyphal density, and the superscript ''b'' refers to influences on easily extractable Bradford-reactive soil protein (EE-BRSP). Bootstrap fit $P = 0.69$, $\chi^2 = 3.96$, $P = 0.68$, $\chi^2/df = 0.66$, GFI = 0.996, and RMSEA = 0.0. In the subsurface stability model (panel B), the superscript letter ''a'' refers to influences on hyphal density, the superscript ''b'' refers to influences on total BRSP, and the superscript ''c'' refers to influences on viable propagules. Bootstrap fit $P=0.75$, $\chi^2=4.088$, $P=0.665$, $\chi^2/df= 0.681$, GFI = 0.996, and RMSEA = 0.0.

fungal abundance, which in turn promotes surface stability in the model. The total influence of plant cover on surface soil stability, including direct and indirect effects, was strongly positive (0.49; Table 3). The variables that best explained AM fungal abundance in the surface stability model were EE-BRSP concentration and hyphal density. Both EE-BRSP concentration (0.84) and hyphal density (0.36) strongly contributed to the AM fungal abundance composite variable. AM fungal abundance had a strong positive relationship with surface soil stability even though AM fungi are not thought to exist in the top few millimeters of soil. A nondirectional residual correlation (0.19) between BSC cover and AM fungal abundance was found.

In contrast to our hypothesized model, rhizosphere soil organic matter content did not explain surface soil stability and was therefore omitted from the final model. Model results imply that microsite positively influenced plant cover (0.87), but negatively influenced BSC cover (-0.43).
In other words, samples from underneath shrub canopies had higher plant abundance, but lower BSC cover than samples from interspaces. Furthermore, microsite had no direct influence on surface soil stability. In addition to directly influencing surface soil stability, soil/climate region strongly influenced BSC cover and AM fungal abundance, indicating that these biotic variables vary considerably across our four sampling regions.

	Surface stability	Subsurface stability	Plant cover (%)	BSC cover (%)	Hyphal density (m/g)	Spore abundance	EE-BRSP (μg/g)	MIP colonization (%)	Organic matter (%)	EC (μS)	pH	P (ppm)	NH_4^+ (ppm)	NO_3^- (ppm)
Surface stability	1.00													
Subsurface stability	0.39*	1.00												
Plant cover (%)	0.23*	0.47*	1.00											
BSC cover (%)	0.19*	−0.36*	−0.62*	1.00										
Hyphal density (m/g)	0.21*	0.41*	0.10	−0.19*	1.00									
Spore abundance	0.27*	0.18*	0.41*	−0.18*	0.18*	1.00								
EE-BRSP (μg/g)	0.34*	0.34*	0.51*	−0.28*	0.29*	0.65*	1.00							
MIP colonization (%)	0.13*	0.45*	0.06	−0.09	0.48*	0.01	0.06	1.00						
Organic matter (%)	0.11	0.47*	0.11	−0.33*	0.73*	0.29*	0.40*	0.43*	1.00					
EC (μS)	0.02	0.42*	0.15*	−0.38*	0.51*	0.12	0.23*	0.32*	0.70*	1.00				
pH	−0.05	0.11	0.03	−0.14*	0.16*	−0.16*	−0.21*	0.04	0.08	−0.06	1.00			
P (ppm)	0.10	−0.05	0.27*	−0.21*	0.12	0.48*	0.70*	−0.13*	0.28*	0.17*	−0.28*	1.00		
NH_4^+ (ppm)	−0.19*	−0.25*	−0.01	−0.11	−0.12	−0.06	−0.02	−0.13*	−0.02	0.13	−0.04	0.13*	1.00	
NO_3^- (ppm)	−0.12	0.07	0.10	−0.28*	0.13	0.23*	0.47*	−0.01	0.34*	0.39*	−0.09	0.47*	0.32*	1.00

Notes: Values indicate Pearson correlation coefficients (r).
* $P \leq 0.05$.

Table 2. Pairwise correlations between surface and subsurface stability and all biotic and abiotic measured variables.

Table 2. Extended

Subsurface stability model

The data were congruent with our hypothesized causal model of the biotic and abiotic factors that influence subsurface soil stability in semiarid shrublands (Fig. 3B). Fifty-four percent of the variation in subsurface soil stability was explained by this model. Plant cover had the strongest direct influence on subsurface stability (0.42) followed by AM fungal abundance (0.32) and soil/climate region (0.31). Results indicate that plant cover positively affected subsurface stability both directly and indirectly through the promotion of AM fungal abundance. The variables that best explained AM fungal abundance in the subsurface stability model were percentage of MIP colonization, total BRSP, and hyphal density. Percentage of MIP (0.68), total BRSP (0.64), and hyphal density (-0.11) all contributed to the AM fungal composite variable for subsurface stability.

In contrast to our hypothesized model, rhizosphere soil organic matter content and BSC cover did not have strong direct effects on subsurface soil stability and were therefore omitted from the final model. Although soil organic matter content was positively correlated with subsurface stability (Table 2), our model indicates that this does not appear to be a causative relationship. Instead, other factors that are also correlated with organic matter, such as hyphal density, are likely affecting subsurface stability. Microsite is positively related to plant cover, such that samples from underneath shrub canopies had higher plant abundance. Furthermore, microsite had no direct path to subsurface soil stability. In addition to directly relating to subsurface soil stability, soil/climate region is strongly related to AM fungal abundance, indicating that AM fungi vary considerably across our four sampling regions.

Discussion

To our knowledge, this is the first study to use SEM to understand the relative influences that major biological components play in stabilizing soil at a landscape scale in semiarid ecosystems. As such, our findings should be considered to be provisional and in need of subsequent testing. Previous studies have used SEM to evaluate the relative contributions of AM fungi and plants to soil stability, but these studies were either conducted in mesic environments or experimental plots at a single site (Jastrow et al. 1998, Rillig et al. 2002). Through our analyses, we explored the many direct and indirect influences that plants, BSCs, and AM fungi may have on soil stability, as well as

Variable	Surface stability		Subsurface stability	
	Direct	Total	Direct	Total
BSC cover	0.60	0.60	···	···
Plant cover	0.44	0.49	0.42	0.42
AM fungal abundance	0.38	0.38	0.32	0.32
Soil/climate region	0.21	0.38	0.31	0.20

Note: Ellipses indicate no influence of BSCs on subsurface stability.

Table 3. Summary of standardized direct and total effects of biotic and abiotic factors on surface and subsurface soil stability.

on each other. The role of plants in the formation and maintenance of soil stability is relatively well established; this study highlights the important role that soil microbial communities, in particular BSCs and AM fungi, can also play in this important ecosystem service. Our results provide evidence that these three major ecosystem players work in concert to generate and maintain soil stability in arid lands. We do not argue that alternative plausible causal schemes do not exist. Instead, we can only claim that our models (and, therefore, the results) are consistent with the data. Furthermore, although our study focused on commonly distributed *Artemisia* shrublands, other prevalent shrubs of semiarid environments (e.g., *Atriplex*, *Sarcobatus*, *Grayia*) vary in their dependency on AM fungi (Miller 1979, Call and McKell 1985). If certain environments lack plants that form AM associations, AM fungi would be less prevalent and the biological contributions to soil stability could differ from those presented in our models.

Our *a priori* hypothesized, causal model of factors that contribute to soil stability in semiarid shrublands (Fig. 2) was supported by the data after incorporating only minor adjustments. In the case of surface stability, 35% of the variation was explained; for subsurface stability, 54% of the variation was explained. In both models, the strongest contributions to soil stability were made by biological components of the system. It is important to note that certain abiotic properties that strongly contribute to soil stability, such as texture and calcium carbonate or gypsum content (Tisdall and Oades 1982), were not included in our models because the focus of this study was on the biological contributions to the stability and erodibility of soils. It is possible that the inclusion of specific abiotic variables could have increased the proportion of variation explained by both models. The composite variable "soil/climate region" included in both models directly influenced soil stability, but the contribution was weak compared to the contributions of the soil organisms. This variable likely accounted for landscape-scale variation in soil abiotic variables, but not site or microsite variation. Across regions, average calcium carbonate content ranged from 3% to 10% in Big Water, 1% to 25% in Escalante, 1% to 5% in Cannonville, and 0% to 2% in Boulder. These values are considerably lower than reported (mean 71%) for studies that show a strong correlation between calcium carbonate content and soil stability (Rillig et al. 2003).

In both the surface and subsurface models, no direct effect of microsite on soil stability was detected. This indicates that the soil stability mechanisms confirmed by our models do not differ substantially between shrub islands and interspaces. These results do not contradict work that suggests that interspace soils are more susceptible to erosive forces than shrub canopy soils (Abrahams et al. 1995, Schlesinger et al. 1996). Instead, we suggest that even in interspaces that appear to be relatively devoid of life in arid environments, biotic communities provide vital ecosystems services, such as the generation and maintenance of soil stability. Belowground, roots and AM fungal hyphae extend between plant canopies and stabilize interspace soil.

Mechanisms that generate surface stability

On the soil surface, BSC communities made the largest direct contribution to soil stability. It was anticipated that the BSC contribution to surface stability would be large because at high stability sites BSC communities comprised an average of 67% of interspace cover. BSCs promote soil surface stability by increasing water infiltration, enhancing soil microstructure, improving soil fertility (Belnap and Gardner 1993), and improving surface soil resistance to rain impact (Eldridge and Kinnell 1997). However, it was not expected that the relative influence of BSCs on surface stability would be much larger than that of plant cover as indicated by the model. Our study underscores the importance of BSCs in the creation and maintenance of soil stability in dryland ecosystems.

Plant cover had the second strongest direct effect on surface soil stability. Plant cover likely directly influences surface stability by acting as a wind break, a rainfall break, and by adding litter-fall, which can improve surface resistance to rain impact. The model also highlights that, by having a negative effect on BSC cover, plant cover may have an indirect antagonistic influence on surface stability. On the other hand, plant cover indirectly promoted surface stability by having a positive effect on AM fungal abundance. Such contradictory effects are often masked when examining a simple bivariate correlation between two variables, which could explain the relatively low bivariate correlation between plant cover and soil surface stability (r =0.23; Table 2). Even with these antagonistic effects, the total effect of plant cover on surface stability was strongly positive (Table 3), confirming the important role of plant communities in creating and maintaining soil surface stability.

Interestingly, AM fungi make a substantial contribution to surface stability, even though they are not generally thought to be abundant in the top few millimeters of the soil profile. Schwab and Reeves (1981) showed that the amount of viable AM fungal propagules was high in the top 10 cm of soil in a semiarid sagebrush community, but did not examine AM fungal abundance at a finer scale. In arid ecosystems, soil moisture and nutrients are patchy and often concentrated in ''islands of fertility'' (Schlesinger et al. 1996) or BSC layers. It is possible that AM fungal hyphae explore soil surfaces comprised of BSCs to mine nutrients and water, leaving behind recalcitrant hyphal filaments and glomalin, which promote surface stability. We are aware of no studies examining the abundance of AM fungi within BSC layers, although some studies have indirectly studied interactions between AM fungi and BSCs in reference to plant growth and nitrogen cycling (Hawkes 2003, Pendleton et al. 2003). More research is needed to examine the nature and mechanisms of interactions between AM fungi and BSCs and their impacts on the formation and maintenance of soil stability.

Although our model was supported by the data, only 35% of the variation in soil stability was explained in the surface stability SEM. This could indicate two things: (1) additional unmeasured factors contribute to soil stabilization or (2) the soil stabilizing properties of the two factors with the strongest direct influences on surface stability, plants and BSCs, were not measured appropriately. First, other organisms such as bacteria, non-AM fungi, soil invertebrates, and cattle influence soil stability (Oades 1984, Friedel 1991, Tisdall 1994). Incorporating measures of other soil organisms or an index of grazing pressure could improve the amount of variation explained by the model. Second, plants and BSCs were quantified using percent cover, which is probably not the best metric to assess the potential for BSC or plant communities to stabilize soil. Instead, densities of cyanobacterial filaments, fine roots (0.2–1.0 mm diameter), and very fine (<0.2 mm diameter) root lengths may be better indicators of the biological soil stabilizing agents. Incorporating stability-related measurements of plants and BSCs could boost the overall R^2 values in both models.

Mechanisms that generate subsurface stability

Plants made the strongest total contribution to subsurface stability. Plant cover had both the largest total contribution and the strongest direct influence on subsurface stability, indicating that mechanisms such as enmeshment of soil particles by roots and root exudates are driving the creation and maintenance of soil stability. Plant cover also indirectly promoted subsurface stability by positively affecting AM fungal abundance. Unlike the surface stability model, there was no strong antagonistic relationship between plant cover and BSCs below the surface of the soil, and thus, the relationship between plant cover and subsurface stability is only positive. In this case, the relationship is not masked by two opposing forces, which could explain the stronger bivariate correlation between plant cover and subsurface stability (r =0.47; Table 2). Although BSCs were found to have no direct influence on subsurface stability, they likely contribute to belowground soil stability at a greater temporal scale since intact soil surfaces can act as the first line of defense against erosive forces.

Comparison with models from mesic systems

Our soil stability models contained many similarities to a soil stability model constructed in a mesic ecosystem. Jastrow et al. (1998) used SEM in a restored tallgrass prairie in northern Illinois, USA, to examine the interacting biotic and abiotic contributions to subsurface stability. They examined the direct and indirect influences of plant root production, AM fungal hyphal density, organic matter, microbial biomass, and hot-water soluble carbohydrate carbon content on water stable soil aggregation. In their model, plants made the largest total contribution to soil stability, as was the case in our subsurface stability model. They also found that soil organic matter had a weak influence on aggregation. Furthermore, in the tallgrass prairie model, the strength of association between AM fungi and soil stability was similar to that found in our subsurface stability model: 0.38 in the tall grass prairie study vs. 0.32 in our semiarid shrublands. These results are striking considering that average hyphal density ranged from 16.9 to 45.4 m/cm^3 in the tall grass prairies and 0.27 to 7.80 m/cm^3 in our semiarid shrublands. This may indicate that even though the abundance of AM fungal hyphae is much lower in semiarid shrublands, the relative contribution of AM fungi to soil stability is similar.

In both the surface and subsurface models, the hypothesis that organic matter content directly influences soil stability (path C in Fig. 2) was not supported. We formulated this hypothesis because plants, AM fungi, and BSCs all contribute to soil organic matter pools, and it has been suggested that organic matter is important in generating soil structure and stability (Tisdall and Oades 1982). In our study, rhizosphere organic matter content did not predict soil stability in either the surface or subsurface models and was therefore omitted from the models. These results indicate that organic matter may not be an important driver of soil stability in arid and semiarid ecosystems. Instead, aboveground plant mechanisms of erosion prevention such as decreasing wind erosion, aeolian dust trapping, and decreasing splash erosion may be of particular importance in arid ecosystems compared to organic matter production. Indeed, it has been observed that the influence of organic matter on soil aggregation is related to the decomposability of the material (Tisdall and Oades 1982). In arid and semiarid regions, decomposition rates can be slow or rapid depending on climate patterns, evapotranspiration rates, latent heat flux, and the spatial heterogeneity of these factors (Schlesinger et al. 1990, Connin et al. 1997). On the Colorado Plateau, threshold levels of soil moisture and temperature dictate decomposition rates (Fernandez et al. 2006). Furthermore, organic matter content at our sites was very low (mean 1% by mass), and it is possible that a threshold amount of organic matter is necessary before it becomes an important player in the creation of soil structure and stability. Finally, it is possible that instead of directly contributing to soil stability, organic matter indirectly influences soil stability by providing habitat for soil-stabilizing organisms such as bacteria and fungi (Fenchel and Harrison 1976, St. John et al. 1983). This mechanism is corroborated by our data that showed a strong correlation between percentage of organic matter and AM fungal hyphal density ($r = 0.73$).

System approach to erosion control

The purpose of this study was not to identify which communities in arid ecosystems exert the strongest influence on soil stability and then suggest that management efforts focus on those communities alone. Instead, we demonstrated how plants, BSCs, and AM fungi work together to both directly and indirectly influence soil stability in semiarid shrublands. These communities also influence each other; in combination, they provide the vital ecosystem service of creating and maintaining soil stability. Soil aggregate stability is related to many parameters of soil health including soil fertility, biotic activity (Tidsall and Oades 1982), and resistance to erosion (Barthes and Roose 2002). We found that the types of biological communities that influence soil stability in dryland ecosystems differ from those of mesic systems. Erosion prediction equations such as the universal soil loss equation (USLE) and the revised universal soil loss equation (RUSLE) were developed in agroecosystems and are the dominant paradigm for understanding erosion in U.S. public lands (Spaeth et al. 2003). The RUSLE predicts soil loss due to erosion using measurements of climate erosivity, topography, soil erodibility, and land cover/management (Renard et al. 1991). Incorporating dryland specific information on soil organisms into the land cover/- management component of RUSLE reveals that, when the intensity of erosive forces is constant, soil erosion in arid landscapes is primarily an outcome of land cover and management practices (Bowker et al. 2008). The formulation of dryland-specific erosion models is important as organisms in arid ecosystems experience unique selection pressures, potentially occupy different niches, and serve different ecosystem functions than those in mesic environments.

Constructing quantitative models that estimate the relative contributions of biotic and abiotic components to soil stability directly addresses the needs of practitioners who require information relating to best practices in erosion control. Often such efforts are restricted by limited resources such as time, money, and labor. Estimates of direct and total effects of biotic and abiotic factors generated by our models (Table 3) could be used to prioritize the allocation of resources in erosion control efforts. The relative strengths of these effects are then directly proportional to the amount of time, money, or effort spent on each component of the system to control erosion. By examining the proportional differences between the total effects that BSCs, plants, and AM fungi have on surface and subsurface stability we can estimate the relative amounts of resources that erosion control practitioners should spend on promoting each of these components of the system. Our models suggest that in erosion control practices conducted in semiarid shrublands of southern Utah, where the relative costs per unit output for plants, BSCs, and AM fungi are equal, practitioners should spend roughly 22% more resources on promoting BSCs than on promoting plants. Roughly 30% more resources should be spent on promoting plants than on promoting AM fungi.

This study highlights the need for system approaches in combating erosion, soil degradation, and arid-land desertification. Management efforts that contain no biotic components or incorporate only one type of organism (e.g., plants) fail to consider the long-term sustainability of soil stabilization and restoration. We predict a higher probability of long-term success in projects that recognize the vital role of soil microorganisms (and their many interactions) in the formation and maintenance of soil stability.

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Appendix

Climate, soil, and dominant vegetation details of sampled regions within the Grand Staircase Escalante National Monument, Utah, USA (*Ecological Archives* A019-006-A1).

Using Packrat Middens to Assess Grazing Effects on Vegetation Change

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ABSTRACT

Research on grazing effects usually compares the same sites through time or grazed and ungrazed sites over the same time period. Both approaches are complicated in arid environments where grazing can have a long undocumented history and landscapes can be spatially heterogenous. This work employs both approaches simultaneously by comparing grazed and ungrazed samples through both time and space using fossil plant macrofossils and pollen from packrat middens. A series of 27 middens, spanning from 995 yr BP to the present, were collected from Glen Canyon in southeastern Utah, USA. These middens detail vegetation change just prior to, and following, the historical introduction of domesticated grazers and also compares assemblages from nearby ungrazable mesas. Pre-grazing middens, and modern middens from ungrazed areas, record more native grasses, native herbs, and native shrubs such as *Rhus trilobata*, *Amelanchier utahensis*, and *Shepherdia rotundifolia* than modern middens from grazed areas. Ordinations demonstrate that site-to-site variability is more important than any temporal changes, making selection of comparable grazed versus ungrazed study treatments difficult. But within similar sites, the changes through time show that grazing lowered the number of taxa recorded, and lessened the pre-existing site differences, homogenizing the resultant plant associations in this desert grassland. Published by Elsevier Ltd.

Keywords: desert grassland, grazing effects, grazing history, packrat middens, species diversity

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1. Introduction

Research on the effects of grazing usually compares sites either spatially or temporally. Spatial studies require the assumptions that the grazed and ungrazed sites were the same prior to the grazing, and that the ungrazed site was either never grazed or that the consequences of the historical grazing have since become insignificant. These assumptions are especially problematic in the southwestern US where local species distributions can be strongly influenced by the complex underlying geologic substrates and diverse topography. And, the slow recovery of plants to disturbance in these semi-arid ecosystems (Bowers et al., 1997; Lovich and Bainbridge, 1999) requires that the entire history of grazing be understood; yet reliable grazing records extend back for only a small portion of this time. Studies of changes through time must assume that the vegetation was not influenced by other temporal variables such as climate, succession, or invasive exotics.

This research, conducted within Glen Canyon National Recreation Area (NRA), focused on how grazing affected the plant associations of the Colorado Plateau along Cataract Canyon of the Colorado River. In this project, we confront the assumptions of temporal and spatial homogeneity by employing two unique features of the Glen Canyon area: assemblages of fossil plant debris called packrat middens, and inaccessible, cliff-lined, ungrazable mesas (Tuhy and MacMahon, 1988). These features allowed us to simultaneously examine the effects of grazing through both time and space.

This study demonstrates an important tool that can be applied in many other situations where historical baseline and natural reference conditions are unclear. Although the fortuitous combination of fossil packrat middens and ungrazable mesas found at Glen Canyon NRA are rare, other areas often have overlooked paleoecological assets, such as deposits of fossil pollen and charcoal (Davis et al., 2002), opal phytoliths (Fisher et al., 1995), or even dehydrated dung (Mead et al., 1986). These resources can provide an historical depth to help understand areas where change can be too slow for observation within a human lifespan (Bowers et al., 1997).

1.1. Packrat middens

Most packrat midden studies have concentrated on the effect of climate change on major perennial plant species over tens of thousands of years (Betancourt et al., 1990). This study applied a novel approach by comparing plant community change in grazed versus ungrazed areas concentrating on just the last 1000 years. Because of the importance of the families Poaceae and Asteraceae in grassland histories, and the low frequency and difficult identifications of their macrofossils, these deposits required exceptional detail in their analysis. This is a new application for packrat midden studies and a unique approach to studying grazing effects.

Packrats (genus *Neotoma*) are nocturnal browsers that find shelter in caves, crevices, or under spiny plants. Next to their home they will create a midden, or garbage pile, out of collected objects partially barricading the nest entrance. Packrats collect not only their food plants but also any plant parts and other objects from the vicinity of their home base within a radius of 20–100 m (Cole, 1990). Packrats then urinate and defecate on this pile, and over time the urine crystallizes, forming a hard, indurated midden, sealing this protective barrier around the packrat's nest. In arid regions, middens in caves or under overhangs that are protected from moisture can survive far beyond 50,000 years (Betancourt et al., 1990). Modern middens typically are not yet consolidated, being essentially debris piles of loose twigs, pellets, and finer plant material collected by the packrat.

Dating fossil middens only a few hundred years of age is problematic. Samples post-dating 1950 AD produce distinctively high values due to atmospheric testing of nuclear weapons. But samples dating between about 1750 and 1950 AD can be statistically indistinguishable from each other. As a result, this study required the collection of midden deposits estimated to be between 300 and 1000 years in age based upon subjective field criteria of hardness, geomorphic context, smell, and preservation. The actual ages are then determined through radiocarbon dating. Middens yielding radiocarbon ages between the pre-settlement (pre-1750 AD) and post-settlement (pre-1950 AD) periods are then classified as ‘‘transitional'' in age.

Plant macrofossils such as seeds, twigs, fruits, and flowers are the most commonly analyzed fossil remains in middens. The excellent preservation of these plant parts, which have been mummified within the matrix of packrat urine, usually allows their identification to the genus or species level. Pollen is also well-preserved in middens, and can be useful for vegetation reconstructions (Anderson and Van Devender, 1991). Pollen and macrofossils each tell a different story about the paleobotanical record of an area. Because wind-blown pollen is more widely dispersed, pollen grains can represent a more regional picture of the past vegetation. Macrofossils, which usually enter the midden by being carried in by the packrat, show a more detailed picture of plants growing immediately adjacent to the midden. Because they represent different source areas and emphasize different taxonomic perspectives, fossil pollen and plant macrofossils compliment each other by showing slightly different views of the same paleoenvironment.

1.2. Description of study sites

Glen Canyon (NRA) is located in southeastern Utah and northern Arizona along the Colorado River as it cuts across the Colorado Plateau, an uplifted Plateau encompassing the Four Corners Region of the Southwest (Fig. 1). Glen Canyon NRA encompasses 500,540 ha with an elevational range from 940 to 2300 m. Average annual precipitation (1970–1999 AD) is modeled to be about 23 cm (PRISM) at the main study sites from Cove Canyon to Waterhole Flat between 1600 and 1640 m elevation. About 20% of this precipitation falls during the winter months (DJF). Following an arid foresummer in May and June, most of the annual precipitation (38%) falls during the late summer monsoon months (JAS). Mean monthly high temperatures in July are about 34 C while January lows are about 7 C.

Horses, sheep, goats, and cattle were introduced into the Southwestern USA by Spanish colonists in the 16th Century (Underhill, 1971) and were quickly adopted for use by Native Americans. They spread to the indigenous tribes of the Colorado Plateau and Great Basin and were abundant by the 1800s (Cole et al., 1997; Knapp, 1996). By the 1840s severe grazing impacts on grasslands from the expanding sheep herds of the Navajo Nation were reported (Bailey and Bailey, 1986) which may have caused a drop in fire frequencies as early as 1829 AD (Savage and Swetnam, 1990). Grazing of both cattle and sheep was especially intense on the open range between 1870 and 1890 AD (Topping, 1997). Cattle grazing then continued throughout the 20th Century at a more moderate rate until it ceased in this study area soon after the completion of this project.

Over 800 species of plants have been recorded within Glen Canyon NRA and the Utah Heritage Program lists 18 species as ‘rare’ (Flowers, 1959; National Park Service, 1999). Native ungulate grazers in the NRA include mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), desert bighorn sheep (*Ovis canadensis*) and Rocky Mountain elk (*Cervus elaphus*). Other grazers include black-tailed jack rabbit (*Lepus californicus*) and desert cottontail (*Sylvilagus audubonii*). Bison (*Bison bison*), although not present today, may have occurred sporadically in this region since the Pleistocene (Johnson et al., 2005; Mead and Agenbroad, 1992).

Middens were collected from five areas within Glen Canyon NRA (Fig. 1) representing a range of grazing histories. All the selected sites were within the same grassland plant community as classified and mapped by the park (Spence et al., 1995) on similar sandstone substrates, and at similar elevations. Two recently grazed areas, Waterhole Flat (WF) and Cove Canyon (CC), are 10 km apart but at the same elevation and on the same geologic substrate. Middens from within the Cove Canyon area were further subdivided into three sub-sites of variable grazing intensity. CC-cow shade and CC cow tank are directly adjacent to water resources and had a high density of cattle dung. CC-cow shade is along a wash where high cliffs create a comfortable location sheltered from wind and sun. CC-500m from tank, as its name implies, is 500 m away from the water source and had a far lower density of cattle dung – a rough proxy for grazing intensity.

Middens were also located at Gandolf’s Staircase (GS), an ungrazed site immediately between the Waterhole Flat and Cove Canyon areas. This site is on a bench just below the rim of Cataract Canyon of the Colorado River, and has steep vertical cliffs on all sides. Its only possible access is one route over 2 km from the nearest currently developed cattle tank over terrain too steep for cattle but possible for deer, bighorn sheep, or rock scrambling humans. Although a bone of a native mule deer was found at the site, the abundant and thick biological soil crusts showed no sign of visible impacts from any large animals. Further from these areas we located middens on two ungrazed mesas surrounded by vertical cliffs: 5381 Mesa (5M) and Mazuki Point (MP) (Tuhy and MacMahon, 1988).

2. Methods

Forty-one packrat middens were collected over four years of field work. This cyclic pattern of field collection, lab dissection, and radiocarbon dating, followed by additional field collection, was essential for the refinement of subjective age estimations in the field as well as identification of unknown plant macrofossils. Of the midden

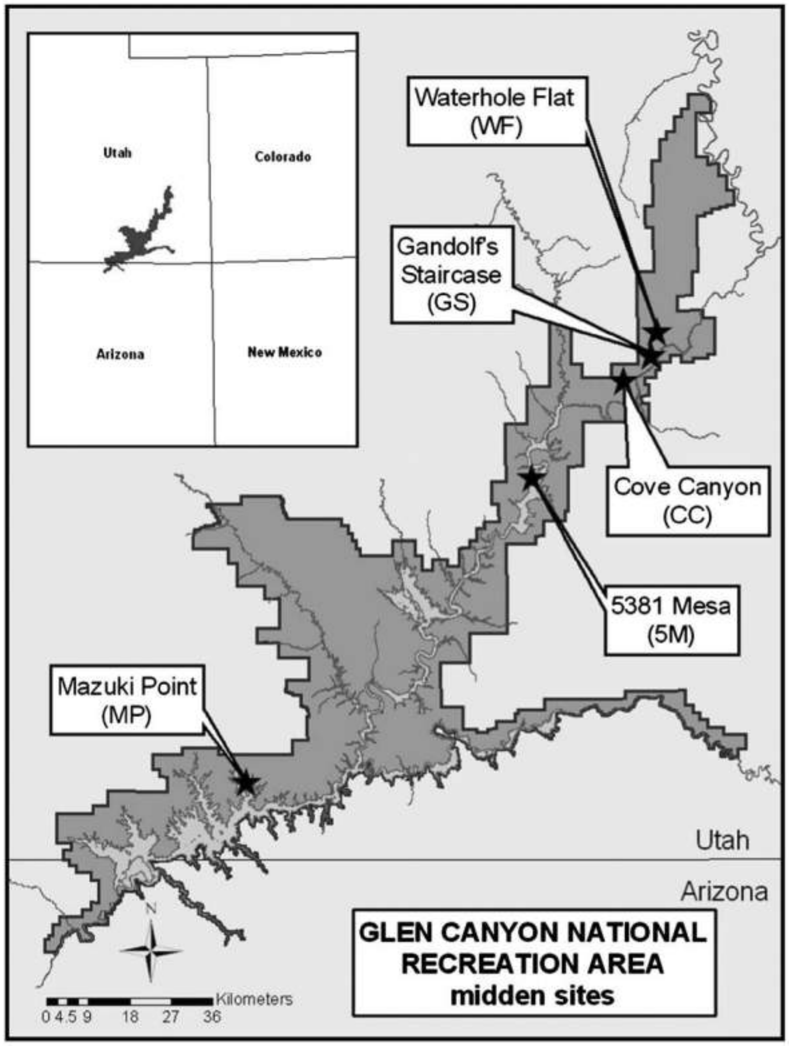

Figure 1. Map of Glen Canyon NRA showing midden collection sites and their proximity.

collections, 12 were modern debris piles, 14 were presettlement fossil middens, one had a transitional age, and 14 were fossil middens ranging between 1000 and 17,000 years in age (to be reported separately). Radiocarbon analysis was usually conducted on each midden using conventional techniques on *Neotoma* pellets although nine additional samples were aged by applying Accelerator Mass Spectrometry (AMS) analysis on individual macrofossils. AMS techniques allow the dating of samples weighing only 3–10 mg.

The modern debris piles were judged to be currently active as evidenced by fresh plant parts, which were usually still green or yellowish, and/or post-1950 AD radiocarbon ages. Efforts were made to include all size fractions in these modern collections rather than just the large twigs so that they resembled the composition of fossil middens as much as possible.

The modern vegetation was quantified for comparison with the modern midden collections in several areas using circular plant plots. Each plot consisted of a circle extending 14 m outward from the midden collection site. All individuals were counted and measured within this plot, providing quantification of the areal cover and density for each species tabulated.

Our methods were adjusted to maximize the recovery and identification of tiny Poaceae florets and Asteraceae seeds since these were the most important taxa for the study of the grazing effects. Fossil middens were collected and prepared following methods similar to those described in Cole et al. (1997) using smaller samples than have often been used (Betancourt et al.,1990). The indurated midden samples were selected from fossil-rich layers, and were usually under 500 g. Once disaggregated and washed in the laboratory, the resulting plant macrofossil matrix, minus the urine, rocks, and fecal pellets, was usually under 200 g. These smaller sample sizes minimize contamination between layers of different ages, allow detailed quantification of the smallest size fossils, and remove as little as possible from the field localities where they are the most safely curated.

The middens were disaggregated and rinsed using only 4 l of water and this rinse water was captured and used for the pollen sample. The pollen was extracted and analyzed from the rinse water for 11 middens reported here using standard extraction and analysis techniques (Fægri and Iversen, 1989). After extraction of the pollen sample, the resulting plant matrix was further washed and collected on a 0.5 mm screen. After drying, this matrix was weighed and examined under a 20 × dissecting microscope, and individual taxa were sorted into glass vials. These weight and fluid measurements allow calculation of both plant macrofossil and pollen concentrations so that middens of different size can be more equitably compared. Plant species nomenclature is from the Integrated Taxonomic Information System (http://www.itis.usda.gov/ index.html).

2.1. Multivariate ordinations of change

Trends of change for plant associations were analyzed using multivariate ordinations. Detrended Correspondence Analysis (DCA) was applied to compare the effects of spatial and temporal variability between samples based upon their plant fragment concentrations. This technique not only allows display of the samples relative to each other, but also simultaneously the plant species and loading factors responsible for distinguishing between samples. Furthermore, the DCA axes are scaled in units of species turnover (Gauch, 1982), allowing quantification of the amount of vegetation change between assemblages.

3. Results

3.1. Comparison of modern vegetation and modern middens

Table 1 contrasts the modern vegetation measurements at two plots with modern middens from those plots. These comparisons aid in understanding how different plant species are represented in fossil middens. Dominant species are typically represented by a high number of identifiable specimens (NISP) and infrequent species by low NISP. Records of species absence, although more problematic than presence with individual midden assemblages, also seem to be accurately reflected using several assemblages (Nowak et al., 2000). But, the NISP totals do not directly correspond to species cover, density, or relative importance values, and these different measures of the same modern vegetation values do not directly correspond with each other as they are all different methods for quantifying vegetation amounts (Spaulding et al., 1990). But in terms of representing the dominant species of a specific area, the midden is very analogous to the species dominance and number of species found in a small plot such as those on Table 1.

The NISP values are influenced by several factors such as the abundance of each species, the number of identifiable specimens produced by that species, the distance to the plant, and a packrat's desire and ability to transport those specimens to the midden. Species present within only a couple of meters distance are well represented in a midden, possibly from debris shed from the plant as much as the packrats collecting (K. Cole, unpublished data). Species producing a very high number of identifiable specimens include *Juniperus*, as its twigs easily fragment, multiplying into even higher numbers of easily identifiable specimens. Conversely, species such as *Populus* produce only a limited number of poorly identifiable twigs and very rarely, leaves. Species that are packrat food items (*Juniperus* and *Opuntia*) are often transported longer distances and are very commonly found.

Comparisons between middens, such as those shown in Table 1, suggest that while *Juniperus* likely will be recorded if a tree is within 50 m, *Pinus edulis* is not usually represented if the nearest tree is greater than 30m distant. Only one

Species	Cove 3				Waterhole 10			
	% Cov.	Den.	NISP = 4651		% Cov.	Den.	NISP = 1278	
			Matrix = 186 g				Matrix = 189 g	
			Rel. IP	% NISP			Rel. IP	% NISP
Trees, Shrubs, Succulents								
Amelanchier utahensis	1.4	8	1.4					
Artemisia bigelovii	15.8	76	15.8	4.5				0.2
Atriplex canescens					0.3	3	0.3	12.1
Atriplex confertifolia				0.9				
Coleogyne ramosissima	12.8	73	12.8	8.9	8.8	67	8.8	17.9
Ecinocereus sp.	0.3	2	0.3		0.3	3	0.3	
Ephedra torreyana								0.1
Ephedra viridis/cutleri	6.1	10	6.1	0.7	14.1	192	14.1	5.4
Fraxinus anomala				0.1				
Gutierrezia microcephala					9.7	338	9.7	4.1
Gutierrezia sarothrae	8.8	52	8.8	4.6				
Isocoma acradenia				0.1				
Juniperus osteosperma	38.7	10	10.9	38.7	12.3	11	12.3	21.0
Krascheninnikovia lanata								1.6
Mahonia fremontii				0.1	6.2	5	6.2	3.4
Opuntia erinacea	0.05	2	0.5	0.4	0.4	65	2.5	19.9
Pinus edulis	8.22	10	29.2	39.8	2.52	10	6.4	7.4
Sclerocactus whipplei var roseus	0.01	2	0.3		0.01	6	0.2	0.9
Symphoricarpos longiflorus	0.03	3	0.6	0.1				
Yucca angustissima	0.09	13	2.3	0.2	0.01	2	0.1	0.5
Herbs & Grasses								
Abronia sp.					0.01	5	0.1	
Achnatherum hymenoides	0.02	5	0.8	0.6	0.02	10	0.3	2.0
Aristida purpurea	0.05	39	6.1		0.09	28	0.9	
Astragalus sabulonum					0.01	5	0.1	
Bromus tectorum					0.02	18	0.5	0.4
Chaenactis steviodes				0.1				
Chamaesyce fendleri				0.1	0.02	18	0.5	
Cryptantha sp.	0.02	2	0.4		0.01	2	0.1	
Delphinium sp.	0.01	2	0.3					
Elymus elymoides								0.2
Eriogonum corymbosum								
Hesperostipa comata	0.01	3	0.5		0.4	161	4.7	0.2
Lappula occidentalis								0.2
Lepidium montanum	0.04	8	1.4	0.1	0.14	57	1.7	0.8
Machaeranthera canescens	0.1	2	0.6	0.3				0.8
Phlox hoodii	0.01	3	0.5					
Plantago patagonica					0.01	13	0.3	
Pleuraphis jamesii					1.25	1052	27.5	
Salsola sp.								
Sphaeralcea parviflora	0.01	2	0.3		0.01	10	0.3	0.9
Sporobolus contractus					0.2	73	2.2	0.1
Vulpia octoflora								0.1
Total	14.86	327	100	100	20.31	2154	100	100

The vegetation is quantified by percent areal cover (% Cov.), density (Den.) expressed as the number of plants in a 1000 m^2 area, and a relative importance value (Rel. IP) averaging the scores for relative % of total cover and relative % of total density. These values are compared to the relative number of plant parts for that species in the midden (% NISP). NISP, total number of identified specimens. The total NISP for each midden is shown along with the weight of the dry midden matrix minus any rocks or fecal pellets. All positive values are rounded up to at least 0.1 for % NISP and .01 for % cover.

Table 1. The contents of two circular land plots, 14 m in radius (616 m^2), are compared with two modern midden collections taken from the center of each plot.

seed and one needle of *P. edulis* were found in a modern midden 28 m from the nearest tree, while none were found in a midden 80 m from the nearest tree.

The midden assemblage also incorporates collections through time. Although one-time measurement of a plant plot likely will not reveal seasonal herbs not present at the time of measurement, they are more likely to be found within the midden. The modern midden probably incorporates specimens of nearby plants present over the last couple of years, while a fossil midden layer may incorporate plants from over a decade or more. The number of years represented within a fossil midden cannot be precisely determined since middens differ greatly in their rate of deposition and because the statistical error in radiocarbon samples is usually a century or more. Thus, two samples of identical age can yield radiocarbon ages 100 years apart.

3.2. Midden ages and macrofossils

Fourteen middens represented the pre-settlement period, with ^{14}C ages ranging from 995 ± 65 yr BP to 220 ± 45 yr BP. The two most recent radiocarbon ages, 220 ± 45 yr BP and 250 ± 45 yr BP have less than a 15% probability of post-dating 1750 AD once converted to calendar years (Stuiver and Reimer, 1993). One large debris pile was of transitional age – CC-1, containing both presettlement (pre-historic corn cob) and post-settlement (exotic species cheatgrass and pollen of Russian thistle) plant parts. Presettlement archaeological materials, especially corn cobs, are frequent in modern packrat debris piles in cliffs near archaeological corn storage sites. However, these items only impose a maximum possible age on the deposit as foraging packrats will readily collect any nearby fossil items as well as contemporaneous materials.

Ninety-eight different plant types were identified from the middens. Identification of this unusually high number of taxa was made possible through the fine sorting of the midden matrix, and extensive comparison of tiny plant fragments such as Poaceae florets and Asteraceae achenes with those from the regional flora. The most frequent and relevant taxa, representing less than half of the total types identified, are displayed in Figs. 2–4. The figures illustrate macrofossil concentration through time displayed on a logarithmic scale, which helps normalize the values and allows comparison between middens of different size.

3.3. Pre-settlement time period

Middens representing the pre-settlement period, from 1000 to 1750 AD, come from all sites except Mazuki Point. Blackbrush (*Coleogyne ramosissima*), *Ephedra* (*Ephedra* spp.), prickly pear (*Opuntia* spp.), Bigelow's sagebrush (*Artemisia bigelovii*), fourwing saltbush (*Atriplex canescens*), winterfat (*Krascheninnikovia lanata*), broom snakeweed (*Gutierrezia* spp.), narrowleaf yucca (*Yucca angustissima*) (Fig. 2), pinyon pine (*P. edulis*), and Utah juniper (*Juniperus osteosperma*) (Fig. 3) were all dominant members of the plant associations found in these middens. Native grasses were frequently found through this time period, particularly Indian rice grass (*Achnatherum hymenoides*), needle and thread (*Hesperostipa comata* ssp. *comata*), galleta grass (*Pleuraphis jamesii*), and six weeks fescue (*Vulpia octoflora*) (Fig. 4). These middens averaged 19.1 ± 5.4 genera/midden.

Shadscale (*Atriplex confertifolia*) was found only in five middens, all near areas in Cove Canyon currently populated by shadscale. Rubber rabbitbrush (*Ericameria nauseosa*), skunkbush sumac (*R. trilobata*), and roundleaf buffaloberry (*Sheperdia rotundifolia*) were all seen frequently in the younger half of the series. Cheatgrass (*Bromus tectorum*), an introduced exotic, occurred in three middens in the later part of the series. In each case, no more than two spikelets were recorded, suggesting that these small plant parts were contaminants, incorporated into the midden after it was formed. Indeed, AMS radiocarbon dating of two of these samples, from GS-3 and 5M-1, proved them to be modern contaminants. Light macrofossils such as these can easily blow into fissures within older middens emphasizing the need for either discounting the presence of a few wind-transported macrofossils or verification of the age of such taxa using AMS procedures.

3.4. Post-settlement time period

Thirteen middens represented the post-settlement, or modern, era. All five sites contained at least one modern midden, while all three middens from Mazuki Point were modern. Six modern middens represented ungrazed sites: one from Gandolf's Staircase, two from 5381 Mesa, and three from Mazuki Point. Most of these middens were diverse, averaging 21.2 ± 4.2 genera/midden. Most of these middens shared sub-fossils of blackbrush, ephedra, opuntia, rubber rabbitbrush, milkvetch (*Astragalus* spp.), desert needlegrass (*Achnatherum speciosum*), Indian rice grass, and cheatgrass. Narrowleaf yucca, Bigelow's sagebrush, fourwing saltbush, and roundleaf buffaloberry were also common. Two middens from Mazuki Point had specimens of filaree (*Erodium cicutarium*), an invasive exotic, while two middens had plant parts of red brome (*Bromus rubens*), another invasive exotic, along with cheatgrass. Only two middens contained Utah juniper and only one pinyon pine. However, neither species grows today on Mazuki Point and only Utah juniper grows on 5381 Mesa. All of the ungrazed area middens contained at least two native grass species.

Six modern middens were collected from two grazed areas: Cove Canyon (CC-3, CC-5, and CC-20) and Waterhole Flat (WF-1, WF-3, and WF-10). All these middens contained Utah juniper, prickly pear, ephedra, and Fremont's barberry (*Mahonia fremontii*). Five out of the six contained Indian rice grass, pinyon pine, and fourwing saltbush. Four middens have a species of snakeweed, either *Gutierrezia sarothrae* or *Gutierrezia microceph-*

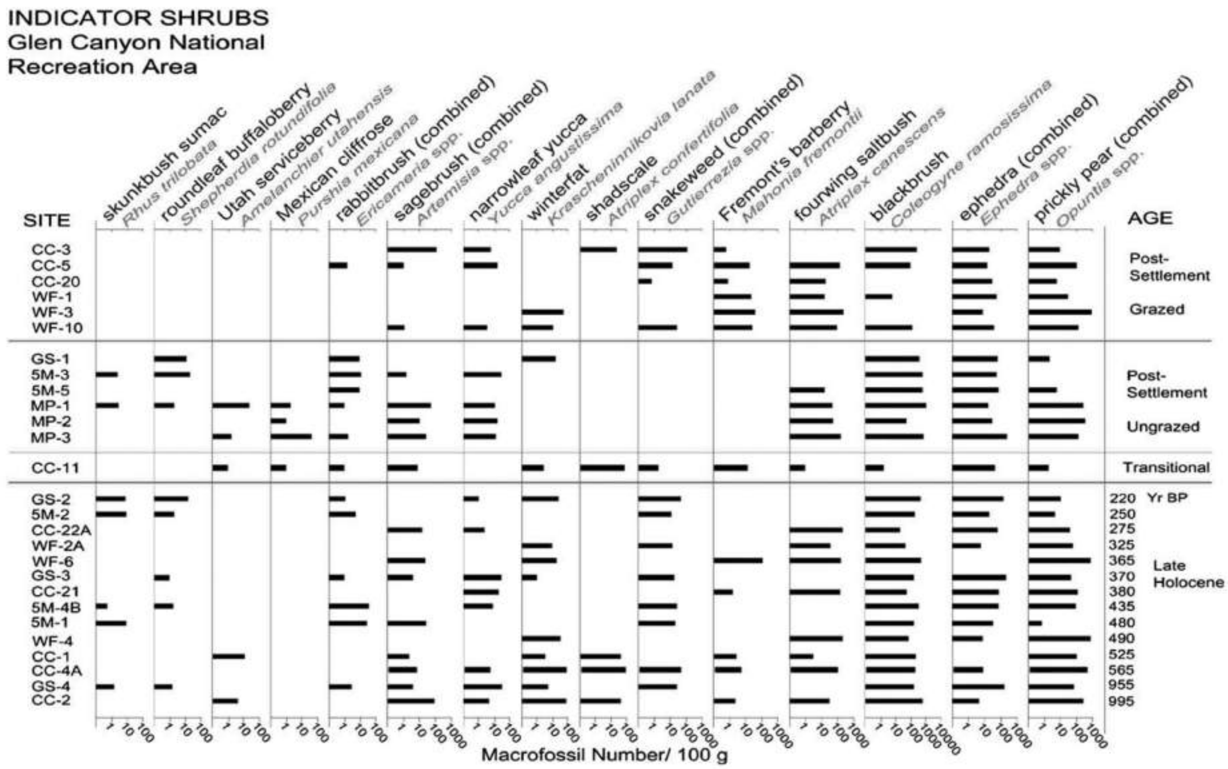

Figure 2. Graph showing the macrofossil concentration of key indicator shrubs through the Glen Canyon NRA midden series. Midden names are abbreviated along the left (see Fig. 1) and ages arranged along the right.

ala. Three middens contained cheatgrass. Plants of interest seen less frequently included rubber rabbitbrush, winterfat, shadscale, native herbs, and native grasses. One midden, CC-5, contained the exotic plant prickly Russian thistle (*Salsola tragus*). This group of middens had the lowest number of taxa, averaging only 14.5 ± 6.2 genera/ midden.

3.5. Pollen analysis

Pollen was analyzed for 11 middens (Fig. 5). The four postsettlement middens analyzed for pollen are all from grazed areas. Of the arboreal pollen, juniper was abundant in all middens throughout the time series. Some shrub pollen types decreased in counts from pre- to post-settlement eras, including pollen of Chenopodiaceae and *Amaranthus* spp. (cheno-am pollen type) and prickly pear. Ephedra-type, mountain mahogany-type (*Cercocarpus*- type), blackbrush, and roundleaf buffaloberry increased during those time period transitions. Sagebrush and Torrey's Ephedra-type remained constant.

Several herbs also had abundance switches from the pre- to post-settlement periods. Fishhook cactus-type (*Sclerocactus*-type) and grass family counts all decreased from pre-settlement to the modern, grazed era. Globemallow (*Sphaeralcea* spp.) decreased, while ragweed (*Ambrosia* spp.) remained fairly constant. One modern midden, CC-5, contained high counts of *Sporormiella*, a dung fungus spore, which is often found in association with cattle dung (Davis et al., 1977, 2002).

3.6. Species trends

The midden data (Figs. 2–5) allow examination of species trends as they are affected by grazing through both time and space by the plant macrofossil record, and through time by the pollen record. Changes for many individual species are reflected in the macrofossil records, while the different taxonomic levels represented in the pollen record display broader, often family-level, changes across the landscape.

Fremont's barberry and prickly Russian thistle were more abundant in middens from the grazed sites and times as reflected by both the macrofossil and pollen records. The change in Fremont's barberry was particularly evident in the macrofossil record (Fig. 2). Blackbrush was less concen-

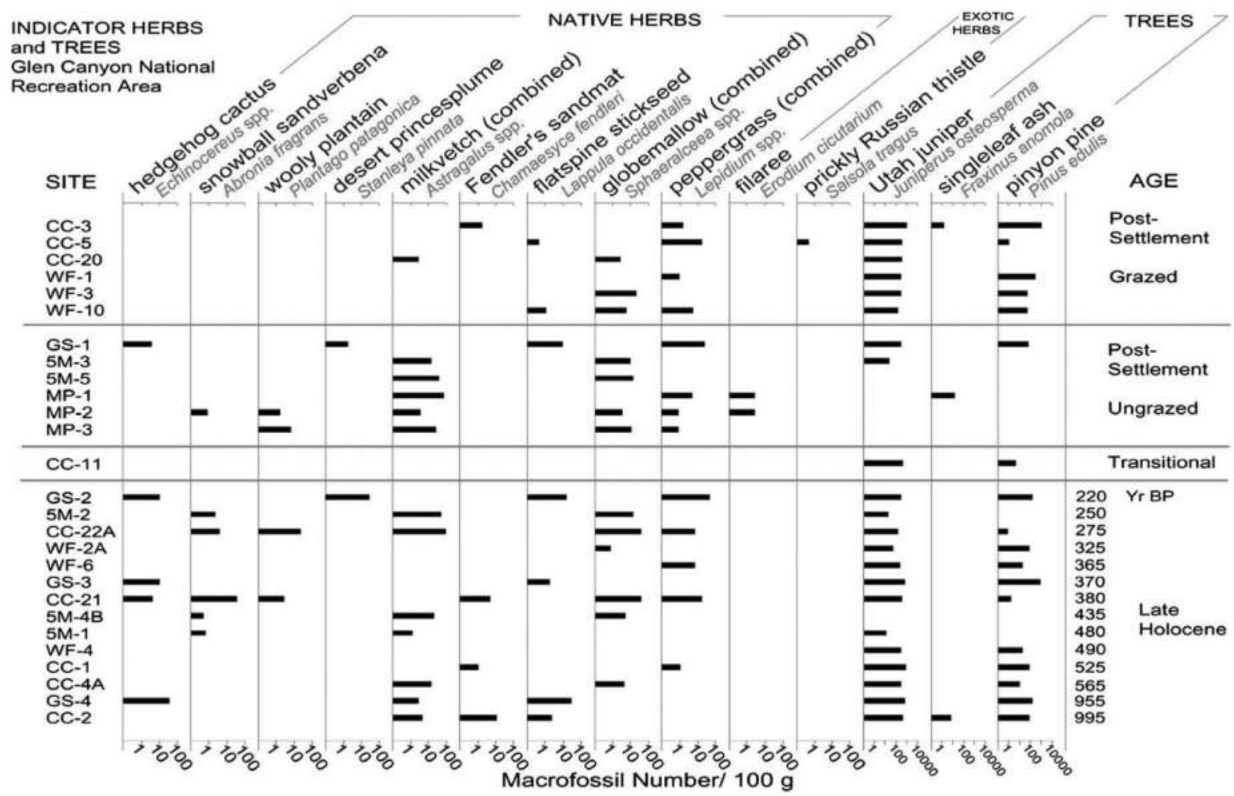

Figure 3. The macrofossil concentration of key indicator herbs, trees, and one succulent through the midden series. Midden names are abbreviated along the left and ages arranged along the right.

trated in middens from the grazed sites; a change also somewhat reflected by the pollen record (Fig. 5). Utah serviceberry, roundleaf buffaloberry, and skunkbrush sumac were absent from the middens from the grazed sites, while rabbitbrush was only found in one grazed midden. These taxa are all frequent at the sites ungrazed over both space and time but none were represented in the pollen record.

The most conspicuous change in macrofossils between the grazed and ungrazed sites through both time and space is the frequency of native herbs (Fig. 3) and native grasses (Fig. 4). Some of these individual taxa are represented only sporadically from the ungrazed sites, but as a group they are far less frequent from the grazed sites. Although many of these taxa are unlikely to be represented in the pollen record, the decreases in pollen of globemallow and the Poaceae family with grazing likely reflect these same trends. The most conspicuous differences for individual species are the abundances of desert needlegrass, galleta grass, and milkvetch in the temporally and spatially ungrazed samples when compared to their total absence in the grazed samples (except for one milkvetch sample). Cheatgrass, an introduced exotic, is also far more frequent on the spatially ungrazed sites.

The records for some taxa suggested a change in either the temporal, spatial, or pollen records that was not replicated in the other series. Winterfat, frequent in the pre-settlement middens, is rare in both the modern grazed and ungrazed middens. Shadscale shows a similar, if less pronounced, trend. These taxa are likely the primary constituents in the cheno-am pollen record showing a similar trend. Snakeweed, a frequent component in the presettlement middens, was only found at the grazed sites.

3.7. Midden ordinations

An ordination of all of the middens is shown in Fig. 6. The middens cluster together most closely by site location as illustrated by symbol shape, but not by age or treatment (grazed vs. ungrazed). The middens from the two grazed sites, Cove Canyon (CC) and Waterhole Flat (WF), form one overlapping cluster while the three ungrazed sites,

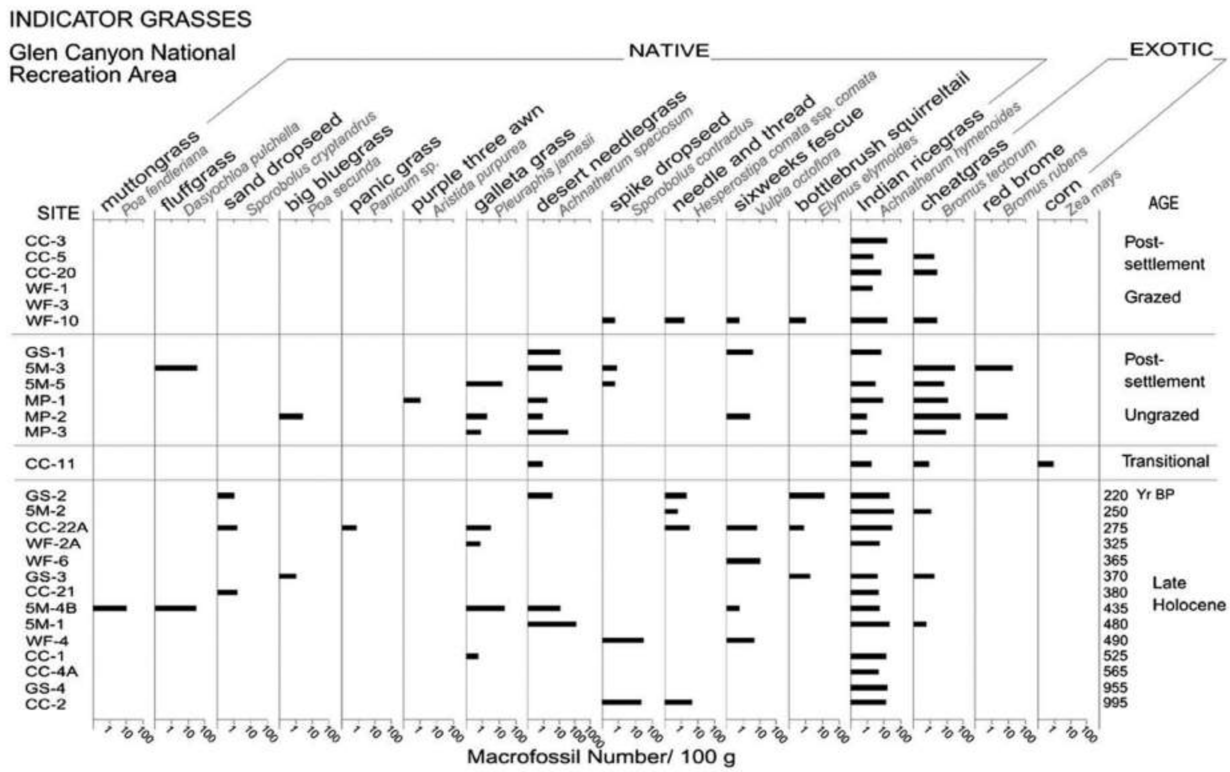

Figure 4. The concentration of key indicator grasses through the midden series. Midden names are abbreviated along the left and ages arranged along the right.

Gandolf's Staircase (GS), Mazuki Point (MP), and 5381 Mesa (5 M), form separate clusters. This ordination shows that the main differences in the midden assemblages are site-to-site differences, reflecting some combination of variability in history, microclimate, geology, soil, or hydrology. It is logical that CC and WF group together, being close in physical proximity on the same stratigraphic level of the Cedar Mesa Sandstone. These site-to-site differences are remarkable in light of the fact that every site was selected to be within as similar ranges of elevation, plant community, and substrate type as possible.

This finding highlights one of the fundamental problems with many grazing studies: the assumption of spatial homogeneity among grazed and ungrazed sites (Guenther et al., 2004). Although Gandolf's Staircase is directly in-between the two grazed sites, CC and WF, (Fig. 1), and on the same geologic substrate, it forms a very distinct cluster apart from them. However, it is at a slightly lower stratigraphic level of the Cedar Mesa Sandstone Formation. Apparently, a combination of minor substrate differences, isolation, and/or the reduction of insolation and wind by its surrounding cliffs are sufficient to modify local conditions, resulting in subtle differences in its plant association. Mazuki Point and 5381 Mesa are both much further away on isolated mesa tops with greater wind exposure and underlain by different sandstone geologic units.

The ordination also demonstrates that the age of the midden has little bearing on the clustering. Modern middens are found to be very similar to middens from up to 995 yr BP. This shows that it is acceptable to compare the middens from less than 1000 yr BP to modern middens, and that climatic conditions have not changed drastically enough that the resultant plant assemblage changes are evident in the packrat midden assemblages.

A second ordination eliminates most of the site-to-site variability by graphing only the pre- and post-settlement middens from the most similar sites, CC and WF (Fig. 7). This graph, again, shows that there are no obvious trends along the axes reflecting middens of different age. This ordination further divides the CC middens into subsites, CC-cow shade, CC-cow tank, and CC-500m from tank. WF, CC-cow shade, and CC-cow tank are all intensively grazed in the winter and spring

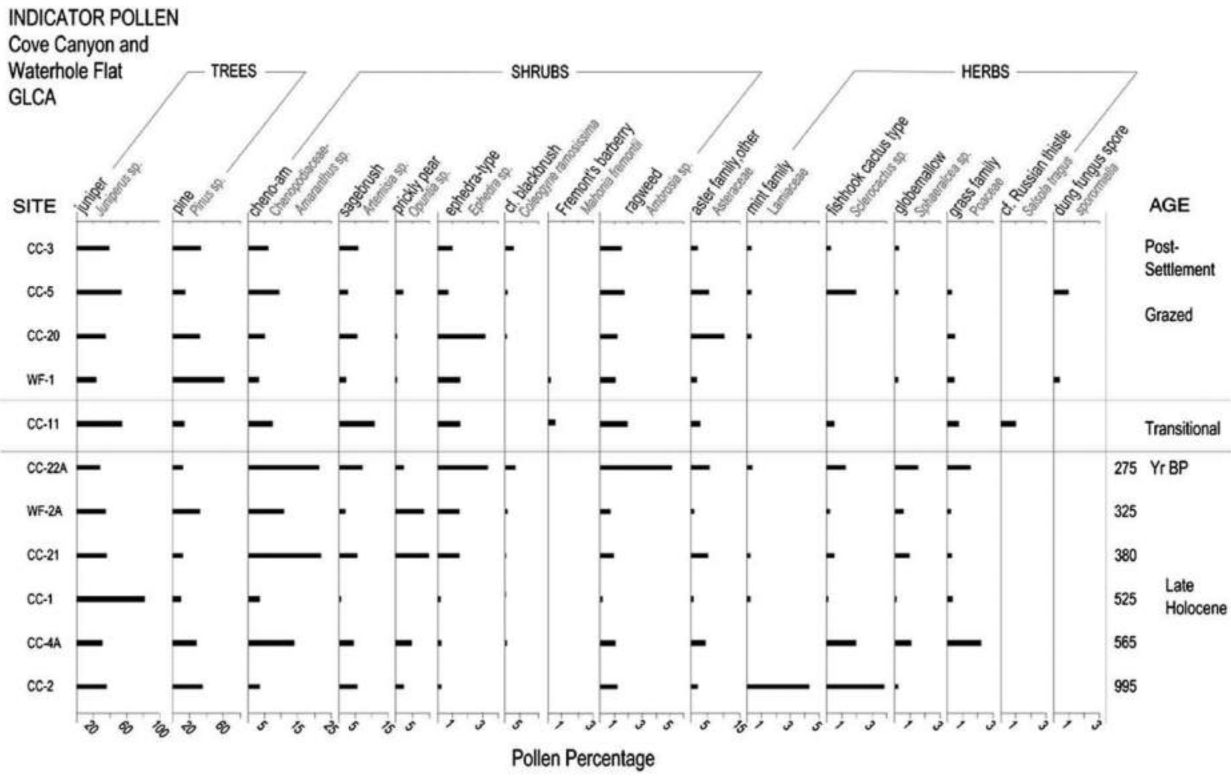

Figure 5. The percentage of pollen from 11 middens in the midden series (note changing % scales).

months while CC-500m from tank is further from available water and is only moderately grazed.

In this ordination, pre- and post-grazing middens do become separated. Because there is only one moderately impacted site, CC- 3 from CC-500m from tank, it is not possible to tell whether intensively and moderately grazed sites cluster separately. That midden, though, does fall to the periphery and is not central in the cluster. CC-11, the transitional midden, also is on the periphery of the cluster.

Fig. 8 represents changing assemblages through time as shown by the arrows. At this enlarged scale, there is a differentiation by age. The middens tend to move up Axis 2, and towards the middle of Axis 1. Although the CC-cow shade middens differ on Axis 1 from the CC-cow tank and CC-500m from tank middens, the grazing treatment seems to draw middens toward the middle of the ordination. The moderately grazed site, CC-500m from tank, shows less movement through ordination space, suggesting that the effect of grazing is not as strong here as with the more intensely grazed sites. These results suggest that grazing resulted in a homogenization of the plant associations; previously different associations became more similar following the grazing.

This homogenization may result from a lowering of diversity in the grazed assemblages and the number of genera identified in each midden type supported this conclusion. The 14 pre-settlement middens and 6 post-settlement, ungrazed middens, contained a more diverse set of genera (19.1 ± 5.4 & 21.2 ± 4.2 genera/midden) than the 6 post-settlement grazed middens (14.5 ± 6.2 genera/midden). Comparing the modern grazed middens versus the ungrazed middens (pre-settlement & modern) yielded a significant difference between the groups using a t-test ($P = 0.046$).

4. Discussion

4.1. Expected vs. observed changes

A comparison between abundance of various species in the grazed versus ungrazed middens, summarized by Fisher (2005), supports many of the changes expected from a review of grazing effects literature (Parker, 1972; Stubbendieck et al., 1997; USDA, 1988; Whitson et al., 1991) in at least one of the three measures (macrofossils

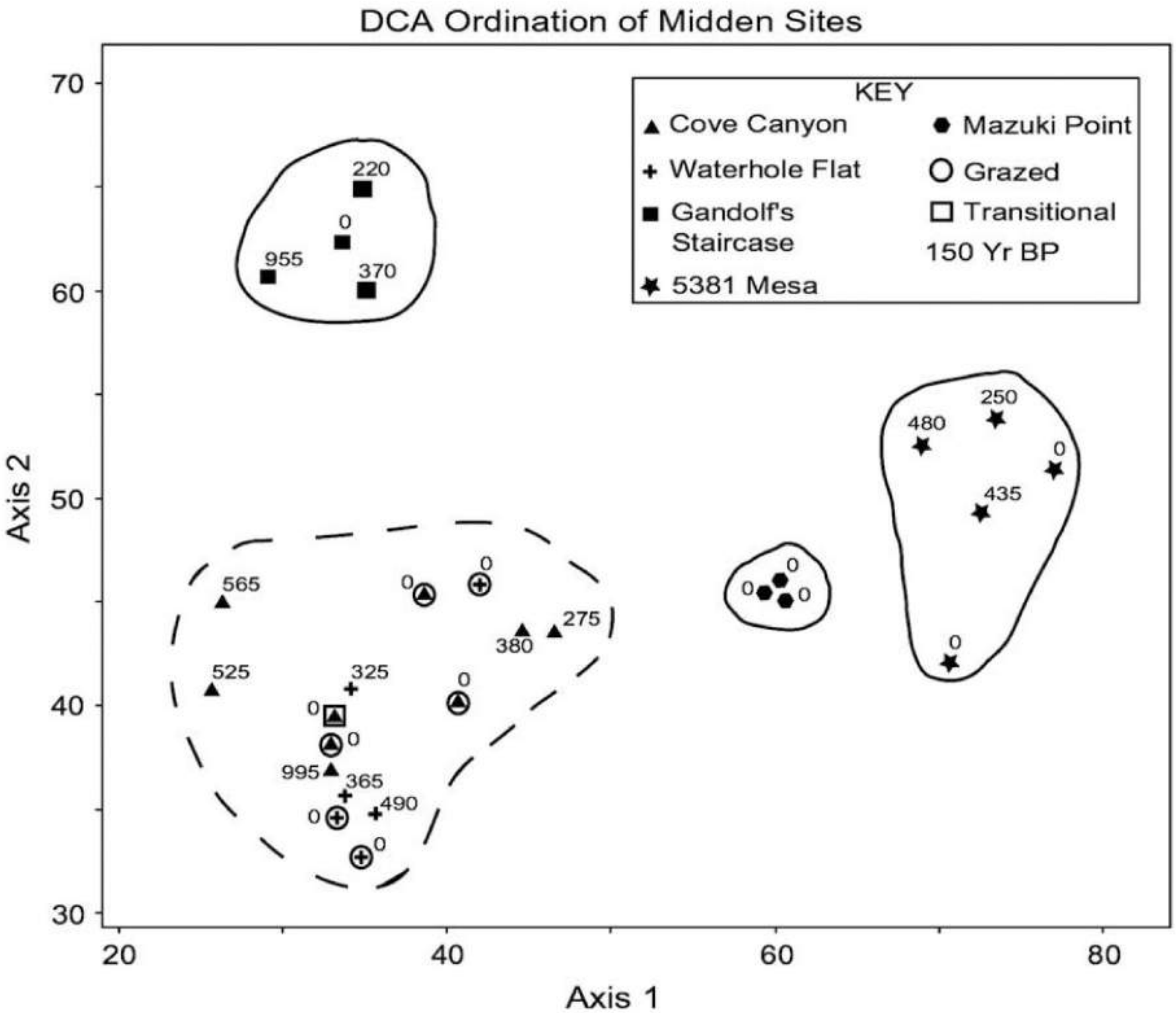

Figure 6. Detrended Correspondence Analysis (DCA) ordination of all five Glen Canyon NRA midden sites demonstrating the geographic differentiation between assemblages from different sites. Samples from the two grazed sites are encircled by the dashed line. Numbers adjacent to the symbols show the age of the assemblages (yr BP).

through time or space, or pollen through time). The results from the different measures were rarely in direct conflict. As expected, many palatable herbs and shrubs had lower values in middens collected from the grazed areas but remained present in the ungrazed areas, such as: native grasses, native herbs, Utah serviceberry, roundleaf buffaloberry, and skunkbush sumac. Fremont's barberry and prickly Russian thistle were more abundant in the grazed middens as expected.

Some might have expected higher numbers of exotic grasses on grazed areas, but our results clearly support the opposite. Cheatgrass and red brome had higher values from post-settlement ungrazed areas suggesting that the winter and spring cattle grazing reduced the frequency of these species just as it did the native grasses.

Rabbitbrush (*E. nauseosa*, recently *Chrysothamnus nauseosus*) is often expected to increase with grazing, but the identification of these shrubs is complicated by interspecific, and likely intergeneric, hybridization. Also, different subspecies of rabbitbrush have a great range of palatability for cattle (Hanks et al., 1975). The consistent presence of these plant parts in both fossil and ungrazed middens versus only three achenes found in one post-grazing midden from the least impacted grazing site (CC-500m from tank) strongly implies the reduction of these plants from the *Ericameria/ Chrysothamnus* complex from these grazed areas.

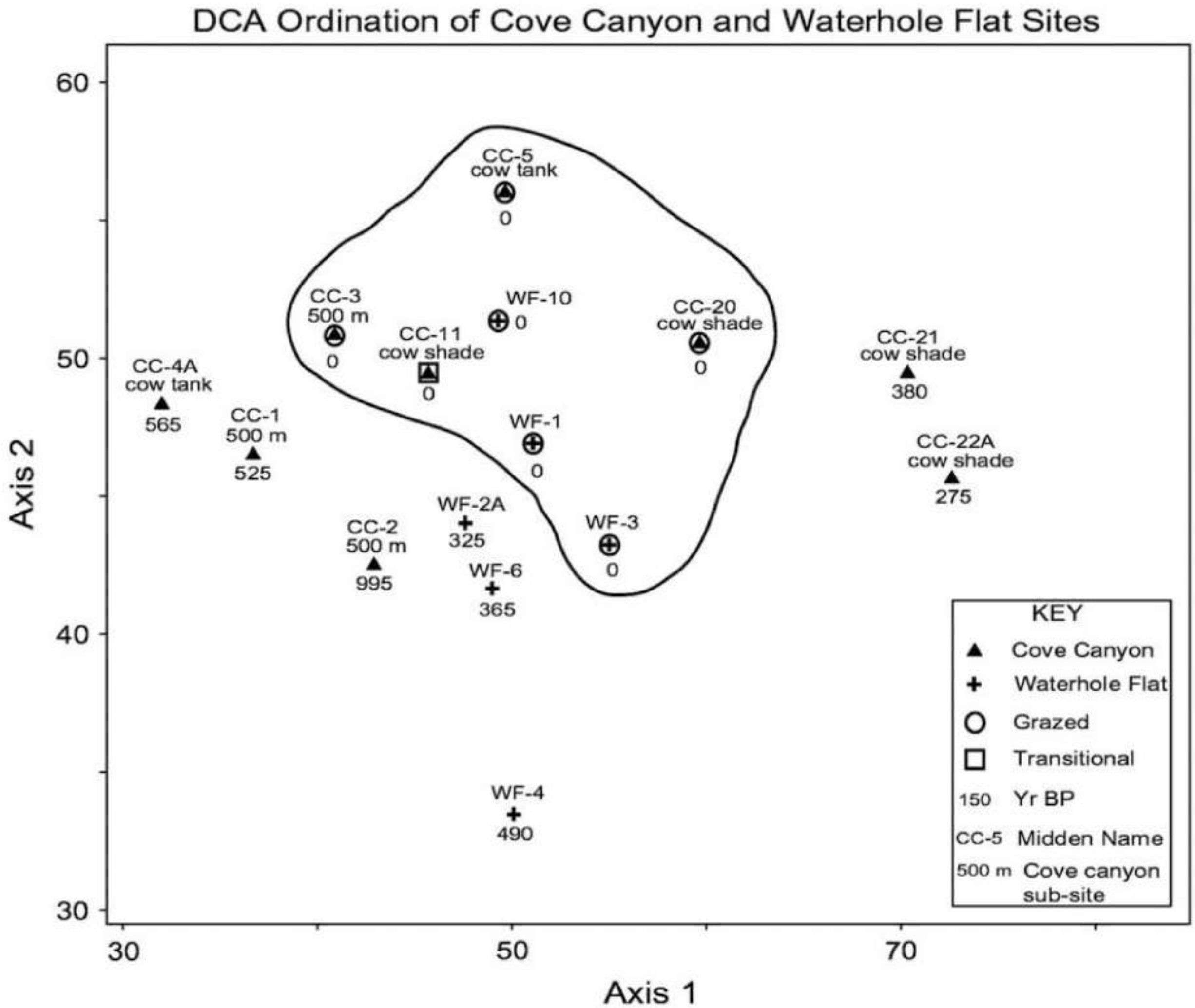

Figure 7. Detrended Correspondence Analysis ordination of WF and CC sub-sites. Note that the grazed assemblages, indicated by the 0 ages, cluster within the line, suggesting that they are less diverse than the older assemblages.

Sagebrush and blackbrush became less frequent on grazed sites. Although not highly palatable, these could be a food source of last resort as preferred grasses disappear, and this could cause their decrease. However, this is unlikely since cattle are usually grazed in Glen Canyon NRA only during the less-stressful periods of winter and spring. It is more likely that it has been impacted by trampling since they primarily grow on well-developed soils in this area, or possibly a reflection of early historic sheep and/or goat grazing which could have affected the area (Cole et al., 1997).

Prickly pear and ephedra are two plants that are highly valued by packrats as food items, and also as defensive nesting material. These plants are likely picked by the packrats selectively over other plants, and are unlikely to be ideal grazing indicators in packrat middens. Both of these plants remained at similar levels through time and space with the macrofossils, even though decreases in their pollen percentages were evident.

4.2. Plant community change

Evidence for plant community change is found in long-term studies of historical change (Brown et al., 2001; Mack, 1981) as well as in studies of micro- and macrofossils found in the paleoecological record (Davis and Turner, 1986; Lavoie and Filion, 2001). By looking at past plant communities and assessing the factors that have caused them to change, the characteristics of future communities might be predicted, and undesirable human-caused modifications can potentially be prevented or mitigated.

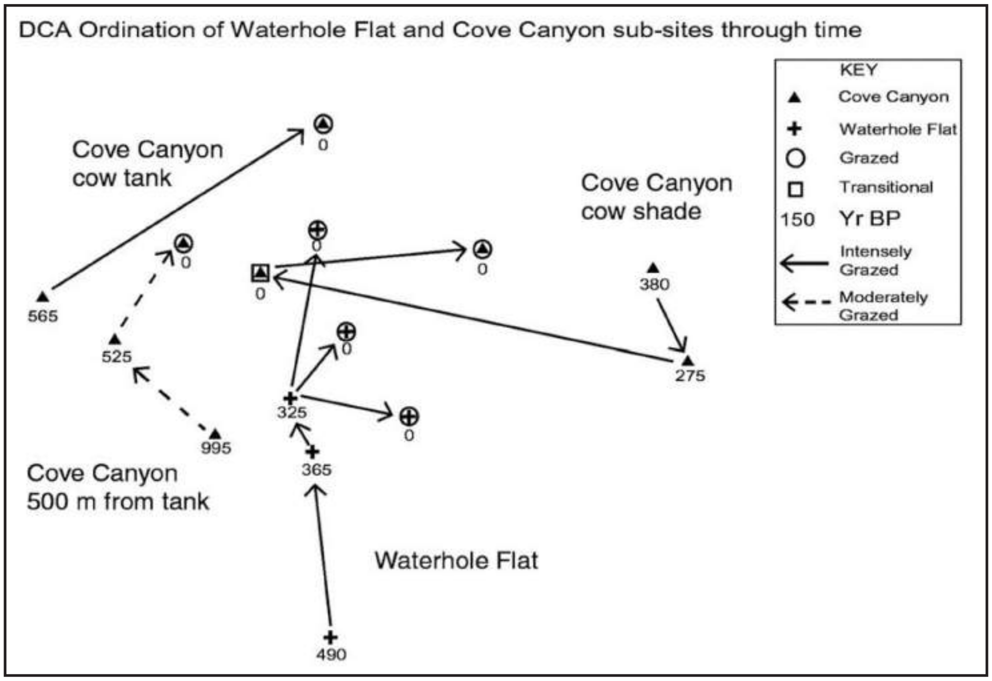

Figure 8. Detrended Correspondence Analysis ordination of WF and CC grazed sub-sites through time. The amount of vegetation change at each sub-site is indicated by the length of the arrows.

The human-influenced changes observed in ecosystems of the deserts of western North America range from those affecting a single plant species to those having broad and sweeping community-wide alterations. Grazing can affect native (Cole et al., 1997) and exotic (Bashkin et al., 2003; Knapp, 1996) plants, species richness (Fleischner, 1994; Jones, 2000; Rambo and Faeth, 1999), sex-distribution (Cibils et al., 2000), plant cover (de Soyza et al., 2000), plant composition (Menke and Bradford, 1992), and above-ground (Barrow, 1997) and below-ground (Abbott et al., 1991) plant architecture. Our results supported previous studies that suggest grazing decreases plant species richness.

From the DCA ordinations comparing the different Cove Canyon sub-sites, this study shows that the grazing had the effect of homogenizing the plant assemblages by reducing their spatial variability, and that the moderately grazed areas have changed less dramatically than heavily grazed areas. These results suggest that more moderate grazing had less impact on plant associations than heavier grazing. This has been shown to be true in other studies as well, where light grazing can even have a positive effect on abundance, richness, and diversity of certain species on the landscape (Valone and Kelt, 1999).

Four exotic species, prickly Russian thistle, filaree, cheatgrass, and red brome, were found in the middens. Surprisingly, large amounts of exotics were also found on the relict ungrazed mesas. Because these exotics are wind and avian-dispersed, their high abundance in the ungrazed areas suggests that they are capable of spreading to ungrazed areas and are probably reduced themselves by grazing at critical times.

4.3. Natural reference conditions in desert grasslands

Because ecosystem restoration requires returning an area to its ‘‘original'' condition, it is imperative to know just what this ‘‘original'' state was. For restorationists, the difference between ecosystem improvements and impacts may be largely one of personal opinion unless this history is known. This is especially important in arid and semi-arid areas such as the arid southwestern U.S. where vegetation recovery is very slow, paleoecological data are poor, and major changes caused by grazing likely occurred during the 19th century, pre-dating the detailed historical record. Packrat midden research assists with this by showing which species have undergone the largest changes in specific areas.

Complete restoration to historical ecosystems in this region may be impossible due to increasing moisture deficits projected for this region (Seager et al., 2007). These changes will also likely result in an increase in the dominance of early successional species and a decline in late successional species (Cole, in press). Nevertheless, knowledge of the historical reference conditions is still imperative. Vegetation change driven by this climate shift cannot be known without an understanding of the rate of recent changes and their starting point.

This study found a high frequency of native grasses and herbs in both the pre-settlement and ungrazed assemblages. When these values are compared to the grazed assemblages, they should serve as a caution to anyone classifying the natural vegetation in desert areas that have undergone a century or more of grazing, even well after that grazing has ceased. Although these areas may currently be shrub-dominated, this likely was not always the case. Regions with abundant 19th century cattle or sheep industries, before the development of modern water storage and transportation improvements, must have had significant biomass of grasses and herbs in order to remain viable. This transformation from desert grassland to shrub desert must have also affected other natural features as well, such as animal populations and fire frequency (Davis et al., 2002).

Packrat midden series have traditionally been used to reconstruct major shifts in plant associations caused by large-scale climate changes occurring over thousands of years. This study demonstrates that they can also be used to document more subtle vegetation changes such as those brought about over decades to centuries. Our results suggest that unless identical adjacent areas that have never been grazed are available for comparison (a very rare situation), one should be very careful about assuming they know the natural reference conditions for an area.

5. Conclusions

The temporal changes of the last 1000 years and changes due to grazing were less significant than the original site-to-site variability in grasslands on sandstone substrates at similar elevations of Glen Canyon NRA. These differences were not necessarily evident through casual observation at the start of the study and all of these areas had originally been mapped as the same desert grassland plant association. These results emphasize the difficulty with assuming spatial homogeneity between sites in a study of this type.

Our results also demonstrate that changes have occurred on the grazeable areas through time, but it remains unknown which of these changes can be attributed to cattle grazing of the late 20th century versus the possibly more severe cattle and sheep impacts prior to that time. Packrat middens from grazed areas contained far fewer taxa and the plant assemblages were more homogenous.

It is clear from the temporal trends in this data that the grazing had an effect on some plant species which were not apparent on the ungrazed areas. Also, although our results support many of the expected effects of grazing on most species, this was not true for all species. These results caution that just as the plant associations are highly variable from place to place, the effects of grazing can also be variable depending on the grazing species, the density of animals, and the season of grazing.

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Soil Survey of Grand Staircase-Escalante National Monument: A Comprehensive Framework for Planning, Adaptive Management, and Research

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ABSTRACT

The conservation of soil resources is key to sustaining the health, diversity, and productivity of rangeland ecosystems. In 2005, the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) completed a soil survey for Grand Staircase-Escalante National Monument to meet planning and management needs of Bureau of Land Management (BLM) staff and collaborating researchers. While preparing the survey, NRCS soil scientists and rangeland ecologists systematically inventoried Monument soils, described their attributes, and mapped their distributions across the 1.9 million acre survey area. Soil scientists identified 136 distinct soil types with attributes and distributions controlled by combined effects of geology, landforms, topographic relief, climate, and natural vegetation. Forty of these are new soil types identified and described for the first time in this soil survey. Rangeland ecologists identified and described 50 distinct ecological land types (ecological sites) associated with the diverse range of soils and landscape settings found within the Monument. Digital products include a GIS based soil map with almost 6000 map-unit polygons; a soil attribute database with the capacity to automatically generate tabular reports, soil interpretations, and thematic maps; and a soil-survey manuscript with detailed descriptions of soil map units and individual soil types, including photographic descriptions for a limited number of map units. Together, this set of soil inventory products provides a rich body of information to support adaptive management of Monument resources. In addition, the survey establishes a solid framework for applied ecological research investigating effects of soil properties on responses of rangeland ecosystems to climate variability and land use.

Keywords: soil inventory, rangeland ecology, soil science, soil conservation

Using Biological Soil Crusts as an Indicator of Rangeland Health

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ABSTRACT

Rangeland health is an abstract concept that is impossible to measure directly. Range managers require useful measurable indicators of rangeland health. Biological soil crusts are a diverse soil surface community, prevalent in semi-arid regions, which perform numerous important ecosystem services. Because these crusts are in decline due to surface disturbance, they are an excellent negative indicator of disturbance to rangelands. We sampled relatively undisturbed portions of Grand Staircase-Escalante National Monument, and modeled the potential cover of four crust types (dark cyanobacterial, moss, lichen, and moss + lichen + dark cyanobacterial) based upon GIS data layers (soils, precipitation, and elevation). The correlation between predicted and observed values for the four models were moderately high (R^2 = 0.49, 0.64, 0.55, and 0.64, respectively). We were less successful modeling light cyanobacterial cover and chlorophyll *a* (a biomass proxy; R^2 = 0.22 and 0.09 respectively). We selected four sites surveyed in a GSENM rangeland health survey representing a wide variation in potential soil crust cover based upon our models. This data set contains cover data on biological soil crusts among seventeen other indicators. Although two of these sites had low to very low soil crust cover, we found that they were at or near their potential according to this indicator. The two other sites had fairly high soil crust cover, but we found that one was somewhat below its potential and one was well below half of its potential. This exercise demonstrates our potential crust cover data layers will allow: 1) Better rangeland assessment *via* comparing the modeled potential soil crust condition of a site with its actual condition, and 2) Development of appropriate restoration reference conditions.

Keywords: rangeland health, indicators, biological soil crust models

Editor's note: This GSENM-funded project resulted in the following peer-reviewed publications:

Matthew A. Bowker, Jayne Belnap, Mark E. Miller. 2006. Spatial Modeling of Biological Soil Crusts to Support Rangeland Assessment and Monitoring. *Rangeland Ecology and Management* 59:519-529.

Matthew A. Bowker. 2007. Biological Soil Crust Rehabilitation in Theory and Practice: An Underexploited Opportunity. *Restoration Ecology* 15: 13-23.

Matthew A. Bowker, Jayne Belnap. 2008. A Simple Classification of Soil Types as Habitats of Biological Soil Crusts on the Colorado Plateau, USA. *Journal of Vegetation Science* 19:831-840.

Matthew A. Bowker, Mark E. Miller, Jayne Belnap, Thomas D. Sisk, Nancy C. Johnson. 2008. Prioritizing Conservation Effort through the Use of Biological Soil Crusts as Ecosystem Function Indicators in an Arid Region. *Conservation Biology* 22:1533-1543.

Matthew A. Bowker, Jayne Belnap, V. Bala Chaudhary, Nancy C. Johnson. 2008. Revisiting Classic Water Erosion Models in Drylands: The Strong Impact of Biological Soil Crusts. *Soil Biology and Biochemistry* 40:2309-2316.

Matthew A. Bowker, Fernando T. Maestre, Cristina Escolar. 2010. Biological Crusts as a Model System for Examining the Biodiversity-Ecosystem Function Relationship in Soils. *Soil Biology and Biochemistry* 42:405-417.

Landscape-scale Assessment of Grand Staircase-Escalante National Monument

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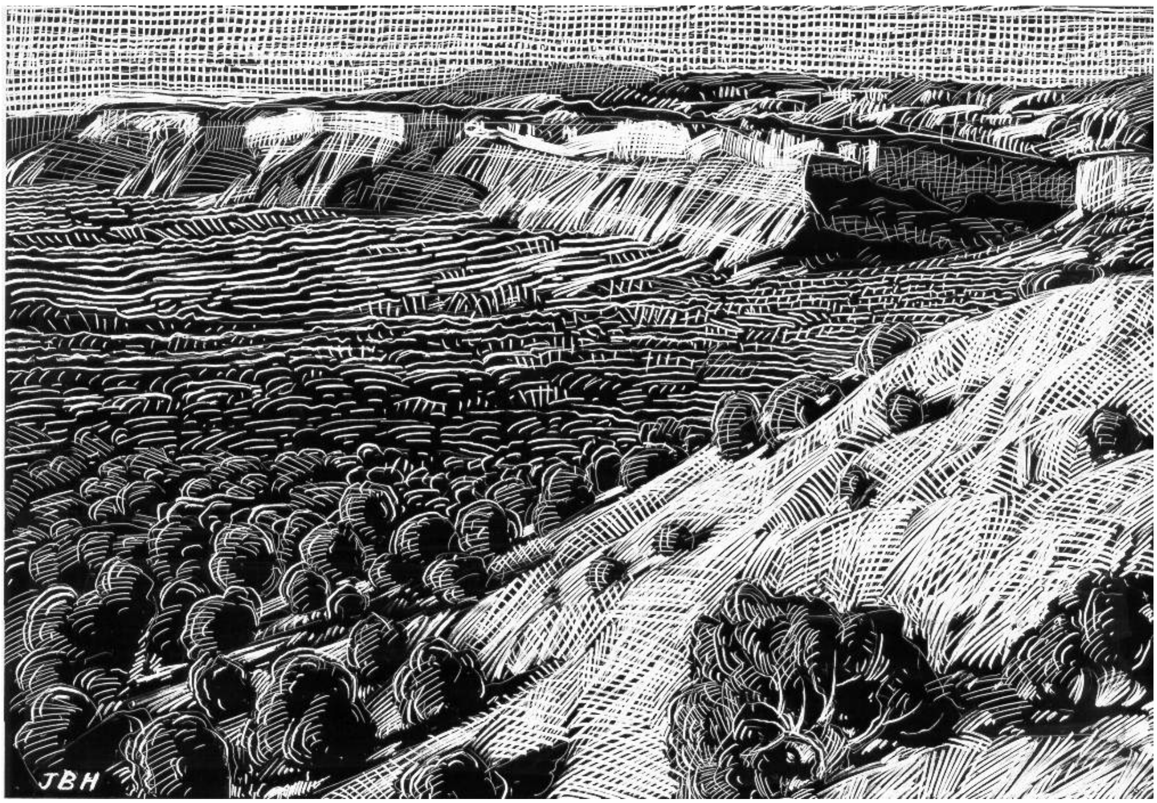
ABSTRACT

Between 1998 and 2003, field sampling was conducted to create an extensive database that was used in various analyses of vegetation and soil characteristics within the Monument. The primary objectives were to produce (1) detailed baseline data on native and non-native plant species, cryptobiotic crust communities, rare/unique habitats, and soil characteristics; (2) geographic information system-based spatial analyses of the patterns of plant diversity, hot spots of diversity, and rare/unique habitats; and (3) the establishment of long-term study plots to monitor and evaluate the status and trends of botanical resources over time. To meet these objectives, we (1) identified hot spots of native plant diversity and rare/unique habitats; (2) determined areas where cryptobiotic crusts and plant vegetation types are particularly sensitive to disturbance; (3) detected the loss of native plant diversity caused by non-native plant species; and (4) established long-term study plots to monitor and evaluate vegetation and soil resources. Over the six years of the study some consistent patterns emerged that highlight future research and management needs: (1) native and non-native plant species thrive in rare, mesic habitats that are high in soil fertility, moisture, and foliar cover; (2) highly disturbed habitats such as post-burn areas have exceedingly high levels of plant invasions related to the destruction of soil crusts and local displacement of native species by non-native species; (3) more common xeric habitats are high in endemic species and have considerably lower non-native species and cover; (4) plant species life history can be an important predictor of successful invasion because it integrates specific environmental variables; (5) the high frequency of occurrence of non-native species in the Monument is a great cause for concern; and (6) cryptobiotic crusts play an integral role in the Colorado Plateau ecosystem.

Keywords: mycorrhizal fungi, soil stability, diversity, rangeland health, disturbance

Archaeology



"Perhaps among the ashes, sherds, and crumbling walls we may find a strange and unexpected sort of wisdom."

– Richard W. Lang –

A Preliminary Report on Human Occupations at North Creek Shelter: A Stratified Site in Escalante Valley

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ABSTRACT

Archaeological research at North Creek Shelter in Escalante Valley has discovered evidence for human occupation dating prior to 9500 rcybp (radiocarbon years before present). This is the earliest evidence of human occupation on the Northern Colorado Plateau. The excavations here have focused on the earliest periods. Of particular interest has been the exposure of a heavily used surface dating to the early Archaic period, ~8000 rcybp. Several pits, a hearth, grinding implements, and other artifacts are associated with this surface. Faunal bone, chipping debris, and a stemmed point were recovered from the deepest levels. Although not the primary focus of the project, the site was also intensively occupied during the Fremont period. Preliminary results reveal evidence of a cooler, wetter period prior to 8000 rcypb. Additional excavations are planned for the 2007 season to expose other possible early Archaic use areas and to extend the excavations to sterile sediments.

Introduction

The Escalante River drainage in south central Utah is known for its rich cultural heritage, although research into human history has been sporadic and typically has focused on structural sites representing the Formative periods (Fremont and Anasazi) (e.g., Gunnerson 1959; McFadden 1997; Baadsgaard and Janetski 2005). Recent work by Brigham Young University over the past several seasons has expanded research over a broader region and discoveries at North Creek Shelter have dramatically expanded the temporal view as well. Here we report preliminary results of three seasons of excavations at North Creek Shelter. We first describe the site and findings and then integrate those findings into regional prehistory.

Site Description

North Creek Shelter (elevation 6150 ft) lies at the base of a south-facing sandstone cliff about 400 m northeast of the juncture of North Creek and the Escalante River; in fact, three streams come together here within about a quarter mile—Upper Valley Creek, Birch Creek, and North Creek—to form the Escalante River (Figure 1). North Creek is the largest of the streams and would have provided a reliable water source in the past (Figure 2). Several Fremont-age granaries, and rock art, both painted and pecked, are present on the cliff face. Rock art panels include historic inscriptions as well as historic aboriginal, Fremont, and Archaic style elements. A layer of historic dung overlies much of the flat area at the cliff base, while chipped stone debris, ceramics, bone fragments, and ground stone are abundant there as well as down the slope below the cliff. Culturally stained sediments are present on the slope, and several concentrations of stained earth and artifacts appear where the slope flattens near the flood plain. These stains likely mark Fremont house pits, although this would require testing to verify. Several smaller rock art panels and a scatter of cultural debris are present on the cliff face that continues 100 m or so to the east and several hundred meters to the north.

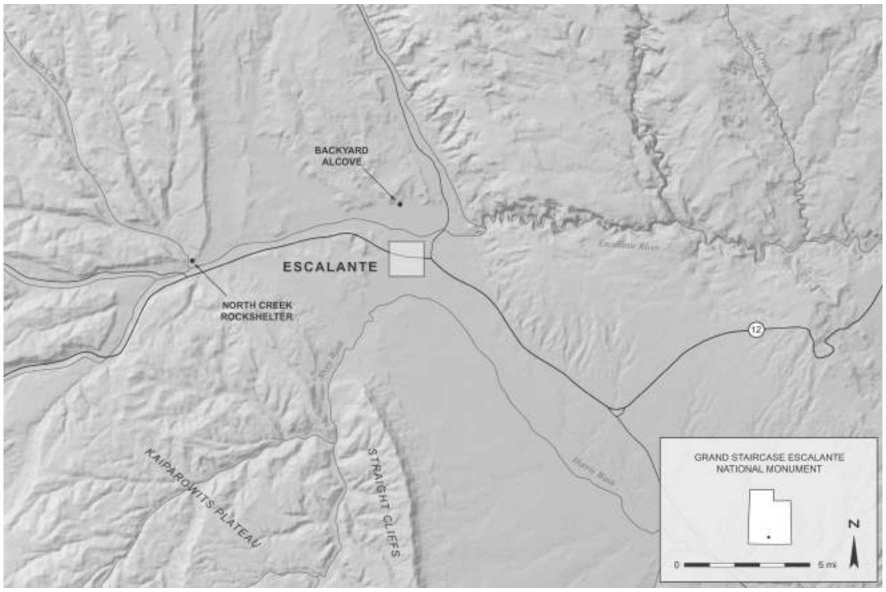

Figure 1. Map of southern Utah showing location of North Creek Shelter at the headwaters of the Escalante River.

Project Background

In 2004 the BYU archaeological field school obtained permission to test North Creek Shelter from the Rex family, who are the land owners and who run a bed-and-breakfast on their property just down slope from the cliff. A portion of the site along the cliff face was mapped and a metric grid established prior to the test. The initial test in 2004 was excavated to a depth of 2.20 m below ground surface in a single 1-by-1 m unit but did not reach sterile (non-cultural) deposits. The 2005 work expanded the test to 6 m² and extended the depth in two of the grids to 2.63 m below ground surface but still failed to reach sterile sediments.

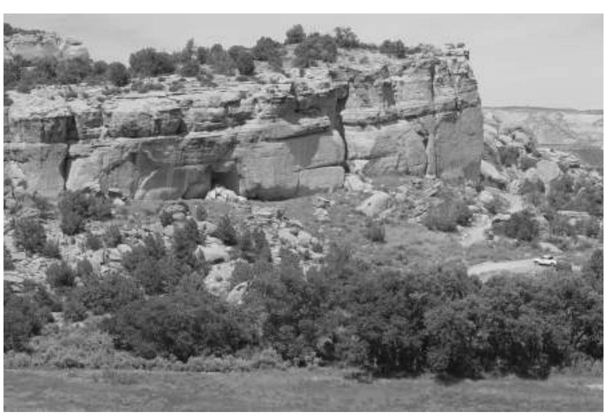

Figure 2. View of North Creek Shelter looking roughly northeast. Excavations are at the base of the cliff to the left of the large rock fall.

The 2006 excavations stretched the horizontal exposure from 6 m² to 26 m² and extended the depth in three units to 3.17 m below ground surface. This season's work revealed multiple Fremont, early Archaic, and Paleoarchaic-age use surfaces but, once again, failed to find the bottom of human occupation.

Stratigraphy

Stratigraphic levels have not been assigned numbers as we have yet to reach sterile sediments. This discussion, therefore, relies on temporary feature numbers for distinct strata and features, although some interpretive terms are used when function seems clear. Some observations on the sediment characteristics can be made as well. The stratigraphy is complex at all levels, although for differing reasons, and the following discussion is simplified somewhat.

The uppermost levels (F13, F25, F37, etc.) at the site demonstrate evidence of intense human occupation with numerous discontinuous lenses of ash and fire-reddened sediments (Figure 3). These uppermost levels contain evidence of burning across much of the site area adjacent to the cliff face. This burning may have been a natural event given the extent of these layers and the evidence of burning. The fairly deep sediments (F14) below the burn layer date to the Fremont occupation but have been heavily churned by rodent activ-

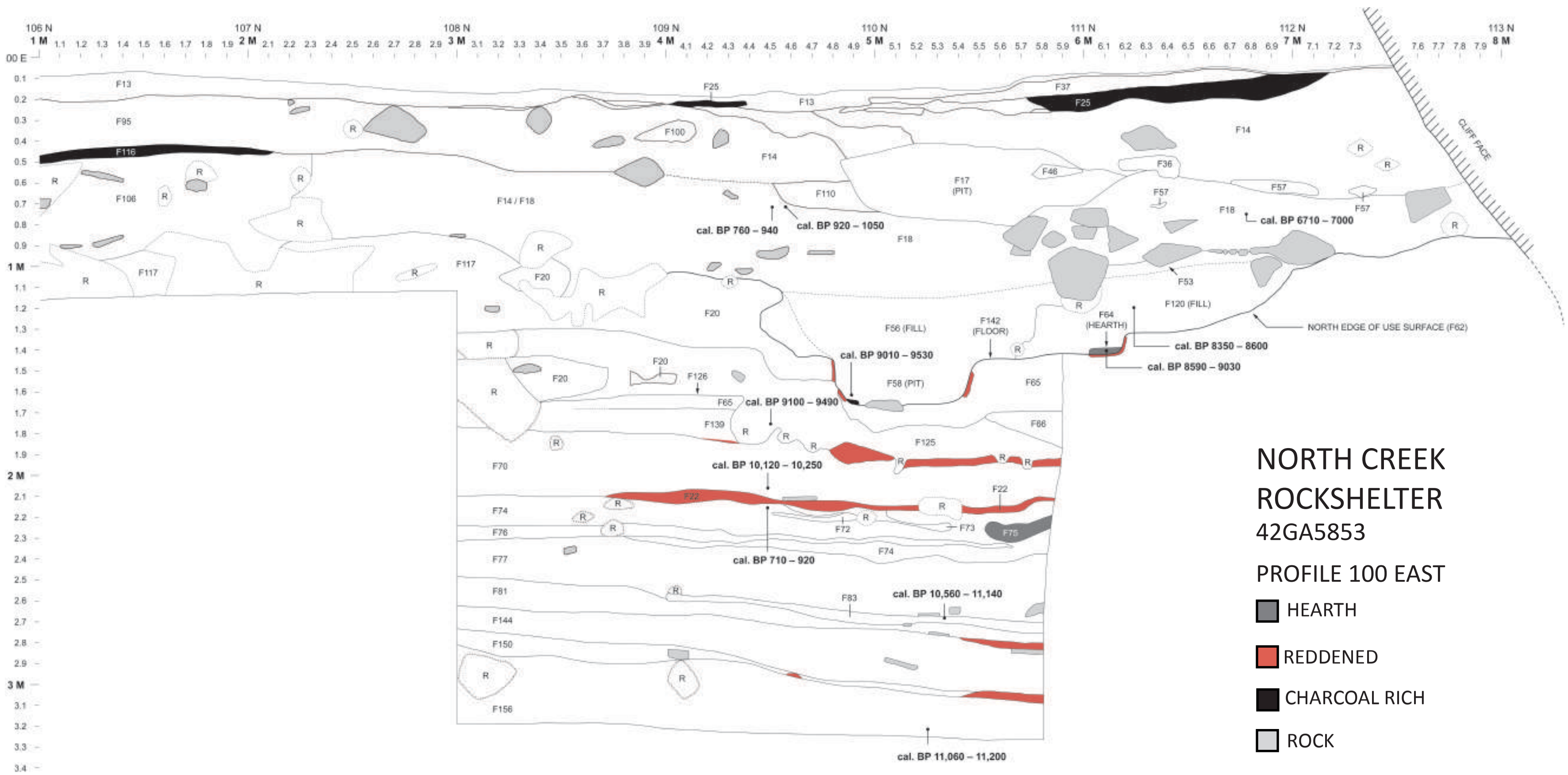

Figure 3. Profile of North Creek Shelter along the 100 east line with radiocarbon dates inserted. No stratigraphic designations are provided as the sterile deposits have not yet been reached.

Beta Sample No.	Material, Provenience	Depth cmbgs	Conventional Radiocarbon Age	2 Sigma Calibrated Age	2 Sigma Cal BP Age
197358	Corn, F14/F18	~65	940 ± 40 BP	AD 1010 -1190	760 - 940 BP
221411	Corn, F134	~65	1050 ± 40 BP	AD 900 - 1030	920 - 1050 BP
221414	Pooled charcoal F18 stratum fill	~75	6020 ± 60 BP	5050 - 4760 BC	7000 - 6710 BP
221412	Pooled charcoal F120 stratum fill	~120	7670 ± 80 BP	6650 - 6400 BC	8600 - 8350 BP
207167	Pooled *Junipe-rus*, F62 hearth	~130	7970 ± 80 BP	7080 - 6640 BC	9030 - 8590 BP
210253	Pooled char-coal, F59	~155	8320 ± 120 BP	7580 - 7060 BC	9530 - 9010 BP
197359	Pooled char-coal, F125	~160	8310 ± 70 BP	7540 - 7140 BC	9490 - 9100 BP
194030	Pooled char-coal, F70	~200	9020 ± 70 BP	8300 - 8170 BC	10250 - 10120 BP
195226	*Atriplex*, F74	~210	890 ± 40 BP	AD 1030 - 1240	710 - 920 BP
207168	Pooled *Pinus*, F83	251 - 254	9510 ± 80 BP	9190 - 8610 BC	11140 - 10560 BP
221415	AMS charcoal, F156	315	9690 ± 60 BP	9250 - 9110 BC	1120 - 11060 BP

Table 1. Radiocarbon dates from North Creek Shelter

ity. Below the Fremont level are more compact deposits (F18) which are Archaic in age given the appearance of atlatl projectile points and radiocarbon dates (see below). Below F18 lies an early Archaic use surface (F62). Much of the fill (especially F56) above F62 was loosely compacted and seemed homogenized by rodent activity, though portions of closer to the cliff face were clearly laminated (F120) suggesting these sediments retain integrity, perhaps due to the fact that rain tends to carry fine silts down the cliff face which have indurated these levels somewhat and are less attractive to rodents.

There is a stark contrast between sediments above F62 and below it. The upper deposits are clearly anthropogenic. They are dark and charcoal-rich with occasional small and large sandstone cobbles and quite complex due to human activity. The sediments below the early Archaic use surface are also complex, although this complexity is due to natural depositional process and, for the most part, consist of alternating, discontinuous bands of tan silts and sands intermingled with varying amounts of cultural debris, primarily charcoal, bone, and chipped stone detritus. Both rocks and rodent activity are less common in these lower levels. Fortunately, because of the more compact nature of the deeper sediments, the rodent burrows that exist can be clearly seen and removed to avoid contamination. These levels date prior to 8000 rcybp, and below F83 they date prior to 9600 rcybp. These lowest levels are considered very early Archaic or Paleoarchaic (see for example Beck and Jones 1997).

Dating

The eleven radiocarbon dates obtained thus far ladder up nicely from the bottom with the exception of an aberrant date of 890 ± 40 rcybp (about A.D. 1100) from a single piece of *Atriplex* (saltbush) from F74 (Table 1). This small charcoal fragment was most likely dislodged from upper levels during the initial site testing. The dates from an early Archaic hearth and pit associated with the F62 occupation place that use between 7970 ± 80 rcybp and 8320±120 rcybp. The bottom of the test reached in 2006 (F83/F81) dates to 9690 ± 60 rcybp. Dates from levels above F62 require some explanation. The laminated sediments (F120) directly above F62 date to 7670 ± 80, just shortly after the occupation of the use surface. The F18 date is also in proper order as it is from sediments about 45 cm above the F120 date and falls about 1600 years later. However, the F18 date (6020 ± 60 rcybp) is from sediments at very nearly the same depth as corn pulled from a slab-lined thermal feature and which dates to 1050 ± 40 rcybp. These two dates are 7000 years apart suggesting a huge temporal gap with only a few cm of vertical deposition. The most logical explanation for this dramatic jump is that Fremont occupants removed existing sediments to manipulate the area to suit their needs. Additional exposure of the Fremont levels could allow testing of this notion.

Site Cultural Chronology

The research has found three primary occupations at the site: the Paleoarchaic (9000 BP and earlier), early Archaic (7000 to 9000 BP), and Fremont periods (900 to 500 BP). So far we have not found definable middle or late Archaic occupations. The early periods are particularly interesting as data on both the early Archaic and Paleoarchaic are scarce.

Paleoarchaic/Paleoindian Levels

As noted, this early occupation is a primary focus of the research at North Creek Shelter, although our interest is not restricted to that era given the richness of the upper deposits. All levels below F62 (Figure 3) are early Archaic and the lowest levels (below F22) are here considered Paleoarchaic. This conclusion is borne out by a shift in tool types (e.g., increasing numbers of unifacially flaked tools, decreasing numbers of grinding tools), the appearance of toolstone apparently exotic to the region, and, at the very bottom of the excavations, a stemmed point fragment (Figure 4). Thus far we have found no ground stone below F22. The levels below F62 are characterized by alternating and discontinuous layers of sands and silts which yielded chipped stone debitage, occasional tools, small sandstone slabs (some of which are fire reddened), faunal bone, and charcoal. The amount of cultural material in these levels varies, and we currently interpret the fluctuating quantities of artifacts as representing periods of more intensive use. Levels containing higher counts of debitage appear to correspond to levels marked by reddened sediments. It is possible that those reddened levels represent sequential use surfaces similar to F62.

All levels below F62 were excavated in 5 cm increments, and all items left in place (usually 5cm in size and above) were mapped point plotted with x, y, and z coordinates. The debitage from these lowest levels are of local Morrison Petrified Wood and what appears to be Paradise chert. However, in the bottom 10 to 12 cm of the excavation we found several flakes of a speckled chert suggesting access to a different toolstone source than those used later in time. The stemmed point toolstone may be exotic to the Escalante Basin, although it is similar to toolstone from the Glen Canyon/Capitol Reef area (Phil Geib, Tony Baker, personal communication 2006).

Faunal remains in the Paleoarchaic levels consist of modern forms, and preliminary analysis of these specimens has identified deer, rabbit, and several rodent species. Some specimens represent species that apparently are now absent from the immediate area, such as yellow-bellied marmot (*Marmota flaviventris*). Analysis findings hint at the possibility of white-tailed jackrabbit (*Lepus townsendii*), mountain cottontail (*Sylvilagus nuttallii*), and possibly white-tailed deer (*Odocoileus virginianus*) in the deepest levels. Although modern, these species preferred the climate and vegetation of wetter and cooler subalpine environments, and their replacement by more xeric-adapted species, namely rock squirrel (*Spermophilus variegatus)*, black-tailed jackrabbit (*Lepus californicus*), desert cottontail (*Sylvilagus audobonii*), and mule deer (*Odocoileus hemionus*), as has been demonstrated at Great Basin sites could signal the onset of the warmer and drier middle Holocene (Grayson 1982; Heaton 1990). Confirmation of the existence of these mesic oriented taxa awaits additional analysis, however. A very high ratio of large to small game within these levels suggests that large mammal capture dominated the subsistence strategy of the period. Bone preservation is surprisingly good at the lowest levels, and nearly all skeletal elements are present.

Early Archaic Levels and Use Surface

The focus of early Archaic occupation thus far has been a heavily used surface (F62) and associated features. The early Archaic, as defined by the

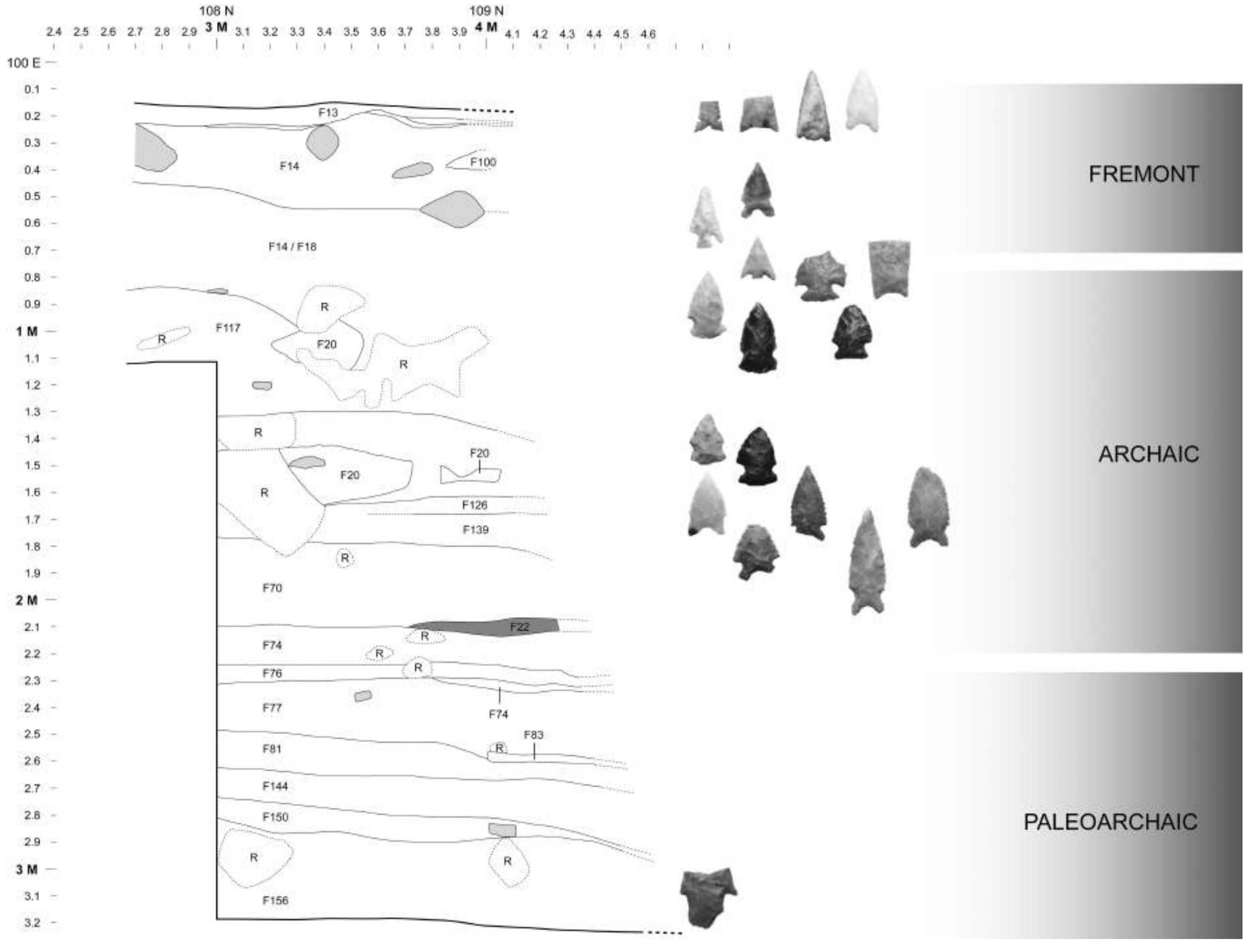

Figure 4. Abstracted stratigraphic profile showing general time periods and associated projectile point types.

distribution of Pinto Shouldered points, extends to at least F22, 40 cm or so below F62. Several pits, at least one hearth, a possible post hole or socket, and a number of artifacts are present on the exposed use surface (Figure 5). The pits are highly redundant in size and shape averaging 35 to 40 cm in diameter and roughly 30 cm in depth. Several exhibit reddened rims suggesting they were thermal features, perhaps used for processing foodstuffs. Others are not reddened and may have been storage features. All appear to originate from the compacted surface. The one hearth (F64) found thus far lies on the east edge of the surface and is shallow (less than 10 cm deep), was full of ashy, charcoal-rich fill, and is reddened on the edges and the bottom. Artifacts found lying on the surface include two metate fragments, two unifacially flaked cobbles, and a mano. A large deer antler tine lay just above the surface on the north edge of F62. The floor of the use surface was compacted and roughly level in the area north of the pits but sloped up quite dramatically toward the cliff. We could not follow this surface to the south of the pits where the area was heavily eroded and bioturbated through rodent activity. Reddening of the surface in several areas and the presence of a possible post socket suggest this surface was covered by a superstructure which burned. The presence of a superstructure remains problematic and awaits additional work for resolution.

As noted above, at least two use surfaces lie below F62: F126 and F22. Both are marked in part by reddened surfaces and artifacts and bone as well as sandstone slabs lying flat. Artifacts lying on F126 include a large quartzite flake used as a cutting and crushing tool. The F22 use surface contained several ground stone tools but represents the deepest level at which ground stone was found. A single circular pit similar to those found in F62 probably originated on the F22 surface.

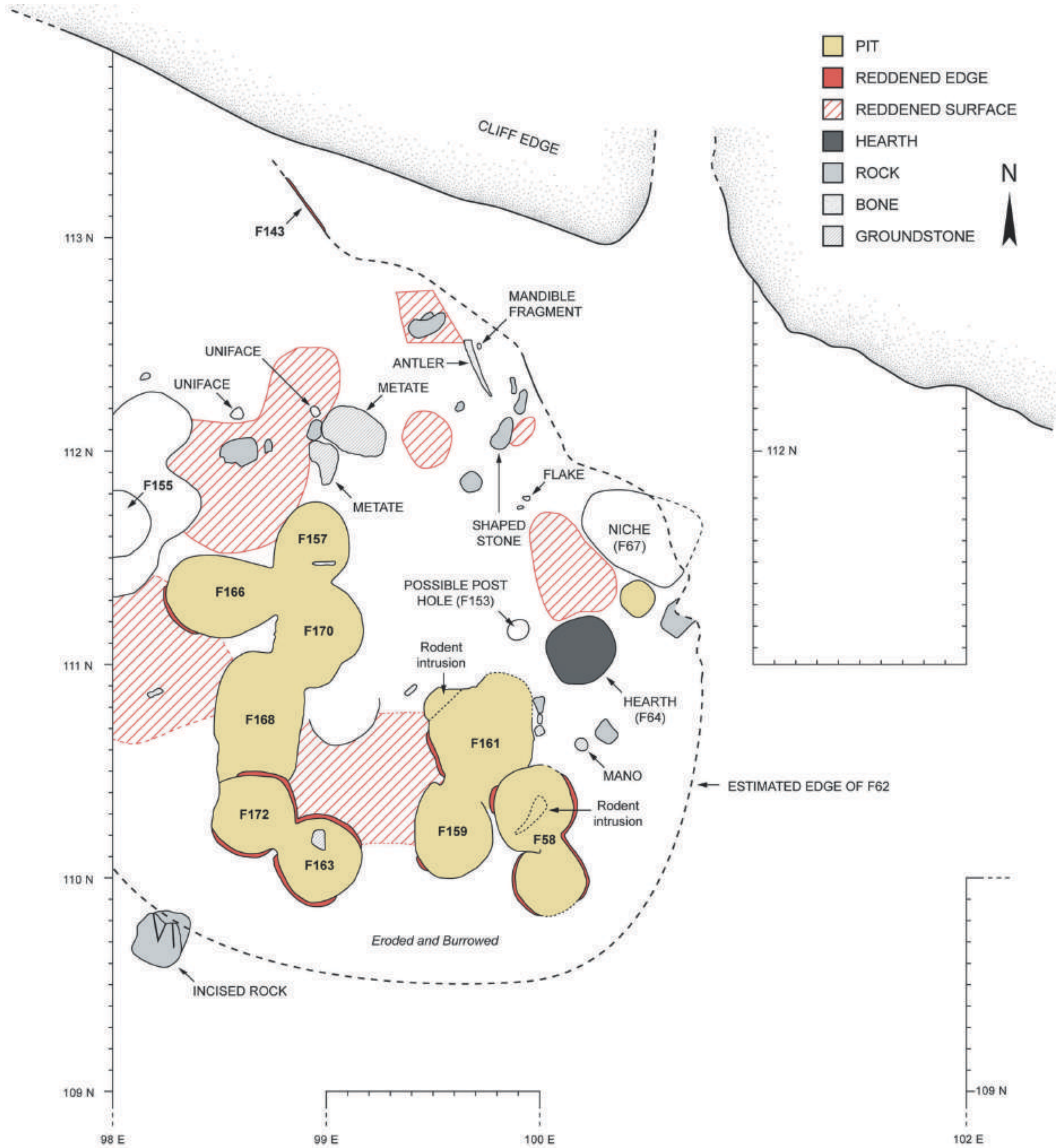

Figure 5. Plan of Early Archaic surface showing abundant thermal features and associated artifacts.

Fremont and Late Prehistoric Levels

The Fremont occupations are marked by the occurrence of several formal features: two clay-rimmed hearths, a slab-lined basin, and other thermal features (Figure 6). An alignment of vertical slabs (F94) and a single vertical slab set in adobe may have been remnants of larger constructions, possibly houses, stratigraphically above the hearths just mentioned. The two clay-rimmed hearths were in separate areas and were at different levels, clear evidence of subsequent use during the Fremont period. We also recovered numerous fragments of burned corn, ceramics, chipped stone artifacts, figurine fragments, and stick-impressed adobe. Projectile points from this period include Rosegate and Bull Creek types. The presence of these features and artifacts are evidence of an intense Fremont occupation at the base of the cliff.

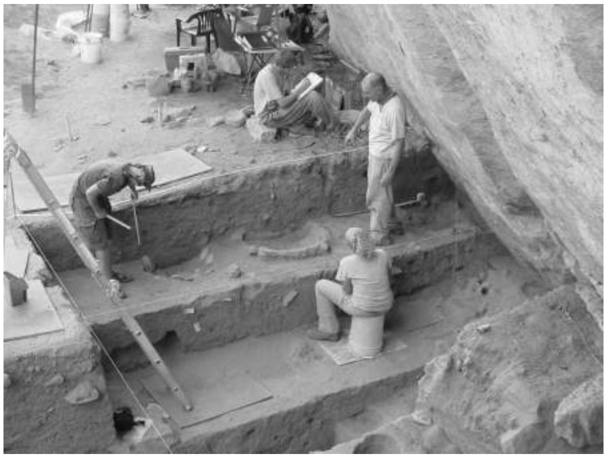

Figure 6. View of North Creek excavations revealing Fremont features dating to about AD 1000. Note clay rimmed hearth and slab-lined pit.

The several granaries in the cliff face above and to the east of the excavation as well as the artifact-rich and culturally stained areas on the slope below reinforce the intensity of human occupation during the Fremont period.

Evidence of Late Prehistoric occupation at the site is also present in the form of Desert Side-notched points and brownware ceramics. These are found in the uppermost levels at the site, mostly stratigraphically above Fremont diagnostics. No features unequivocally assignable to the Late Prehistoric are known as yet.

Discussion of Primary Research Issues

Primary research issues being examined at North Creek include, but are not limited to: 1) the timing of human arrival on the Northern Colorado Plateau and Utah generally and the human lifeway during that period, 2) early Archaic lifeway, 3) the extent of the mid-Archaic cultural hiatus, 4) paleoenvironmental reconstruction.

Timing of Human Arrival on the Northern Colorado Plateau

As noted at the onset, North Creek Shelter contains the earliest evidence of human occupation on the Northern Colorado Plateau as no sites with dates in excess of 9,000 rcybp on human occupation are reported in this area, and only a handful date to before 8,000 rcybp. Insights into this early period of human history have been elusive in Utah. Tantalizing glimpses have come from Cowboy Cave in Canyonlands well to the east of Escalante Valley. Here excavators found dung of mammoth, bison, horse, camel, and sloth, two tips of mammoth tusks, and bison and elk bone in the basal layers of the cave (Jennings 1980). Dates on the dung layer are 11,020 ± 180 rcybp and 13,040 ± 440 rcybp, both considerably older than the North Creek date. The earliest date associated with human occupation at Cowboy Cave, however, is 8275 ± 80 rcybp. Somewhat closer to the Escalante site is Bechan Cave, also in Canyonlands, where massive deposits of mammoth dung are present and which date to 11,000 or more radiocarbon years ago. Schroedl (1991) has reviewed the distribution of mammoth and bison remains on the Northern Colorado Plateau and showed that such are rather common in Canyonlands where considerable exploration has occurred. These finds document a world very different from that seen in southern Utah today, but none contain evidence of humans contemporary with these now-extinct animals. Diagnostic projectile points found with such megafauna on the Plains and in southern Arizona are present in southern Utah near the site. Geib et al. (2001) report possible late Paleoindian points from survey work on the Kaiparowits Plateau just south of Escalante Valley, and Baer and Sauer (2003) illustrate a late Paleoindian base from the junction of Birch Creek and Upper Valley Creek less than a mile from North Creek Shelter. All finds are from the surface, however. The stemmed point base from North Creek Shelter is the first Paleoarchaic point recovered in situ from excavations on the Northern Colorado Plateau.

Sites comparable in age to North Creek Shelter and earlier are likewise scarce in the eastern Great Basin but include Smith Creek Cave in the Snake Range near the Utah-Nevada border (Bryan and Tuohy 1999), Danger Cave in Utah near Wendover (Jennings 1957), and Bonneville Estates Rockshelter in eastern Nevada south of Wendover (Goebel et al. 2006) (Table 2). All contain evidence of human use prior to 10,000 rcybp.

Of critical interest is human lifeway during this early period. As noted, surface finds of fluted points and other Paleoindian style artifacts from across the state are similar to such tools found in Paleoindian sites on the Plains and in the South-

Site	Physiographic Region	Radiocarbon Age	Source
Smith Creek Cave	Eastern Great Basin	11140 ± 200 BP	Bryan and Tuohy 1999
Bonneville Estates	Eastern Great Basin	10800 ± 60 BP	Rhode et al. 2005
Danger Cave	Eastern Great Basin	10310 ± 40 BP	Rhode et al. 2005
The Pits	Rainbow Plateau	9780 ± 80 BP	Geib and Spurr 2002
North Creek Shelter	Northern Colorado Plateau	9510 ± 80 BP	Janetski et al. 2005
Joe's Valley Alcove	Northern Colorado Plateau	8940 ± 180 BP	Barlow and Metcalfe 1993
Jim Walters Cave	Northern Colorado Plateau	8875 ± 125 BP	Jennings 1980
Dust Devil Cave	Northern Colorado Plateau	8830 ± 160 BP	Geib 1996
Hogup Cave	Northern Colorado Plateau	8800 ± 200 BP	Madsen and Schmitt 2005
42GR1547	Northern Colorado Plateau	8780 ± 60 BP	Greubel 2003
Rock Creek Alcove	Northern Colorado Plateau	8660 ± 80 BP	Nickens et al. 1988
42SA17107	Northern Colorado Plateau	8340 ± 290 BP	Tipps and Schroedl 1990
42SA171215	Northern Colorado Plateau	8330 ± 110 BP	Agenbroad 1990
Rock Bar Alcove	Northern Colorado Plateau	8280 ± 160 BP	Geib
Cowboy Cave	Northern Colorado Plateau	8275 ± 80 BP	Jennings 1980

Table 2. Early radiocarbon dates on unequivocal human occupation from the eastern Great Basin and Northern Colorado Plateau

west. These could be interpreted as evidence of a Paleoindian strategy (mobile hunters and gatherers who, on occasion, pursued now-extinct fauna such as mammoth and long-horned bison). Understanding early strategies is of utmost interest in the region; however, detailed insights into lifeways await the discovery of a buried site with diagnostic artifacts. In the eastern Great Basin this early period is often referred to as the Paleoarchaic as subsistence data from sites of this age suggest that an Archaic-like strategy of broad-spectrum hunting and gathering was in place, not a Paleoindian strategy. Diagnostic projectile points of the Paleoarchaic in the eastern Great Basin tend to be the large stemmed variety rather than the fluted types mentioned above and the temporal and functional relationships of these points continue to be debated (Beck and Jones 1997; Rhode et al. 2005).

The findings of the work to date at North Creek include the basal fragment of a stemmed point, but no evidence of either fluted points or of extinct fauna. As mentioned above, all the bone is from Holocene, not Pleistocene, fauna. Projectile points are common in the upper levels with Bull Creek types dominating, but are scarce in the lower levels. A handful of morphologically similar projectile points came from the deposits below the Archaic pit house. These are atlatl points with shallow side notches and basal concavities reminiscent of Pinto points from Sudden Shelter (Jennings et al. 1980) and projectile points from Burial 2 at Sand Dune Cave (Lindsay et al. 1968). The unifacially and bifacially flaked tools recovered from the lowest levels are non-diagnostic but are made from various materials—Paradise chert, Morrison petrified wood, Boulder jasper, dark red chert, and an, as of yet, unidentified green speckled chert. Chipped stone debitage from the basal levels consists primarily of very small flakes, although a few larger bifacial thinning flakes and chunks are present. Raw material in these levels is dominated by Paradise chert and Morrison petrified wood, both local toolstones (Geib et al. 2001). Obsidian is present, but rare.

Early Archaic Use Surface (Possible Pithouse)

The discovery of the deeply buried, early Archaic use surface, which may have been covered, adds greatly to the significance of the site. Definable use surfaces and especially houses of this age are rare in North America generally and specifically in the arid west. Mid-Holocene houses are well documented in southern Wyoming

(Smith 2003), in southern Idaho along the Snake River (Plew 2000:77), and on the west slope of the Rocky Mountains (Stiger 2001). Evidence of houses earlier than 8000 rcybp west of the Rocky Mountains, however, are limited to the surface structure at the Paulina Lake site in central Oregon (Connolly 1999:121), and a structure of Folsom age (10,400 rcybp) excavated by Mark Stiger near Gunnison Colorado (Stiger 2006).

The implications of a possible structure for understanding Archaic lifeways are considerable. The traditional view of this period is one of highly mobile hunters and gatherers who moved to harvest resources in season (Jennings 1978; Aikens and Madsen 1986). The presumption is that, in the temperate climate of the Great Basin/Northern Colorado Plateau, Archaic foragers would have constructed houses for the winter months, but few have been found. The earliest known houses in Utah and the Southwest generally are the four "pit structures" from Stratum III in Cowboy Cave (Schroedl and Coulam 1994; see also Huckell 1996:334). A date of 6830 ± 80 rcybp from Pitstructure A places these circular depressions in the early Archaic. Late Archaic houses are known from the Pahvant Park site just north of Richfield and Aspen Shelter on the Old Woman Plateau of central Utah. These structures date to 3370 ± 80 rcybp, and 3790 ± 60 rcybp respectively (Talbot and Richens 1993:48; Janetski et al. 1991).

It is still not clear that F62 at North Creek Shelter is a structure, however. At a minimum, F62 area is a heavily used, compacted surface with a hearth, numerous pits, and a few artifacts lying on it. The presence of a possible post hole and the abrupt, almost vertical north edge, which has not yet been fully excavated, but which is fire reddened, suggests the surface was manipulated and possible covered. In any case, the several floor features are evidence that Archaic foragers spent considerable time at North Creek Shelter, probably during the cold months of the year. If so, one would also expect storage facilities to be present at the site. Features exterior to the houses at Aspen Shelter, for example, included numerous hearths and small, jug-shaped pits that may have served storage functions (Janetski et al. 1991). Small, slab-lined storage pits were abundant in the Archaic levels of Sudden Shelter (Jennings et al. 1980) as well. The small, circular, intramural, sub-floor pits associated with the F62 surface may represent temporary storage. Analysis of soils recovered from the features may help answer this question.

Mid-Archaic Cultural Hiatus

Another research issue at North Creek is whether human occupation was continuous through the Holocene in southern Utah. Evidence of human occupation in the mid-Holocene on the Northern Colorado Plateau is scarce, more so than evidence for the early Archaic and much more so than for the late Archaic. Old Man Shelter (Geib and Davidson 1994), Atlatl Rock Cave (Geib et al. 2000), Broken Arrow Cave (Talbot et al.1999), Cowboy Cave (Jennings 1980), and Sand Dune Cave (Lindsay et al 1968) contain few dates between ~7,000 and 4,000 rcybp (Geib 1996:31). The reasons for this hiatus are not known for sure but may be related to the climatic warming and drying characteristic of the Altithermal, which may have been especially severe in the more arid reaches of southern Utah. Certainly the region was not abandoned as upland sites such as Sudden and Aspen shelters on the Old Woman Plateau in central Utah yielded mid-Holocene dates (Jennings et al. 1980:21; Janetski et al. 1991 respectively). In addition, tests in 2002 at Backyard Alcove (42GA5171), about five miles east of North Creek Shelter, yielded a date of 3180 ± 40 rcybp from deposits about 60 cm above bedrock. This date approaches the mid-Holocene period noted above and reinforces the possibility that humans visited Escalante Valley at this time.

The radiocarbon data gathered thus far from North Creek Shelter suggest a dramatic mid-Holocene hiatus, perhaps as much as 7000 years. It is our opinion that those dates are misleading and that mid-Holocene sediments may have been removed or at least disturbed by subsequent site occupants, particularly during the Fremont period. The presence of several Rocker Base Side-notched points suggest late-early Archaic to middle Archaic use (~6500 to 5500 rcybp) based on ages of similar points recovered in well-controlled deposits at Sudden Shelter (Holmer 1980). Taken together these data begin to shorten the length of a hiatus in human occupation in Escalante Valley. It is possible a test in a different location at North

Creek Shelter would yield information on the mid-Holocene human use of the site and region.

Paleoenvironmental Insights

Understanding the past environmental conditions at the site holds implications for understanding paleoenvironments for much of this portion of southern Utah and beyond. Important are both botanical and faunal records which have the potential to document environmental change over the past 10,000 years. Initial insights come from charcoal identified for dating. Charred fragments identified from the lowest level (F156) include Douglas fir, hackberry, and aspen (Puseman 2007) which suggest a vegetative community similar to that found at higher elevations (6000-10,000 feet) of the Colorado Plateau. In addition, it is clear that the rate of deposition at the site was much more rapid prior to 8000 radiocarbon years ago. The two meters of sediment below F62 accumulated in about 2000 years while just over one meter accumulated in the 8000 years subsequent to the use of F62. This difference may be exaggerated if significant deposits were removed by subsequent occupants as suggested earlier, however. Nonetheless, these differences imply a very different climatic regime during the earliest Holocene with higher rates of precipitation and deposition. These findings tend to corroborate models that suggest climates were wetter than today but were in transition to the dryer regime of the Holocene (Wigand and Rhode 2002). These characteristics combined with evidence for alternating ponding and drying in the lower sediments suggest a wetter and perhaps cooler climatic regime and consequent increased deposition during the early period. This interpretation is consistent with other climatic reconstructions of the region (e.g., Betancourt 1984; Betancourt and Davis 1984; Agenbroad1990).

Summary

Three seasons of testing at North Creek Shelter have demonstrated that the site contains cultural deposits dating to the Terminal Pleistocene/Early Holocene, a period for which information on human strategies is rare in Utah. Material remains recovered from these early levels include chipped stone tools and detritus, ground stone, and faunal remains. In addition, this work has revealed the presence of an early Archaic use surface with floor features, and redundant occupation during the Fremont period. It is clear the site was a popular spot in the historic era as well as attested by the historic Paiute pictographs and Anglo occupation. Future work at the site will focus on determining the maximum depth and age of the site and expanding the level containing the early Archaic use surface. Paleoenvironmental analyses focused on the fine-grained sediments in the lower levels will be an additional focus of the work at the site.

Acknowledgments

The North Creek Shelter work could not be done without the gracious hospitality of landowners Jeff and Joette Rex. Not only did they allow us to camp on their land, use their water and electricity, they regularly invited us to dinner and hosted volunteers for delightful, free-ranging discussions while sitting on their balcony overlooking the Escalante Valley or within their personal living quarters of their bed-and-breakfast. We thank them for this and for allowing the research to continue. This work was made possible by support from the College of Home and Social Sciences as well as the Charles Redd Center for Western Studies, both at Brigham Young University. We also acknowledge the several volunteers who assisted on the project in various ways—students from BYU and UNLV, USAS members, and others. Finally, thanks are due to Grand Staircase-Escalante National Monument archaeologists, past and present, who have provided the project with a trailer as well as encouragement.

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The Tommy Turf Site 42Ka6032: A Basketmaker II Burial from Kane County, Utah

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ABSTRACT

In October of 2004, water line installation at the privately owned Tommy Turf Farm in Kanab, Utah, encountered an apparent prehistoric burial. The resulting archaeological excavation revealed a single-episode burial of at least ten individuals ranging in age from a neonate to elderly adults. Both males and females are represented in the burial. Interestingly, while some of the interred individuals were primary burials, it appears that others within the single burial pit may have been interred as secondary burials. Carbon dating revealed that this burial falls within the calibrated, 2 Sigma range of BC 200 to AD 70, or the Basketmaker II period. This site is situated on a low, open ridge top, contrasting with other Kanab-area BM-II multiple burials which have been located in rock shelters and alcoves. Osteological analysis identified well healed antemortem trauma, evidence of generalized infection, indications of habitual activities, osteoarthritis, and poor dental health among the individuals. No perimortem trauma was indentified among the remains of the mass grave. Stable isotope analysis indicates a population heavily dependent on maize agriculture, which is supported by the poor dental health exhibited.

Introduction

This report documents the excavation and analysis of human remains from the Tommy Turf Site 42Ka6032 in Kanab, Kane County, Utah. In October of 2004 backhoe operations in conjunction with water line installation at the privately owned turf farm uncovered apparent human remains. Immediately upon the discovery of skeletal materials in the backhoe trench, operations were shut down and local law enforcement officers were called to the scene. Recognizing that the remains were probably archaeological, the law enforcement officers contacted BLM archaeologists at Grand Staircase-Escalante National Monument. The archaeological nature of the site was verified, and consultations with Utah State archaeologists resulted in arrangements for the remains to be excavated by BLM archaeologists from Grand Staircase-Escalante National Monument, working on behalf of the State of Utah. The excavation was performed in late October and early November of 2004.

The site is located at the edge of a housing development within the city of Kanab, three miles north of the Utah/Arizona State line, within the Grand Staircase physiographic province. Kanab lies at the foot of the Vermilion Cliffs where Kanab Creek emerges from the cliffs and flows southward into Arizona, eventually emptying into the Colorado River within the Grand Canyon (Figure 1). The site is found on a low, flat-topped ridge at an elevation of 5000 feet, surrounded on the east, south, and west by relatively flat alluvial drainage bottoms that were undoubtedly Anasazi farmlands (Figure 2).

Local archaeological sites span most of the Holocene, from early Archaic times through the late Prehistoric and historic pioneer periods, but sites from the Formative period dominate the landscape through shear numbers. The Tommy Turf ridge is privately owned and has never been

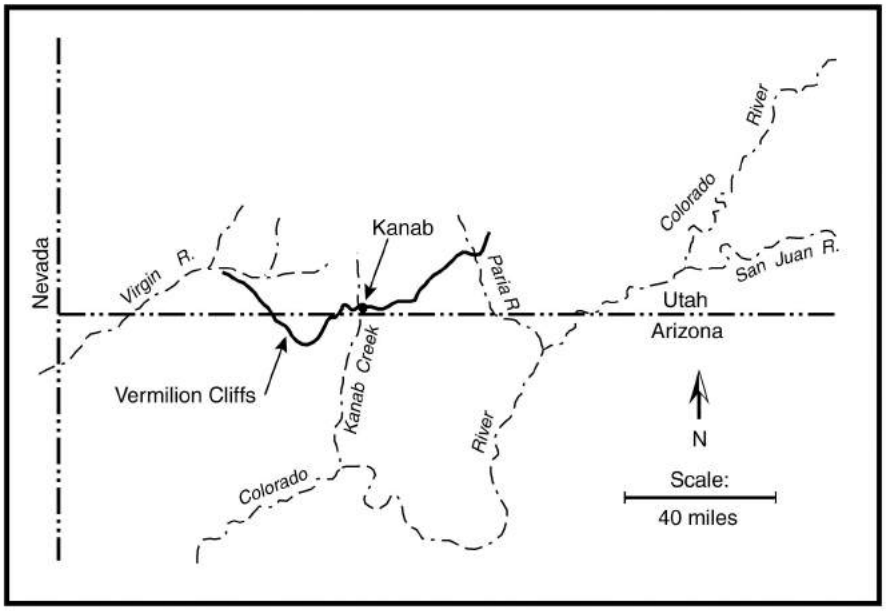

Figure 1. Location of the Tommy Turf site 42Ka6032 in Kanab, showing significant drainages and the Vermilion Cliffs line.

subject to cultural resource inventories, but a quick walk across the ridge reveals significant amounts of archaeological materials. Although moderately to highly disturbed by more than 130 years of Euroamerican use, the ridge was apparently the location for a series of Formative era residential sites. Masonry stone, tabular sandstone, staining, ceramic sherds, lithic debitage, and occasional artifacts are commonly found here, and local residents report finding buried prehistoric features during modern house and road construction. Ceramics indicate a significant BM III and Pueblo I presence, with some later Pueblo II materials as well. Residents also recall another potential burial that was exposed by erosion several years ago, but these remains were covered with soil at that time and have not apparently resurfaced.

Methods and Procedures

The Tommy Turf human remains were found exposed at the southern end of the backhoe trench approximately 30 cm below the modern ground surface. At the time archaeologists arrived at the site, a few skeletal fragments had been recovered from the backdirt by the backhoe operator and law enforcement officers and placed next to the trench, and two long bones and additional smaller fragments could still be seen in the trench. Recovery efforts began with the screening of all backdirt from the potential burial area, and screening of all loose dirt within the end of the backhoe trench. The trench walls were cleaned and the burial pit boundaries defined by soil and sediment differences.

Standard excavation procedures were followed for this burial recovery. All sediments were screened through ¼” mesh, and all skeletal remains and potential cultural materials were saved, and bagged and labeled appropriately. Although it would have been preferable to use 1/8” mesh for screening, the dampness and clay content of the sediments did not allow the use of anything smaller than ¼” mesh. Once the burial pit boundaries had been identified in vertical profile within

Figure 2. Setting of the Tommy Turf site, on the low ridge through the center of the photo. View is to the west, with Kanab Creek between the ridge and the distant Vermilion Cliffs.

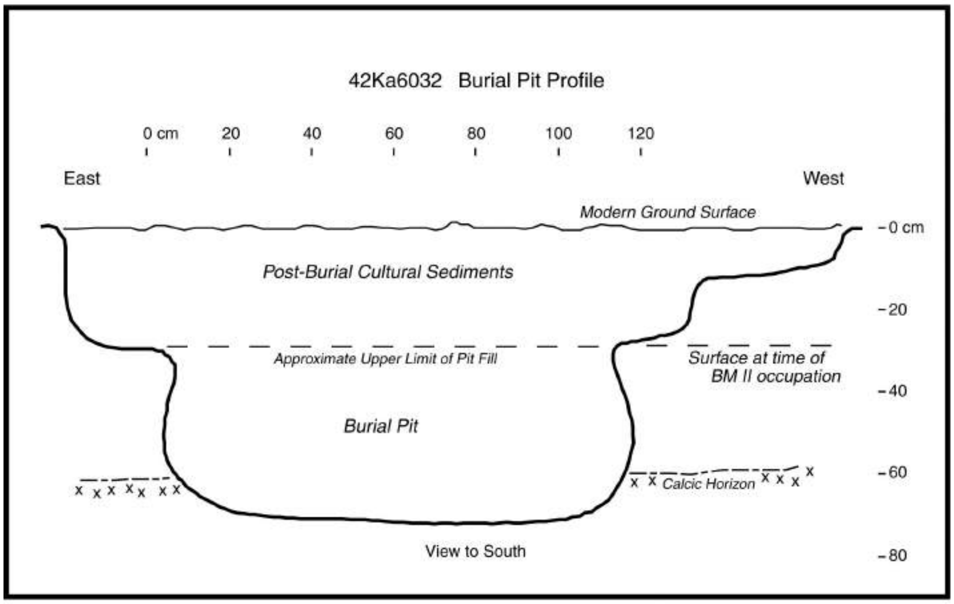

Figure 3. Profile of the 42Ka6032 burial pit, view is to the south across the center of the pit.

the backhoe trench, a 1x1 meter, horizontal grid was placed over the probable burial pit area and excavation proceeded from the surface downward in typical archaeological fashion in an attempt to define the burial pit horizontally. Once the extent of the burial pit had been identified, excavation continued only within the pit; no attempt was made to excavate anything but the burial pit fill. Post-burial cultural sediments were encountered in the 30 cm above the pit (Figure 3), but the pit itself had been prehistorically excavated into culturally sterile sediments.

It was determined that the backhoe trench had just clipped the northeastern section of a roughly circular burial pit, disturbing portions of at least two individuals (Figure 4). Considering the small size of the burial pit (140 cm across and 40 cm deep) and large size of the backhoe shovel, it is lucky that more damage was not inflicted upon the burials. Only the immediate cessation of backhoe operation by the landowner prevented much more significant damage to this site.

This excavation proceeded as a salvage project and was completed over the course of five days using a crew of two or three BLM archaeologists. This was something of a local event, and there were always several volunteers attending to help shake the screens, offer advice, and oversee the work. It was initially assumed that this was the burial of one individual, as is the usual pattern for Virgin Anasazi burials in this area. However, it quickly became apparent that multiple individuals had been interred at this location, complicating the excavation. All cultural and skeletal materials were exposed as much as possible, mapped, and photographed prior to removal. All materials were given mapping and Field Specimen numbers in an effort to control the jumble of human remains present in the pit.

This proved to be a very complex burial. The remains of at least ten individuals were eventually recovered, most of which were complete, primary burials. However there were at least two individuals with incomplete skeletons that may represent secondary burials. The adult individuals had been placed in the burial pit in more-or-less flexed positions, but this may be the result of placing several bodies into a relatively small pit rather than a cultural choice of flexed vs. non-flexed positions. At least two of the individuals had been placed on their sides or backs, but post-burial settling of the remains within the pit made it impossible to determine the original position of many individuals. The remains of a child found at the site were aligned lengthwise along the southwestern edge of the pit rather than flexed, as were the adults. There was no consistent orientation to the bodies, although there is a suggestion of head-to-toe in a counter-clockwise pattern around the interior of the burial pit. Several individuals were oriented with their heads in the southern and southeastern perimeter of the pit, one was found along the east-

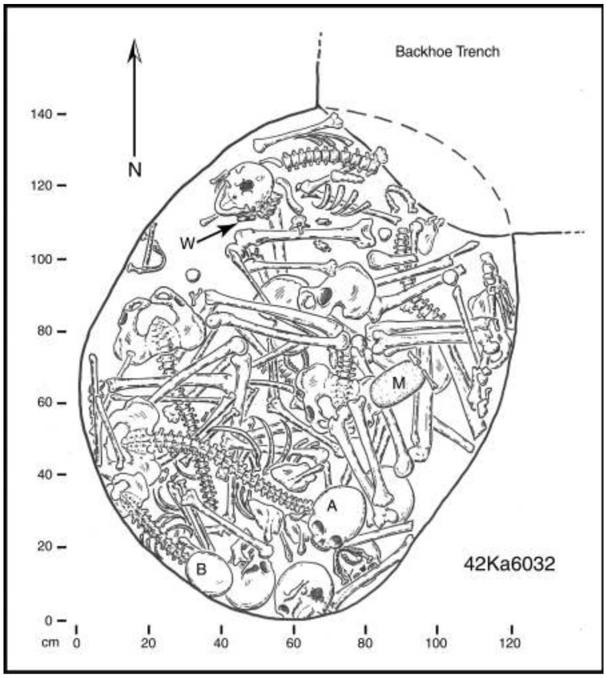

Figure 4. Plan view of the 42Ka6032 burial pit and human remains. Note that the tabular sandstone fragments and many skeletal elements, including most of the ribs and smaller elements, have been omitted for clarity. A: individual 7, adult male. B: individual 9, child, sex unknown. W: bone whistle or flute on pit floor. M: mano.

ern edge of the pit with its head to the north, and one individual was found along the northern edge of the pit with its head oriented to the west.

Preservation of the human remains was generally good, especially considering the open setting. Skeletal elements closest to the surface suffered from weathering, and the remains found on the caliche layer at the bottom of the pit were in rather poor condition. However, the bulk of the remains were in good condition. The southern edge of the pit had been impacted by use of a dirt road across the site, and some crushing and fragmentation, especially of crania was noted. Considering the post-burial settling of skeletal elements and the inclusion of possible secondary burials, the potential for confusion becomes evident.

Skeletal elements were generally removed, mapped, and bagged individually, but in some instances it proved advantageous to remove some elements in bulk in an effort to preserve the integrity of the remains for laboratory analysis. Fractured crania, for example, were removed with the articulated mandibles and without cleaning the adhering matrix, and in some cases hands and feet were also removed in bulk and carefully bagged.

Analysis

This burial appears to have been a single-episode event. The boundary of the top of the burial pit was readily identified approximately 30 cm below the present ground surface, although an estimated 20-30 cm of additional overburden may have been previously lost due to operations associated with the turf farm. The vertical sides were also readily identified by sediment texture, root growth, and color differences between the pit fill and the undisturbed culturally sterile matrix. The bottom of the pit was found to lie within the top few cm of a thick caliche layer. This may have some bearing on why the pit was prehistorically excavated only to that depth, although the pit was apparently deep enough for its intended purpose at that point. There were no indications that the original burial had been disturbed at any time in the past.

This burial dates solidly to the Basketmaker II period. Samples of bone from Individual 7, an adult male, and Individual 9, a child of unknown sex (Figure 4), were submitted for carbon dating. Individual 7 returned a 2 Sigma calibrated result of BP 2150-1880 (intercept at calibrated BC 50, Beta-222449), while Individual 9 returned a 2 Sigma calibrated result of BP 2120-1900 (intercept at calibrated BC 40, Beta-222450), or approximately calibrated BC 45 for both individuals. These two individuals were selected for dating because both were well-mapped complete, primary burials, and we thought it might prove valuable to date an adult individual as well as a child. Stable isotope analysis was also performed on both individuals. The results of both the dating and isotope analysis will be discussed in further detail in following sections of this report.

Other evidence also supports the BM II date for this site. The Tommy Turf individuals lacked cranial modification (head flattening) that is common to later Anasazi populations, but showed dental attributes of full-time, maize-dependent agriculturalists (see following section). In addition, the burial pit fill was completely aceramic. Plain gray sherds common to BM III and Pueblo I occupations were found within the cultural sediments above the burial pit, but once the upper limit of the burial pit had been defined and excavation proceeded only within the pit itself, a complete lack of ceramics was noted.

Figure 5. Selected artifacts from 42Ka6032. Top: Bone whistle or flute. Bottom, left to right: Discoidal shell beads, euhedral quartz crystal, white stone pendant, and black stone pendant; the types of stone have yet to be determined.

Personal items found in this burial include two small discoidal shell beads (species unidentified), one bone whistle or flute, a small euhedral quartz crystal, and two stone pendants less than 3 cm long (Figure 5), and a kaolinite pipe bowl (Figure 6). Unfortunately, due to the settling of the remains within the burial pit, it could not be determined with any degree of accuracy with which individuals most of these personal artifacts had been associated. The whistle or flute was found adjacent to a skull and mandible at the northern edge of the pit (Figure 4), and was likely associated with that person. The human remains, bone whistle, and shell beads were the only perishable items found at this site, as the open setting did not allow for preservation of clothing, baskets, or other organic artifacts that might have originally been included. Note again the lack of ceramic vessels as grave offerings, a common practice with later Anasazi populations.

Other artifacts found within the burial pit included a sandstone mano, lithic debitage, and the distal half of a dart-sized projectile point. The biface and lithic debitage were all of locally available cherts. Seven tabular pieces of sandstone, varying between about 15 to 30 cm in length/width, were found within the pit among the human remains, but there was no apparent patterning to their placement. The mano was found in association with the flexed legs of several individuals (Figure 4).

Osteological Analysis

Osteological inventory and analysis was conducted at the Utah Division of State History Archaeology Laboratory following standard procedures. Most of the osteological material exhibited moderate to severe post-mortem damage due to post depositional conditions. The remains were highly comingled and required extensive sorting of individuals prior to skeletal analysis. Sorting and matching was based on location within the burial pit, and similarities in morphology, age, and pathology. After sorting each individual was given a randomly assigned individual number (1-10). Estimation of age and sex were accomplished following standard procedures and technique based on pelvic, craniofacial, and postcranial morphology. At least ten individuals were identified within the mass burial including six adult males, two adult females, one child, and one neonate (Table 1). Cranial modification has been documented in some Anasazi populations, but this characteristic was not observed in the Tommy Turf individuals.

Figure 6. Kaolinite pipe bowl from 42Ka6032.

All skeletal elements were examined macroscopically, and when necessary with the use of low magnification, for lesions. Identification and, if possible, diagnosis of any pathological conditions were based on several sources, including Roberts and Manchester (1995), Aufderheide and Rodriguez-Martin (1998), and Ortner (2005). Many pathological conditions affect the development and remodeling of bone. Disease (e.g., tuberculosis, syphilis), diet (e.g., malnutrition, undernutrition, intestinal parasites), aging (e.g., osteoarthitis, carcinoma), trauma (e.g., fracture), and congenital defects (e.g., clubfoot) can often be detected in the skeletal system. The skeleton responds to these factors by either producing new bone or reduction (resorption) of the existing bone. All skeletal remains were also assessed for trauma. In archaeological samples, antemortem fractures are identified as those that occurred well before death and in which healing has been initiated. Perimortem fractures are lesions that occur at or near the time of death, and no healing is evident. Postmortem fractures are those that result after the bone is no longer "green", meaning that collagen fibers have degraded. Ground pressure, insects, animals, soils, and other taphonomic disturbances may produce postmortem fracture (Galloway 1999). The pathological conditions exhibited by the skeletons in this series included osteoarthritis, antemortem fractures, enthesophytes, and evidence of a generalized infection.

Osteoarthritis

Osteoarthritis, a chronic inflammatory disease that frequently results in the destruction of weight-bearing joints, is the most common joint disease observed in archaeological specimens. The disease is associated with one or a combination of the following: aging, a genetic predisposition, obesity, activity level, and environmental factors. Osteoarthritis is characterized initially by the development of osteophytes or lipping on the margins of joints, pitting of the joint surfaces, and deformation of the joint contour. In the most severe cases, eburnation on the joint surface can also occur. Osteoarthritis can be observed on any joint surface, but it occurs most frequently on the hips and knees and in the vertebrae (Roberts and Manchester 1995:105).

Mild to moderate osteoarthitic alterations were common among the middle and older adults for most joint surfaces. Additionally, severe osteoarthritis of the lower back was exhibited by Individual 4 (Figure 7). This individual had two lower thoracic vertebrae fused together (Figure 8) as well as severe alterations to the lumbar vertebrae (Figure 7).

Antemortem Fractures

Skeletal fractures can be classified as pathological or nonpathological. Pathological fractures occur secondary to a pre-existing disease that has weakened and undermined the underlying bone structure. Non-pathological fractures are those that result from excessive mechanical stress or injury from extrinsic forces (trauma). The ante-

	Male	Female	Unkown
Neonate (3rd term to new born)		-	1
Child (1.5 - 2.5 years)			1
Young Adult (18 - 29 years)	1	1	-
Middle Adult (30 - 49 years)	2	1	
Older Adult (50+ years)	3		

Table 1. Sex and age range distributions for the Tommy Turf individuals.

Figure 7. Anterior view of Individual 4 lumbar vertebrae showing severe osteophytic lipping and near fusion of the vertebrae.

Figure 8. Anterior-lateral view of fused lower thoracic vertebrae of Individual 4.

Figure 9. Left posterior view of Individual 7 cranium showing well healed depression fracture (arrows).

mortem fractures exhibited by the Tommy Turf individuals are non-pathological, traumatic fractures. Two individuals exhibit antemortem skeletal fractures. Individual 5, an older male, had a well healed depression fracture to the left posterior aspect of the skull (Figure 9). This fracture was likely caused by blunt force trauma to the head. Individual 7, also an older male, had a well healed fracture to the left tibia. The fracture occurred just below the knee and is marked by swelling and deformation of the tibial shaft (Figure 10).

Enthyesophytes

Enthesophytes are musculo-skeletal markers of stress at tendon or ligament insertions. This type of new bone development at the site of tendon or ligament attachment to bone is usually caused by moderate to severe habitual stress and indicates specific habitual movements using specific muscles or muscle groups. Two individuals from this series exhibited this pathology, both Individual 6, a middle aged male, and Individual 8, also a middle aged male, have severe enthesophytes on the proximal right fibulae near the tibia-fibula articulation (Figure 11). The esthesophytes of both individuals are in the location of the attachement of the interosseous membrane that connects the tibia and fibula, as well as near the insertions of the soleus and tibialis posterior muscles. These muscles are key in walking, running, and standing.

Non-Specific Infection

The pathological changes to bone brought about by many different bacteria, parasites and viruses are often non-specific and complicate specific disease diagnosis. The pathological processes such as osteomyelitis, bone destruction with pus formation, bone repair, and periostitis, an inflammatory reaction that results in new bone formation, can be associated with many different disease etiologies. When seen in skeletal remains, such bone pathology is often used as an indication of a non-specific infection. One individual from this series had significant skeletal pathological alterations. Individual 6 exhibited significant thickening of the cranial vault and long bones that resulted in the bones having a “puffy” appearance. The frontal, parietals, and occipital of the cranium all exhibited thickened diploë, the inner most layer of the cranial bones (Figure 12). This type of pathological alteration is commonly seen in hemolytic anemia as a result of the expansion of marrow spaces. However, this individual did not exhibit the characteristic porotic hyperostosis on the ex-

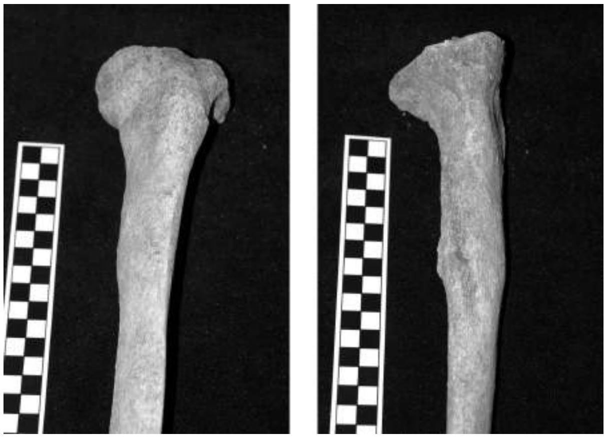

Figure 10. Anterior (left) and posterior (right) views of left tibia of Individual 7 showing deformation from healed fracture.

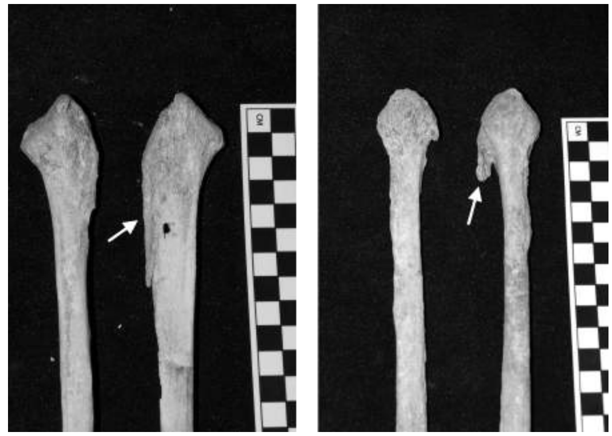

Figure 11. Anterior view of fibulae of Individual 6 (left) and Individual 8 (right) showing enthesophytes (arrows).

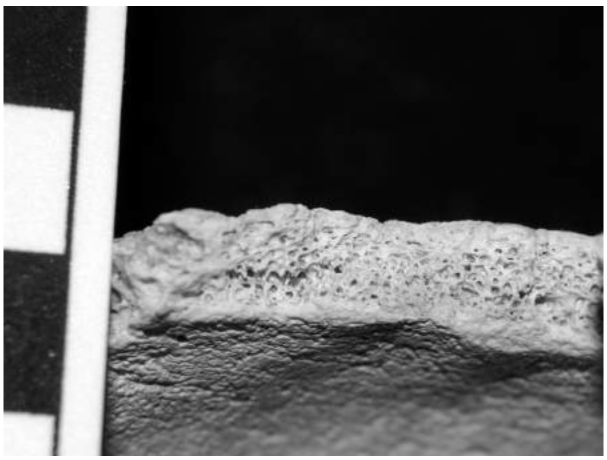

Figure 12. Close-up of postmortem cranial fracture revealing thickened diploe in the cranial vault of Individual 6.

ternal cranial bones that is a hallmark of hemolytic anemia. Additionally, the long bones of this individual were enlarged and had thickened cortices (Figure 13). Such thickening of the long bones can also be seen in hemolytic anemia. While the pathological skeletal alterations exhibited by this individual are suggestive of hemolytic anemia, a diagnosis as such is premature and further research on the subject will occur in the near future.

Dental Disease

The dentition of each individual was inventoried and examined for pathology. Macroscopic examination for pathology was conducted on all teeth in this series. All available dentition were observed under normal lighting conditions or with the help of a 10x hand lens. Dental pathologies were recorded on a standard inventory form that documents the presence or absence of a tooth as well as its condition. Each tooth and tooth socket was examined for carious lesion (cavities), for alveolar abscessing, and antemortem loss. The presence and severity of calculus (tartar) formation on each tooth was also scored. Nearly all the teeth in this series exhibited moderate to severe dental attrition or occlusal wear. This is indicative of food processing technology (grinding implements) that introduces large amounts of grit into the diet.

Caries (Cavities)

Carious lesions (cavities) are the result of decalcification of a tooth's surface by bacteria. The lytic activity of the bacteria can affect any surface of the tooth, including the crown and root. If these lesions are left untreated, the tooth is eventually destroyed. Dental caries are funnel-shaped lesions that penetrate the enamel to the dentin. The carious lesions can continue to penetrate through the dentin into the pulp cavity, allowing transmission of bacteria and the further spread of infection. The alveolar bone can be affected by the infected tooth and subsequently result in an abscess.

The frequency of caries in an individual or population is affected by several factors, including developmental defects and natural fissures in the teeth. The most important factor in the development of dental caries is diet (Ortner and Putschar 1981), especially a diet high in carbohydrates such as sugar or flour. For example, agriculturalists tend to have a higher frequency of caries than do hunter-gatherers (Table 2). This difference has been attributed to the high carbohydrate diets of agriculturalists combined with nutritional deficien-

Figure 13. Image comparing the long bones of Individual 6 (on left in each picture) with those of a non-pathological individual from Tommy Turf of similar size and age (on the right in each picture). Notice the swollen "puffy" appearance of the bones of Individual 6.

cies that can affect tooth development (Goodman et al. 1984).

Caries were exhibited by 8.5% of the teeth in this series. The majority of the caries were large, interproximal (in between the two teeth) caries (Figure 14).

Abscess

When a carious lesion penetrates the pulp chamber, the tissues inside are exposed to infection by the bacteria of the mouth (Hillson 2002). Traumatic fracture of the crown or severe attrition may also cause a similar result. Inflammation and pus production occurs and an abscess is created (Hillson 2002). As the infection worsens, the abscess increases in size and eventually the periapical alveolar bone surrounding the abscess is resorbed, creating a fistula, or opening in the bone. If left untreated, abscesses can cause destruction and antemortem loss of the tooth. Secondary infections of the sinuses and systematic infections can result from the affected tooth, leading to the diminished general health of the individual.

Abscesses were common among the Tommy Turf population, with nearly one fourth (24.6%) of all tooth sockets exhibiting either healed or active abscesses. Antemortem tooth loss due to abscess was the most common type of abscess recorded with 18% of all tooth sockets having antemortem tooth loss and resorption (Figure 15). Active abscesses were seen in 6.6% of the teeth in the series (Figure 16).

Calculus

Calculus (tartar) is a mineralized deposit that accumulates at the base of live plaque that is attached to the surface of the tooth (Hillson 2002). Calculus is present on nearly all of the permanent teeth in this series. The severity of deposits ranges from flecks to moderate/coalesced deposits (Figure 17).

Discussion

The Tommy Turf site is one of six well-documented BM II burials from the Kanab area. Edgar (1994) reported on three BM II burials found in sheltered locations a few miles east of Kanab, in which a total of thirty six individuals were involved, and a pair of earlier, single BM II burials was reported at Hog Canyon Dune (Schleisman and Nielson 1988). Other BM II burials were reported from Cave Dupont by Nusbaum (1922), and apparent BM II burials were also noted by Judd (1926) within rock shelters in canyons near Kanab.

The dating of the Tommy Turf burials to approximately BC 45 places them clearly within the Basketmaker II period, roughly at the temporal division between the White Dog Cave Phase and the subsequent Lolomai Phase (Matson 1991), or

Subsistence Pattern	No. of Groups	Mean percentage of carious teeth	Range: percentage of carious teeth
Hunting and Gathering	17	1.3	0.0-5.3
Mixed Economy	13	4.84	0.04-10.3
Agricultural	32	10.43	2.3-26.9

After Lukacs 1989

Table 2. Dental Caries in Different Subsistence Economies

Figure 14. Representative images of carious lesions.

between the Vermilion Phase and the subsequent Moapa Phase as per Talbot (1998) in his proposed phases specifically for the Virgin Basketmaker II period. This is an important juncture in the Basketmaker period, as this approximates the time at which the Basketmakers began shifting to a more settled village life. It is unclear if the Tommy Turf individuals were part of a "village," but the number of individuals, ages, and sex distributions suggest that more than one household was involved in this burial.

According to current models developed primarily in the four-corners area, Basketmakers at this period were still focused on floodwater or runoff farming, and did not begin dry farming until later (Lipe 1993, Talbot 1998). The Tommy Turf site supports this model. The site setting is a low, flat-topped ridge overlooking flat alluvial valley bottoms on three sides. Although not subject to annual, riverine-based flooding, this bottom land is subject to large amounts of runoff during the annual monsoon season. Prior to the downcutting of Kanab Creek in the late 1880s and the resulting drastic drop in the local water table, the water table was about one meter below the ground surface and produced a grassy meadow approximately 400 meters wide (Webb et al. 1991). Although the Tommy Turf site is approximately 1600 meters from Kanab Creek, the level of the water table at contact times illustrates the sub-irrigated potential for the bottom lands surrounding the site, especially in wetter years.

Figure 15. Occlusal view of a mandible showing antemortem tooth loss and bone resorption.

Osteological analysis of the remains revealed a minimum of ten individuals buried in the Tommy Turf mass grave. The remains exhibited osteoarthritis, antemortem fractures, enthesophytes, evidence of a generalized infection, and moderately poor dental health. The conditions exhibited by the Tommy Turf individuals are likely primarily related to age and habitual activities. Osteoarthritis, dental disease, trauma, and infection are the most common pathological conditions identified in skeletal remains (Roberts and Manchester 1995). The incidence of all of these pathologies increases with the age and especially osteoarthritis and trauma have been linked to habitual/occupational acitivities (Ortnerr 2005). Therefore, considering the adult age of the individuals represented it is not surprising that the skeletal remains from this series exhibit moderate levels of these pathologies. The dental disease seen in these remains is in line with the existing data on populations with a primarily maize based diet. The infection exhibited by individual 6 indicates this individual suffered chronic wide spread infection that was severe enough to effect considerable bony response. Other documented BM II remains from the Kanab area have been described as exhibiting similar age and activity related pathologies (Pecotte 1988, Edgar 1994).

Both stable carbon and stable nitrogen isotope analysis was performed on Tommy Turf

Figure 16. Lateral view of a mandible showing actaive abscesses in the canine and first premolar.

Figure 17. Lateral view of maxillary teeth with coalesced calculus.

individuals 7 and 9. The resulting 13C values of -7.3 o/oo (Individual 7) and -7.9 o/oo (Individual 9) are indicative of diets heavily dependent on maize. 15N/14N values were +8.7 (Individual 7) and +8.8 (Individual 9), again indicating an agricultural emphasis to their diets with the likely inclusion of some terrestrial herbivores as well as pinyon, acorn, and tubers (Coltrain et al. 2007, Trimble and Macko 1997). These figures match very closely with those provided by Coltrain and collegues for Basketmaker II populations in the Four Corners area (Coltrain et al. 2006, 2007), with other BM II burials in the Virgin Anasazi area (Martin 1997), and within the general BM II area as a whole (Matson and Chisolm 2007). These values indicate that by approximately BC 45 (or at least between the 2 sigma dates of BC 200 and AD 70), the Tommy Turf population was heavily dependent on maize as a primary food source.

It was initially considered possible that the potential secondary burials at the Tommy Turf site represented disarticulated individuals interred with the fully articulated individuals at the same time. Disarticulated skeletons could be the result of the bodies having lain exposed to the elements and scavenging animals prior to burial, and this has been suggested as the reason behind a partial skeleton recovered from a Pueblo I site a few miles east of Kanab (42Ka4280, see Ahlstrom 2000). There were, however, no indications of carnivore gnawing found on the Tommy Turf skeletal elements. Towards the end of this excavation, a pile of disarticulated vertebrae was found on the burial pit floor beneath three fully articulated individuals. These vertebrae would surely have been carefully placed on the burial pit floor as a handful of loose bones rather than as part of a disarticulated body. Other disarticulated elements included crania and their mandibles, and probably some long bones that could not be positively associated with articulated individuals at the time of excavation. Therefore these disarticulated individuals have been interpreted as secondary burials.

It is interesting to note that both primary and possible secondary burials are found at the Tommy Turf site, and that two of Edgar's Kanab area sites also display both primary and secondary burials; Edgar's third site contained only two secondary burials (Edgar 1994) and the two Hog Canyon burials (Schliesman and Nielson 1988) were separate and primary. Both primary and secondary burials were also reported in Cave Dupont (Nusbaum 1922). Edgar's sites 42Ka 2548 and 42Ka3576 consisted of multiple cists that were apparently used repeatedly over the course of years, and it is easy to visualize how both primary and secondary burials could be found in this situation. Because the Tommy Turf site consists of one burial event, it is a little more difficult to see how both primary and secondary burials could end up in the same pit. A possible explanation is that earlier burials were encountered during prehistoric excavations for pit houses or related features, and that these accidentally exposed individuals were re-buried along with the Tommy Turf individuals.

In a recent review of BM-II mortuary practices, Mowrer (2006) notes differences between western BM-II populations (roughly the San Juan Basin and points west, including Kanab as per Charles and Cole (2006)) and eastern BM-II populations, including dental attributes, mortuary practices, and material cultural. Important to the Tommy Turf analysis is her observation that western BM-II populations tended to place multiple individuals in one burial, as opposed to the eastern practice of single burials, and that the eastern populations tended to orient their burials to the north, while the western populations were more variable. The Tommy Turf site supports both of these observations. The Tommy Turf burials, as are most other Kanab-area BM-II burials, are multiple in nature. And, as noted earlier, there was no consistent orientation to the individuals within the Tommy Turf burial.

Detailed analysis of the dental attributes from Tommy Turf individuals has not yet been accomplished; how these attributes relate to the eastern vs. western populations will await a future paper. The few artifacts associated with the Tommy Turf burial appear to be common to both populations. Unfortunately, due to the open setting of this site, perishable artifacts such as clothing and basketry that may have contributed to the discussion on regional variation were not present.

Summary

The analysis of the human remains from the Tommy Turf site revealed that at least 10 persons had been buried in a single event. The adult individuals exhibited poor dental health. Evidence for maize-based agricultural life style is supported by stable carbon and nitrogen isotope analysis. The age range of the individuals ran between a neonate to a young child (approximately 2.5 years) to older adult (50+ years), and included at least six males and two females. No temporally diagnostic artifacts were included in this burial, but carbon dating places these burials at about BC 45, within the Basketmaker II period. Cause of death could not be determined, but disease or sickness is suspected.

The Tommy Turf site 42Ka6032 is one of four well-documented BM II multiple burials from the Grand Staircase area of the Vermilion Cliffs. This is the first BM II multiple burial in the Kanab area to be found in an open setting, although two, single-individual BM II burials in an open setting were recovered at Hog Canyon Dune, three kilometers north of Kanab. BM II sites have also been well documented in the rock shelters and overhangs near Kanab, and open setting residential BM II sites are known along the Vermilion Cliffs front. One such site is found on the opposite side of Kanab Creek from the Tommy Turf site in a very similar setting, where an apparent pit house has been carbon dated to approximately AD 74 (McFadden 2000). It is almost certain that an open BM II residential site is associated with the Tommy Turf burial as well, but the disturbed and privately owned nature of the site location, in addition to later Formative use of the same ridge, might make identification of such a site very difficult.

Basketmaker II sites have been found across the much of the Virgin Anasazi area, from the Moapa Valley in southeastern Nevada, across the corner of northwestern Arizona north of the Grand Canyon, and along the Vermilion Cliff front to Kanab. Geib and Spurr (2000), following their research on the Rainbow Plateau, noted that their study area might prove to be a valuable location for examining the BM II/BM III transition. This is indeed a very significant time period for southwestern archaeologists, as it set the stage for the following Puebloan development. Talbot (1998) notes that the Vermilion Cliff front was ideally suited for the early Basketmaker practice of floodwater or runoff farming, and the location of the Tommy Turf site above runoff-irrigated alluvial flats would certainly support this model. Recent archaeological surveys in the uplands above Kanab hint at BM II sites in dry farming settings. While the Vermilion Cliff front is already proving to be a good research area for examination of the BM II/BM III transition, it may also prove to be valuable in understanding the BM II transition from runoff farming to dry farming as well.

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Akchin on the North Kaibab

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ABSTRACT

Small catchment alluvial outwash fan deposition within poorly developed, escarpment-controlled drainage systems on portions of the north Kaibab Plateau, adjacent to Grand Staircase-Escalante National Monument, appear to have created particularly desirable upland agricultural habitat during late Pueblo II, ca. AD 1100 Virgin Branch times.

Keywords: North Kaibab Plateau, agricultural habitat, Pueblo II, Virgin Branch

Introduction

This paper is an expanded version of a brief presentation made at the 77th Pecos Conference on southwestern archaeology in Bluff, Utah in August 2004. It concerns a local distribution of small archaeological sites notable in the strong patterning of their locations within a particular physiographic setting. The setting itself is striking, along the base of a steep fault escarpment in the northern part of the Kaibab Plateau uplift. At the end of this paper I contrast this pattern very briefly with a related and contemporary prehistoric pattern of small-scale alluvial terrace farming seen regionally during a more recent survey.

The term *akchin* in my title refers to the particular locations and use of arable arroyo-mouth outwash soils, as first described in the desert southwest among the Tohono ‘O’odham of southern Arizona (Bryan 1929; but without implying specific correspondences to the lowland seasonalities of Tohono ‘O’odham agriculture). John Hack, in his classic description of Hopi agriculture, succinctly observed (1942:28) that “The akchin is a favored place for the location of a field because the runoff of the entire watershed of the arroyo, which has been concentrated in the stream channel, spreads out naturally over a relatively smooth surface without the aid of artificial spreading.”

In the long view of human adaptations, the window of possibilities facilitating agricultural success has many shapes and constraints. And as a contrast to modern methods including laser topographic control and mass consumption of petroleum products, it is a rich pleasure to come face-to-face with pre-industrial modes using only the topography itself in creating an agricultural niche. In this spirit I want to briefly describe an apparent form of very localized, small-scale floodwater outwash or *akchin*-type farming identified during archaeological survey in the North Kaibab Ranger District of the Kaibab National Forest (Keller 2004).

In late 2003 and early 2004, variously, Brian Kranzler, Ted Neff, Terry Samples, Amy Frost, Jason Shields, Ryan Bryson and I conducted survey here for the Museum of Northern Arizona’s archaeological contract program (Keller 2004; Keller, Neff, and Kranzler 2004). The area was surveyed for the National Forest for potential fire management measures which may be carried out in response to increasing fuel loads and wildfire potential. The project was conceived by Forest archaeologists Connie Reid and John Hanson.

North Kaibab Plateau

Significant environmental features of the local region are a result of uplifting and erosion controlled by the parallel and twin geologic structures of the West Kaibab Fault and East Kaibab Monocline, bounding the Kaibab Plateau northward to Buckskin Mountain. The resulting upland ridges and valleys trend strongly south to north at elevations within the project area of 7500 feet down to 7100 feet on ridge crests and down to 7000 to 6800 feet in valley bottoms. Surface bedrock consists of units of the Permian Kaibab Limestone, with associated soils having strong residual components. Concentrations of colluvial and especially alluvial soils contrast with larger areas of rocky and gravelly surfaces having little agricultural potential. Average rain and snowfall probably total

Figure 1. View eastward across North Kaibab survey area in upper pinyon-dominant zone, with long graben-controlled valley running north-south in the middle ground. Runoff down short, steep catchments originating at the foreground ridgeline deposit soil and moisture in the valley bottom. Small prehistoric agricultural sites are arrayed along the near valley side at the top of the valley-bottom soil deposition zone. There is little entrenchment or master drainage definition in the valley bottom itself.

around 15 inches of precipitation annually, based on the area's elevation and comparisons with the mid-20th century regional record. Because of the gradually rising elevation southward towards the Plateau crest near De Motte Park, there is a strong north-south gradient in levels of precipitation. Average annual precipitation at Jacob Lake, a thousand feet higher to the south, is 19 inches.

A strong ridgeline forms the prominent physiographic feature on the survey area's west side, and supports a mature transitional ponderosa pine environment at the high south end that gives way to a dense and healthy pinyon pine, cliffrose, scrub oak, and juniper woodland as one goes northward. The adjacent valley bottom, most of which lies just below 7000 feet, parallels the ridge to the east with sagebrush meadow, woodland, and oak thickets. The valley and paralleling ridge set appear to be primarily structural and faultline-controlled in form and origin, rather than erosional. More specifically, the valley areas are graben-like structures bounded by steep linear escarpments rising 200 to 250 feet above the valley floor.

The ridge escarpment has an average slope of nearly 30 percent, with a maximum 40 percent slope in some portions. Transverse drainages cutting into this escarpment are steep and short, between 500 meters and 2000 meters in length, but most being under 1000 meters. Catchment areas vary from approximately 20 hectares up to 800 hectares, with most falling towards the smaller end of this range. These small incised drainages debauch onto low gradient outwash fans lacking incised watercourses linking to the adjacent valley bottom. This outwash zone, at around 6900 feet with slopes between 10 and 20 percent, appears to mark a transition from high velocity runoff to low velocity deposition. Of soils available in the valley, the toe of the depositional area may be the most fertile and consistantly moist. This zone along the west side of the valley is also a relatively warm and well-sheltered part of the valley, and at the present time supports a tall and dense pinyon-juniper woodland. Based at least on surface appearances, the catchments and outwash zones lack any prehistoric water control features.

The valley-bottom master drainage is not well-defined nor even apparent in all locations. Northward past the valleys, the drainage course again becomes incised as it turns westward through the West Kaibab Fault zone within narrowed canyons, and then finally southward in the Kanab Creek canyon to the lower Grand Canyon.

Arrayed in linear fashion along the foot of the steep upland escarpment are eleven small structural sites, more-or-less evenly distributed over a distance of 2.5 kilometers. The small habitation or field house and storage units sit on low rises or ridges between drainage mouths, just below 7000 feet elevation, and situated within 50 to 200 meters of the apparently most desirable outwash soil areas. Within the site distribution area, the total amount of relatively desirable soil along the toe of the escarpment appears to be on the order of 50 hectares, or about four to five hectares per site. These sites represent a late Pueblo II Virgin Anasazi occupation, identified on the basis of various associations of ceramics, ground stone, arrow points and other lithic materials, and small masonry and upright slab room outlines and stone rubble.

Ceramic types, following Colton's typologies (1952, 1955, 1956) within Virgin and Shinarump Gray and White Wares and San Juan Red Ware (or Shinarump Redware), are North Creek Gray, Corrugated, and Black-on-gray; Shinarump Brown and Corrugated; Virgin Black-on-white; and Middleton Red and Black-on-red and Nankoweap Polychrome. These types, taken together, are a hallmark of late prehistoric Virgin Anasazi or An-

Figure 2. View northwestward of representative small Pueblo II habitation and storage site on west edge of graben-controlled North Kaibab valley. Our recording included careful mapping of extant limestone slab and masonry wall alignments, documentation of lithic and ceramic artifact content, and an estimation of cultural depth. The site is located within an occupation zone running along the upper west edge of the gently sloping valley bottom, where soil has been deposited at the outlet of relatively steep catchment areas.

cestral Pueblo settlement seen across the Arizona Strip from House Rock Valley to the Virgin River itself. Although no actual trade pieces or Kayenta or Tsegi Series types from east of the Colorado River were seen, dominant designs are similar in most respects to Black Mesa, Sosi, and Dogoszhi black-on-white design styles, and to Tusayan and Citadel black-on-red and polychrome styles. The consistent co-occurrence of these types and designs at project sites suggests occupation during a phase limited to the period A.D. 1050 to 1150 or less, perhaps within a 30 to 50 year period circa A.D. 1100.

Twenty structural features consist of single-room units or occasionally double or triple-room units, and comprise 25 rooms total. One to three single-room features per site is the most common arrangement. Functionally, larger single room features, with internal dimensions in the 3 meter size range and having upright slab and limited masonry remains, appear to have been habitation or field houses employing perishable superstructure construction. Smaller room sets with internal room dimensions in the 1.5 to 2 meters size range and with abundant, possibly full-height masonry appear to have been better-protected storage units. Typically, there is a single habitable room and one, two, or three storage rooms constituting a site. Among the eleven sites, there are at least seven habitation or field house rooms and 16 storage rooms. Though not all features can be clearly classified, the features and the range of cultural items used here, as well as the sites' physiographic setting, are compatible with and perhaps suggestive of year-around occupation.

What questions arise from consideration of these sites and their physiographic setting? Most importantly, can the equation being made here between site location, function, and alluvial outwash soils be strengthened by other evidence? In the absence of any observed water control features, the argument is admittedly somewhat circumstantial at this point. Then more specifically, how are individual site locations influenced by the steepness and length of adjacent catchments? There are some indications that sites tend to cluster near the mouth of longer, less steep drainages. More generally, are these sites part of a larger settlement system buffering against spatial variation and risk in rainfall and other environmental conditions? The site array discussed here is quite small in total area, and in itself would offer only a very limited range of environmental options. What might this array, considered as a commitment to a very particular habitat niche, say about variation and reliability of the circa A.D. 1100, late Pueblo II agricultural environment? On the face of it, the commitment shown by these sites suggests considerable reliability.

Are there stone terraces or other water control features possibly buried within the aggrading outwash zone that could be revealed by subsurface testing? Agricultural intensification with water control features, an expected aspect of *akchin*-type systems, was regionally present in the House Rock Valley, Saddle Mountain, Walhalla Glades, and Powell Plateau settlement areas (Altschul and Fairley 1989:135; McFadden 2004:7). Its absence here, whether because of catchment size, elevation, or other factors, merits attention. Finally, how do the effects of cold air drainage influence the length of growing season in a relatively high elevation, circa 7000 feet situation such as that obtaining in this valley? Some other alluvial outwash situations to which this may be compared are located at considerably lower elevations, for instance, Cowboy Wash below 5900 feet in southwest Colorado (Huckleberry and Billman 1998), the House Rock Valley complex (McFadden 2004) at 5500 feet, near Bluff in southeastern Utah in the Comb Ridge/Butler Wash Valley at 4600 feet (Robins and Keller 2006), and among the southern Arizona Tohono 'O'odham largely between 2000 and 4000 feet in elevation (Castetter and Bell 1942).

Kanab Plateau Uplands

The use of small-scale natural concentrations of alluvial outwash and alluvial terrace soils for agriculture during the middle and late Pueblo II Virgin Anasazi occupation of the northern Kaibab Plateau and adjacent areas of the Kanab platform appears to have been widespread. Just west of the Kaibab Plateau, at somewhat lower elevations between 6000 and 6500 feet on an upland portion of the Kanab Plateau, are extensive areas of pinyon and juniper woodland. This area is also on eroded limestones of the Kaibab Formation, and is an environment and human settlement area having similarities but also significant differences with the higher northern Kaibab Plateau. Doug McFadden, with myself, Jeremy Omvig and Brad Heap, has been conducting an inventory of sites in this isolated Kanab Plateau area east of Kanab Canyon (McFadden 2006; McFadden and Keller 2007). The project is supported by Kaibab National Forest and Arizona Game and Fish habitat improvement programs.

We are finding here a strong pattern of small sites associated with isolated upland patches of alluvial terrace soil--in contrast to outwash soils--located at the junctions of small tributary drainages near the upper end of local drainage catchment areas. These small wash bottoms are fourth and fifth rank-order tributaries with respect to the primary Kanab Canyon trunk. The small structural sites at these locations appear to be single fieldhouses, storage rooms, and perhaps single living rooms.

These very small sites were undoubtedly associated in turn with considerably larger, multi-room habitation and storage sites located on somewhat higher, ridge-like open divide areas. The divide locations also have easy access to probably larger alluvial terrace and outwash soil concentrations along third and, in some areas, second rank-order tributaries. Depositional areas suitable for *akchin*-type outwash farming, however, appear to be uncommon in comparison with the northern Kaibab Plateau area discussed above. No checkdams or other water control features have been found in the present Kanab Plateau uplands survey area, although they are reported elsewhere in the local region.

We have recorded two apparent water catchments or small reservoirs in the areas under discussion (McFadden 2006; Keller, Neff, and Kranzler 2004). These highlight the rarity of available surface water for domestic consumption in the survey areas. The distance of living sites from known water sources, for instance springs in Coconino Sandstone exposures deeper within the canyons or along the West Kaibab Fault escarpment, and in sinkhole lakes high on the Kaibab Plateau, presents a problem and points perhaps to significant differences in climatic conditions here during the eleventh and twelfth centuries from those obtaining at present.

In all, the results of this Kanab Plateau uplands study should provide a picture of a close and carefully adapted agricultural settlement pattern in what on first viewing is an unpromising and rocky landscape. Together with the contemporary prehistoric settlement of the northern Kaibab Plateau, these very local adaptations show the people of the Virgin Branch Anasazi responding creatively to changing regional environmental conditions, population pressures, the strength and apparent flexibility of their family and social networks, and no doubt other elements of their preceding, millennium-long history on the Arizona Strip.

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Architecture and Cultural Identity Along the Fremont-Anasazi Interface

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ABSTRACT

An important issue facing researchers is defining the relationship between Fremont and Anasazi groups in the northern Grand Staircase-Escalante National Monument and vicinity. Each has a unique culture history that implies contemporaneous but distinct social identities. Ceramics are traditionally the primary medium for dialogue in addressing cross-cultural contacts, but here I consider pithouse architecture as a useful and perhaps more telling alternative. Using Sackett's (1990) "isochrestic variation" approach to stylistic examination, pithouse construction style is seen as a mostly passive, deeply-rooted form of communicating social identity. Recent excavations near Escalante, Utah, have uncovered sites whose material culture is clearly Fremont, but with pithouses resembling those at Anasazi sites to the south. A regional overview of AD 800-1300 pithouses reveals some limited evidence for cross-cultural transmission of certain architectural styles at other sites besides those near Escalante. I suggest that this may be an example of an "indirect bias" (Richerson and Boyd 1992) form of trait copying by the Fremont. This implies an initial stage of acculturation at the local level but also helps to inform on the breakdown of the Late Formative Anasazi-Fremont boundary, proposed by Geib (1996). The latter is demonstrated not only by the more frequent appearance of Anasazi tradewares in the Fremont region but also by a copying of many common Southwestern architectural styles by the Fremont after AD 900.

Keywords: Fremont, Anasazi, architecture, isocrestic variation, style, culture history, acculturation

Overview

Grand Staircase-Escalante National Monument (hereafter "Monument") holds many secrets of the human past. One of the most intriguing, but by its very nature the most frustratingly difficult to unlock, deals with social identity during the period when prehistoric farmers and farming were spread across the Northern Colorado Plateau. To the south are archaeological sites identified as "Anasazi"(see Endnote 1) and to the north are archaeological sites recognized as "Fremont." These are different cultures in the traditional sense of recognizably distinct material remains defined by archaeologists and interpreted to signify distinct societies. The interface zone where contact was most likely to occur between those societies is also the most likely to provide the clues about the influences and social identities evident in that zone.

In his reporting of work in Glen Canyon, Phil Geib addressed the issue of social identity, and why it was important for archaeologists to study. Geib (1996:102) states that:

> "Admitting the possible existence of prehistoric ethnic groups does not mean that such groups necessarily existed in a given study area or that they can be recognized archaeologically. Any claim for ethnic groups must be based on detailed analysis of physical remains taking into account the various factors that could

have produced material culture patterning. Nevertheless, after subjecting archaeological data to various forms of dissection and analysis it is evident that social identity and cultural tradition cannot be ignored if we are ever to achieve a fuller understanding of prehistory."

Historically ceramics have garnered the bulk of attention in material culture patterning studies and subsequent interpretations of cultural identity. Here, however, I will look at architecture, and specifically at Late Formative period pithouse styles found within the northern Monument and in nearby areas–areas where there was potential for significant interaction between the Fremont and the Anasazi–and suggest how pithouse style can be relevant to the study of cultural identity within the interface.

As a point of departure and as a general temporal framework, I take Geib's recognition of a cultural boundary of sorts that existed between Fremont and Anasazi groups from about AD 500-1000, but that probably was established earlier as regionalization occurred among early farmers. Geib defines this boundary as a buffer zone about 30-60 km wide between early Formative residential sites of the Escalante River Basin and the Kaiparowits Plateau, and those to the south and east in the areas around the Rainbow Plateau, Cedar Mesa, and vicinity (Geib 1996:112-113). He indicates that around AD 1000 that boundary seems to have dissolved; indeed, in the two or three centuries thereafter Anasazi tradewares are commonly found, though not in great abundance, at many Fremont sites throughout Utah. Geib (1996:112) suggests that "*There apparently was a change in cultural boundedness, such that the late Formative archaeological record appears gradational*." Past work in the northern Monument has been too sporadic to reveal whether or not this change in cultural boundedness included a spatial overlap of Fremont and Anasazi settlement (see McFadden 1997; Geib 1996; Geib et al. 1999). More recent studies, however, suggest that the two groups may have lived in very close proximity at times during the post-AD 1000 period (Talbot et al. 2000; 2005).

A change in cultural boundedness raises a whole host of questions about who these people were, and how they interacted. Most are beyond the scope of the current database. Here I simply ask: What inroads, if any, can pithouse architecture provide toward answering these questions?

Architectural Style and Ethnicity

A useful organizing approach in seeking the broader patterns of behavior relative to cultural identity is that of Isochrestism (see Endnote 2). Isochrestism (see Sackett 1990) begins with the tenet that there is a spectrum of alternatives in making or using items. Ethnographers and archaeologists often refer to these alternatives as different 'styles' of material culture, and use style to inform on regionally variable patterns–patterns that might denote cultural order and identity, including ethnicity. The approach infers that choices of style are dictated by group traditions, or a structured vernacular substratum that underlies group identity. Both an active style such as might be represented by decoration applied to a ceramic vessel, and a passive style such as the traditional form and methodologies applied in the construction of that same vessel, might inform on social identity. When patterns are found, the interpretation can then be strengthened by looking at a more complete archaeological assemblage, including the range of material culture, settlement and subsistence strategies, iconography, etc., to find additional patterns that might be ethnic identifiers.

> "Given the level of resolution at which prehistorians work, vernacular style may be responsible for a significant portion of the ethnically significant variation they are capable of perceiving. And the notion may be equally useful to the ethno-archaeologist precisely because it takes us, so to speak, both behind and beyond the merely fashionable" (Sackett 1990:40).

Architecture, for the most part, is a passive form of cultural communication. It is typically not meant to draw attention to a groups' cohesiveness or uniqueness. Rather it is functional in the sense that the construction methods and forms are passed down to successive generations as the best or proper way to do things. Some architecture, however, actively seeks to promote group solidarity and identity (e.g., a kiva for Anasazi groups, and a Central Structure for Fremont groups [Talbot

2000]). In either case we must use caution; we are well aware that sherds or other material remains do not equal people (Madsen 1982; Geib 1996). Architecture may not equal people, but neither does it move around very much and confuse us as to where it came from. Architectural styles, however, do migrate across time and space (through a variety of potential mechanisms), and these are best seen as a movement of concept and heritage, of training and experience. And while these are primarily passive styles that likely were not intended to convey an overt message of social identity, they do so nonetheless through the medium of traditional form.

It might be tempting to view architectural stylistic variability (or any other kind of stylistic variability for that matter) as gradational to the point that patterning becomes meaningless in the cultural sense generally, or in the ethnic sense specifically. At the behavioral extremes, where architecture is described and compared either in the most generic terms or in the most minute detail, this might be true, but it is a rather parochial view from an Isochrestic standpoint (see Endnote 3). Most archaeologists recognize levels of patterning – to which we often give names – such as different architectural styles unique at the regional level (e.g., Hohokam, Mogollon, Anasazi, and Fremont of the American Southwest), and the subregional level (traditionally a named variant or branch, e.g., Virgin, Kayenta, or Mesa Verde Anasazi, etc.) or San Rafael or Uinta Fremont, etc., but more commonly now a physiographic area (such as the Escalante River Drainage, the Kaiparowits Plateau, etc.). It is these patterns of largely passive variability that are most likely to represent the vernacular architecture of a "people" in the social and possibly ethnic sense.

Pithouses are one particular functional class of architecture that for archaeologists may be especially informative as to both cultural and ethnic identity, much like ethnographer's interests in learning about people would take them into people's homes where the very foundations of ethnicity lie. Style is usually built into a pithouse (rather than being added on, and hence is functional by its very nature) and so informs about traditions and preferences in construction materials and techniques for the people who lived in that particular house. Some choices of style may be very specific to individuals, but when certain styles are found in many pithouses across a specific region at a particular time, then the style denotes a level of cultural order. It implies that these people were part of a larger social group that shared and perpetuated these and other technological traditions. That interpretation can then be strengthened by looking at a more complete archaeological assemblage, including the range of material culture, settlement and subsistence strategies, iconography, etc., to find additional patterns that might be ethnic identifiers.

Post AD 700 Pithouse Architecture in the Fremont-Anasazi Interface

Pithouses across the Southwest are a primary form of residential unit, yet with regional stylistic variability. The Fremont pithouse vernacular (see Talbot 2000) is rooted in a tradition of very generic appearing round, shallow houses until about AD 900. Between AD 900-1050 pithouse style in the more populous core area along the Basin-Plateau transition zone changes quite radically to a deep quadrilateral form, with complexities of construction including well planned ventilation systems, benches, and various floor features unique to the Fremont region. On the Colorado Plateau, however, this stylistic shift does not occur. Pithouses, for the most part, remain circular and still relatively shallow throughout the Formative period. Boulder-ringing is common but not dominant. Vent/entry tunnels are present (probably after AD 900) though not very formalized. Throughout the Fremont region, deflectors for vent tunnels are typically attached to the wall rather than free-standing. Wing-walls and antechambers are not present. Hearths are typically unlined or clay-rimmed, and slab-lining is rare.

The Anasazi pithouse vernacular of the Monument (see McFadden 2000 for a general overview) and vicinity also begins with round, shallow houses, though with immediate complexity not seen in the Fremont area. As early as Late Basketmaker II and through Basketmaker III times these houses are slab-lined, with some structures having antechambers or long tunnel vent/entryways, free-standing deflectors, and even conventional benches. Wingwalls, unique sand filled pits commonly found between the hearth and the back wall (and which are often sealed over with clay), and even some floor vaults appear early on and become more formalized in Pueblo times (see Talbot 1990). Masonry is commonly incorporated into pithouse construction, either alone or in tandem with the slab-lined walls.

Anasazi and Fremont pithouse styles, then, are recognizably distinct from each other, containing some features and construction methods that are standard for pithouses throughout the Southwest, but also demonstrating their own peculiarities and spatiotemporal separateness from other Southwestern pithouse forms. Of course, besides the architectural style, material culture including ceramics, certain point types, basketry, and even some rock art are recognized by most archaeologists as cultural markers separating the Fremont from the Anasazi (see Talbot et al. 2005). So it was until recently, when Brigham Young University (BYU) archaeologists and students, with the assistance and guidance of Monument staff, excavated at various pithouse sites in the northern part of the Monument, around the town of Escalante, and came face-to-face with a significant contradiction to this view.

Formative Period Sites

In the summers of 1999-2004 the BYU Field School of Archaeology and the Office of Public Archaeology at BYU surveyed over 15,000 acres of BLM/Monument land in the region around the town of Escalante, Utah, recorded nearly 600 sites, many of them multicomponent, and tested or excavated at 13 sites located on either Monument or private land (Figure 1). The surveys documented a strong Fremont presence in the general project area with at least 179 total components. The Anasazi presence is less than half that number, with at least 69 total components. Many of the Fremont and a few of the Anasazi components are or may be residential in function. But it is the tested or partially excavated sites that best inform on the architectural styles of Formative period populations.

2001 - Big Flat

In 2001 we tested or excavated at three sites on Big Flat, a very long, south-trending tableland feature just east of Escalante. The smallest site was called Roadcut (42GA4095). Here we found a basined circular structure that dated to sometime between AD 700-900. It measured ca. 4 m diameter and was only about 15 cm deep, with the downhill southern side eroded away. It had a slab-lined hearth and four small jug-shaped pits in the floor. Though there were a couple of rock slabs lying against the northwest wall, these do not appear to be true slab-lining and they may have fallen in from outside of the structure. Most of the few ceramics present on site are what Geib et al. (1999:5-72) have described as "Untyped Utility" sherds. We interpret the site to have been a short-term residence associated with seasonal (perhaps late fall) uplands wild resource procurement. The architecture is somewhat generic, though the floor-level (e.g., without an interior basin) slab-lined hearth is atypical for Fremont pithouses.

The other excavated site and the tested site, both of which were badly looted, date to about AD 1000. At the Dos Casas site (42GA4086) we excavated within two obvious depressions, one of which we could see from the surface had considerable slab-lining around the edges. The smaller depression turned out to be a circular pithouse ca. 3.5 meters diameter and 40 cm deep. It appeared to have suffered considerably from the vandalism. Several vertical slabs still lined the walls, but it was obvious that many had been ripped out. Though many subfloor pits were located, only a surface burn was located in the floor center where a hearth should have been, and we believe that the looters ripped out the slabs of a floor level slab-lined hearth. On the southeast side was a shallow vent tunnel 1.3 meters long and about 50 cm wide, which was probably slab-lined, but most of those slabs were also removed.

To the southeast was a larger structure that was less disturbed. This structure measured ca. 6 meters diameter and up to 90 cm deep. Excavation revealed well placed slab-lining that on the east side was apparently topped by coursed masonry (which collapsed into the fill and served as a deterrent to the looters). A slab-lined entry/vent tunnel entered from the southeast with a drop down onto a platform area that apparently was originally partitioned off by slab wing-walls. Part of the wing-wall served as a deflector for a large D-shaped, floor level, slab-lined hearth that was well over a meter diameter. There were many small subfloor

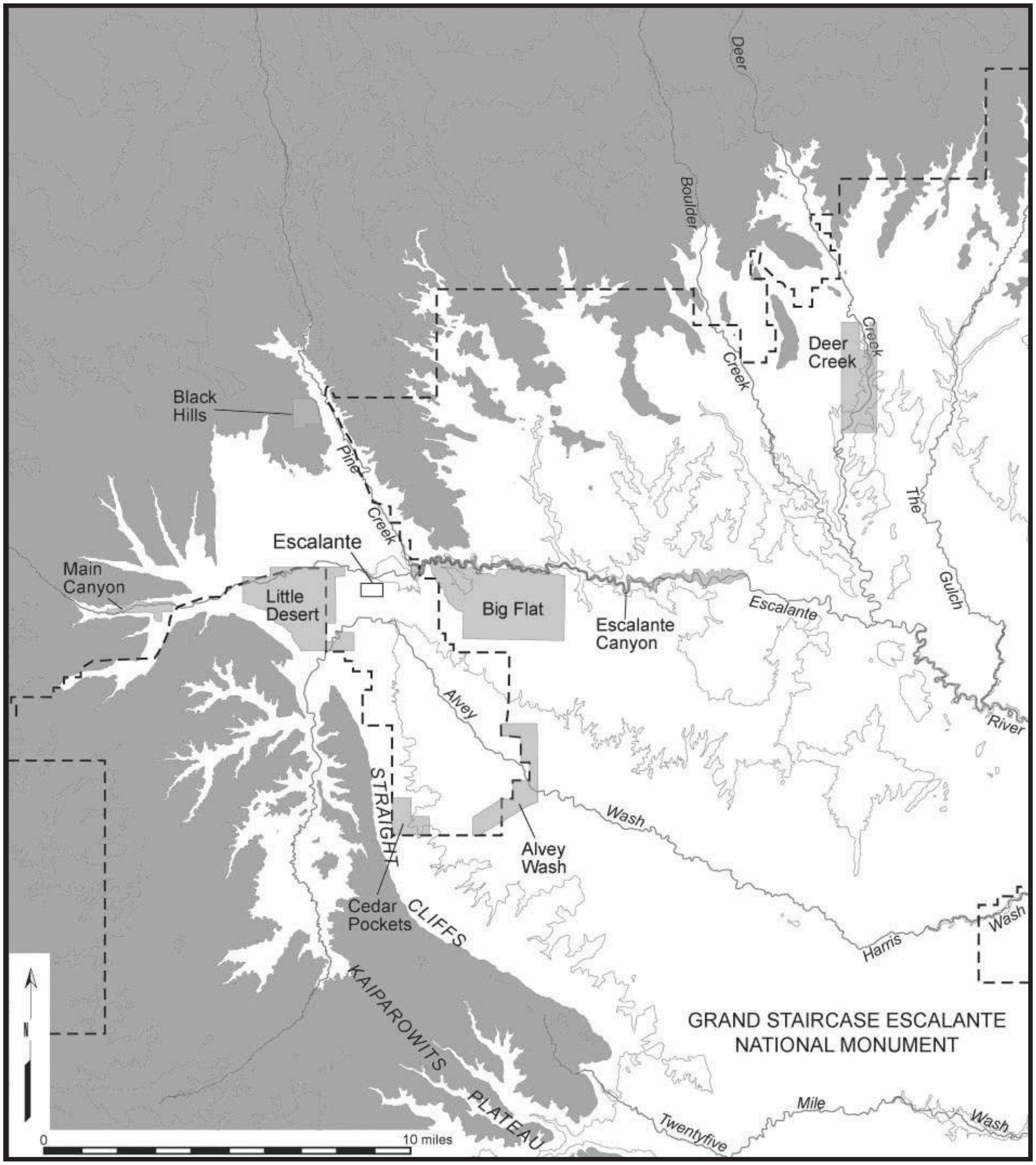

Figure 1. Locations of Significant Survey by Brigham Young University in the Monument, 1999-2004

pits but none of significant size. There was also a niche set into the west wall.

The Outpost site (42GA3891), which we only tested, also contained a slab-lined pithouse very similar in construction to the large structure at Dos Casas. However, the slab-lined walls were not only topped with the masonry, but in places the masonry backed the slab-lining all the way to the ground, suggesting some remodeling had occurred, and/or that those particular areas needed significant shoring up against the sandy soils.

These types of large slab-lined pithouse sites are scattered abundantly across Big Flat, and we believe they represent seasonal residences of farmers living more permanently to the west, in the lowlands along the Escalante River. The material culture is distinctly Fremont, with Emery Gray ceramics and only a few possible quartz tempered sherds present. A small clay figurine was also found at Dos Casas.

On Big Flat, then, we have material remains that are unequivocally Fremont, yet the architecture appears similar in many respects to the Anasazi vernacular. Having previously dug elsewhere in this region, and being generally familiar with the literature, we recognized that this might not be a localized phenomenon—that similar contradictions in the architectural and artifactual record were found elsewhere as well.

2002 - Main Canyon

The Hummingbird Hill site (42Ga4167) lies on the north side of Main Canyon, west of Escalante, and is dated to ca. AD 1000-1200. We located and excavated three pithouses. All were badly eroded but generally circular in shape and shallow. Structure 1 was the best preserved, slab-lined and ca. 4 m diameter. The others were likely about the same size, two had slab-lined vent tunnels on the east side of the structures, and the structure hearths included evidence in some cases of possible adobe rims or slab-lining. A trace of possible wingwall was found in one structure. At least one of the structures appears to post-date the others.

Although artifacts were generally sparse at the site, they included the broader complement of materials typically found in residential structures, including faunal bone, ceramics, lithics, ground stone, and lithic tools. A partially restorable Emery Gray ceramic jar was found on the Structure 3 floor, and a figurine fragment was found in the Structure 3 vent tunnel.

2002-2004 - Escalante Valley

The Rattlesnake Point (42Ga43) site is located approximately one mile southwest of Escalante, on the lower slope of a rocky knoll with the same name, and overlooking Alvey Wash. It consists of at least five structures, including two pithouses that were completely excavated, along with a possible sheltered work area, a possible surface adobe structure, and another unknown structure noted in testing. The site hints at an initial occupation in the AD 1000-1100s, but also a later occupation in the AD 1200s and possibly into the AD 1300s. The largest structure was partially excavated in 1959 by James Gunnerson (1959) during the Glen Canyon research project (Jennings 1966). A local informant also told us that local history teacher and amateur archaeologist Edson Alvey and others excavated the site in the 1950s as part of a science class experience (Carlyle Shurtz, personal communication 2002).

Structure 1, the large circular, slab-lined pithouse previously excavated by Gunnerson and Alvey measured almost 6 m diameter and close to 1 m deep. It had a long, wide, partially slab-lined vent tunnel/entryway extending to the southeast, with a circular, 2.5 m diameter, 25 cm deep antechamber at its terminus. Two non-contemporaneous hearths were present, one adobe rimmed. A raised platform and wattle and daub wingwall were present. Among numerous subfloor pits was one that was 75 cm diameter and 1.18 m deep, with a bell-shape and bi-lobed base. The second pithouse, Structure 3, was smaller than the other, somewhat D-shaped, and shallow. The walls were probably slab-lined originally but the structure had been heavily vandalized. It had an adobe-rimmed hearth, slab wingwalls, and a long vent tunnel cut into bedrock.

Artifacts found at the site included all the typical assemblages found at residential sites, including abundant ceramics, lithics, ground stone and other tools, faunal bone, corn, a figurine, beads, and even a spindle whorl. The ceramic assemblage is clearly dominated by Fremont grayware; also a real diversity of Anasazi wares were scattered throughout the entire collection.

The Barnson site (42GA5168), is located on private property immediately north of the Monument. The land is on a high ridge top overlooking Wide Hollow Reservoir. Three structures were excavated and it is likely that many more are present. The site dates to the AD 700-900 period. One very large structure ca. 7 m diameter was noted on the highest point of the site. It contained a large adobe rimmed hearth, an usual clay platform on part of the floor, and an even more unusual attached room on the west side. Unfortunately the south half of the structure was completely eroded away. A second much smaller circular pithouse intruded in the eastern side of the structure, and a third pithouse was located farther down the ridge. The latter had two non-contemporaneous hearths and very prominent adobe wingwalls. A hint of a vent tunnel was noted on the downhill eastern side of the structure. All artifacts from the site are consistent with this early period Fremont occupation, as described previously.

The Arrowhead Hill site (42GA5169) is also located on private property, just east of Barnson, and on a knoll above Wide Hollow Reservoir. Three pithouses were excavated and more are likely present. The site dates to the AD 900-1100 period. Structures 1 and 2 are large (4.5 to 6 m diameter) circular pithouses with artifacts generally consistent with a Fremont occupation. Structure 1 had clear wingwalls, deflectors and an eroded vent tunnel and hints of a possible antechamber. Structure 2 exhibited multiple occupation surfaces, including several hearths, one being a prominent slab-lined heart and another an adobe-rimmed hearth. No wingwalls were noted but because of the structure reuse there was considerable disturbance. A long vent tunnel going south connected to a shallow and mostly eroded antechamber.

Structure 3 at Arrowhead Hill was distinct from others in the Escalante Valley. It was circular, 3.5 m diameter, and over 2 m deep. Roof support posts were inset into the walls. A vent shaft was found on the east side, with a large deep hole between that and the central hearth. Instead of the typical Fremont artifact assemblage, Anasazi sherds were predominant. The architectural style is very similar to the Anasazi pithouses found at the Coombs site in nearby Boulder, Utah. The site dating suggests this structure dates closer to the AD 1100 period, whereas Structures 1 and 2 were probably occupied a century or more earlier.

Colorado Plateau Architectural Form Comparisons

To examine regional trends in architecture I looked at excavated pithouses across a portion of the northern Colorado Plateau, using the very general boundaries of the Book Cliffs on the north, the Green and Colorado Rivers on the east and southeast, and the Wasatch Plateau and general Monument boundaries on the west and southwest. The earliest dated Big Flat site (the Roadcut site) is from around AD 700-800, and so I have only looked at sites that might post-date that time. This entire region is peripheral to larger population centers for both the Fremont and Anasazi, so none of the sites are very big. Previous excavation efforts include the Glen Canyon excavations of the 1950s and 1960s, as well as smaller scale work. The better published data, and whatever gray literature was available, I used for this study.

In this comparison (see Tables 1 and 2) I looked for only the most obvious features that are known to characterize either Fremont or Anasazi pithouses. These included structure shape, manner of wall construction, ventilation facility type, and floor feature details such as hearth construction and the presence or absence of wingwalls, freestanding deflectors, a bench, a raised platform area other than the bench, and of unusual pit features. The latter category actually refers more specifically to some larger basins commonly found in Virgin Anasazi pithouses, usually located between the hearth and the wall opposite the ventilator/antechamber, and often filled with clean sand and capped over with clay.

Figures 2-6 graph the results of this comparison. There is not a lot of difference in overall pithouse shape, though the Anasazi sites tend slightly more toward D-shaped or other unusual shapes. However, Anasazi use of slabs and/or masonry for wall construction is significant, at 71 percent, while only 31 percent of Fremont pithouses use slab and/or masonry construction. A significant portion of these are from the upper Escalante Valley. Most of those outside of the Escalante Valley area are poor imitations of slab or masonry construction, with some almost resembling boulder-lined walls (e.g., Huntington area sites) and others just partially lining one section of a wall (e.g., sites at Bull Creek).

As for floor features, Fremont pithouses tend to have clay-rimmed hearths, in slightly greater percentages than Anasazi structures. A little more than one-quarter of the Fremont pithouses have unprepared hearths, while almost one-quarter of all Anasazi pithouses have slab-lined hearths. Though not consistently present, Anasazi floors tend to have low to moderate numbers of floor features, with the floor basins most common. With the exception of the Escalante area pithouses, all of these prominent floor features are virtually absent from the Fremont area.

Surprisingly, ventilators (see Endnote 4) are absent in a majority of pithouses, but then site reports are often not as informative in that regard as I had hoped. About one-third of Fremont pithouses had ventilator tunnels, but in the study area for the most part these are relatively simple, even

Table 1. Colorado Plateau Fremont archaeological sites with excavated pithouses or possible pithouses dating between ca AD 700-1300. Study area boundaries are as follows: West - Wasatch Plateau, Cockscomb; South and East - Colorado River; North - Book Cliffs. Some alcove structures that have features similar to pithouses have been included, although they may lack significant depth. Cultural affiliation is based primarily on ceramics.

	Features																				
	Walls					Floor Features								Shape			Other Features (Some structures have multiple features so columns/rows may not add up to # of structures in areas; also % doesn't add to 100 %)				
						Hearth					Vent										
Sites (Fremont)	slab-lined	Slab/masonry	masonry	boulder	other/unk	slab-lined	clay rimmed	unprepared	other/unk	not present	vent tunnel	vent shaft	vent not present	round/oval	quadrilateral	irregular/unk	wingwall	free standing deflector	floor basins	bench	platform
Huntington Area	3		1		2		5	1					6	4	2						
Ferron Area			1		3			1			1		3	3	1						
Emery Area					1		1			3			1	1							
Ivie Creek Area			5	2	10		13	2			5		12	12	4	1					
Hogan Pass Area				10	10		5	11	1	1	4		16	18		2					
Bull Creek Area		2			6	1	4	3		4	4		4	8							
Notom Area				1	1			1	1		1		1	2							
Boulder Area				1				1					1		1						
Upper Escalante Area	7	2	1		5	3	9	1	1	1	8		7	14		1	8	4			2
Harris Wash Area	1						1				1			1				1			
Total Str. (n=75)	11	4	8	14	38	4	38	21	3	9	24	0	51	63	8	4	8	5	0	1	2
Percentage	15%	5%	11%	18%	51%	5%	51%	28%	4%	12%	32%	0%	68%	84%	11%	5%	11%	7%	0%	1%	3%

Fremont:

Huntington Area - Huntington Canyon, Crescent Ridge, Windy Ridge, Power Pole Knoll
Ferron Area - Innocents Ridge, 42Em3, 42Em6
Emery Area - 42Em47
Ivie Creek Area - Snake Rock, Old Woman, Fallen Woman, Ivie Ridge
Hogan Pass Area - Round Spring Sites
Bull Creek Area - Gnat Haven, Ninas Hill, North Point, Playa, Alice Hunt, Charles B Hunt, Basket Hut
Notom Area - Durfey Site
Boulder Area - Apryll's Bench
Upper Esclante Area - Dos Casas, Outpost, Roadcut, Rattlesnake Point, Overlook, Hummingbird Hill, Barnson, Arrowhead Hill
Harris Wash Area - Circle Terrace

Table 2. Colorado Plateau Anasazi archaeological sites with excavated pithouses or possible pithouses dating between ca AD 700-1300. Study area boundaries are as follows: West - Wasatch Plateau, Cockscomb; South and East - Colorado River; North - Book Cliffs. Some alcove structures that have features similar to pithouses have been included, although they may llack significant depth. Cultural affiliation is based primarily on ceramics.

	Features																					
	Walls					Floor Features								Shape			Other Features (Some structures have multiple features so columns/rows may not add up to # of structures in areas; also % doesn't add to 100 %)				
						Hearth					Vent										
Sites (Anasazi)	slab-lined	Slab/masonry	masonry	boulder	other/unk	slab-lined	clay rimmed	unprepared	other/unk	not present	vent tunnel	vent shaft	vent not present	round/oval	quadrilateral	irregular/unk	wingwall	free standing deflector	floor basins	bench	platform
Boulder Area			3		8	4	2	4		1		7	4	4	6	1	1	1	2		
Upper Escalante Area					1		1					1		1				1			
Lower Escalante Area		1				1						1		1							
Fifty Mile Area	2		1			1	1		1		2		1	2		1		3			
Colorado River Area		4	2			1	3	2				2	4			6		1			
Cottonwood Canyon Area	1				2		1			1	1		2	2		1				2	
Kitchen Corral Area	3				1		2		1	2	1		3	1	1	2	1		22	1	1
Johnson Canyon Area	10	1	1			3	7			2	2		10	12			3	1	8	3	
Kanab Area	1						1						1	1					1	1	1
Total Str. (n=42)	17	6	7	0	12	10	18	6	2	6	6	11	25	24	7	11	5	7	13	7	2
Percentage	40%	14%	17%	0%	29%	24%	43%	14%	5%	14%	14%	26%	60%	57%	17%	26%	12%	17%	31%	17%	5%

Anasazi:

Boulder `Area - Coombs Village Mafeetahot
Lower Esclante Area - Davis Kiva
Fifty Mile Area - Golden Stairs, Mudhole Pueblo
Colorado River Area - Hermitage, Talus Ruin, Lizard Alcove
Cottonwood Cyn Area - CC Cliff Dwelling, Gnatmare Site
Kitchen Corral Area - Park Wash, 42Ka2594
Johnson Canyon Area - Bonanza Dune, Dead Raven
Kanab Area - Kanab Site

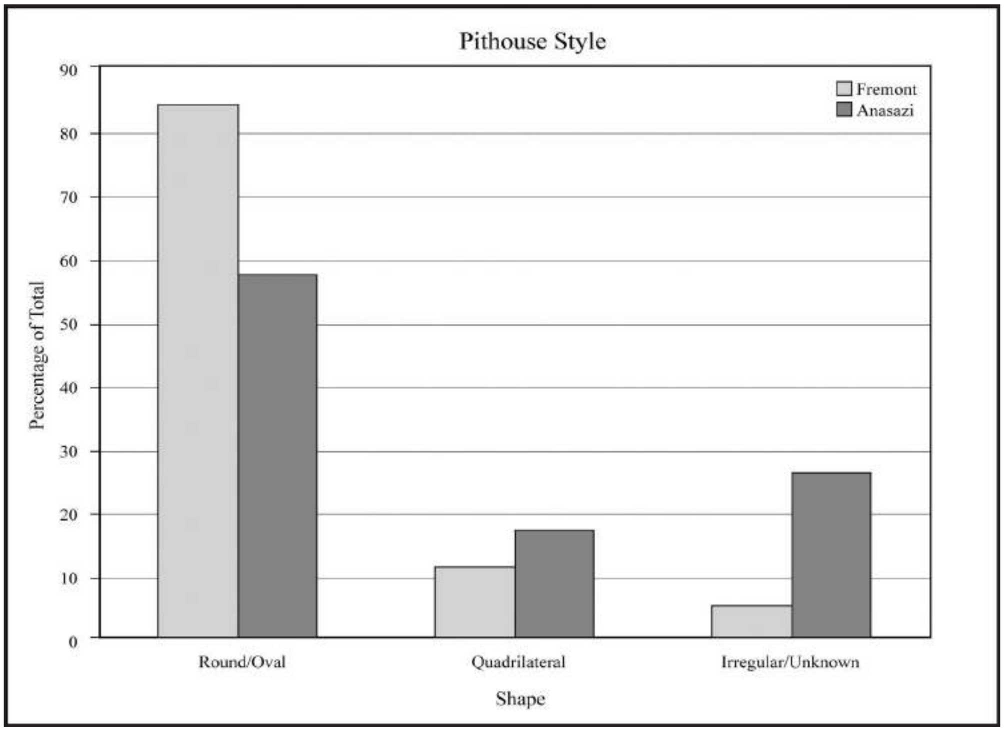

Figure 2. Pithouse shape in the study area.

at times irregularly built. Forty percent of Anasazi pithouses had vents, which for the most part were formalized and well-built. Although not separated out here, slab-lined vent tunnels are present only from the Escalante area southward. Almost two-thirds of the Anasazi vent facilities were shafts. No Fremont pithouses had vent shafts.

Overall, these graphs simply help to quantify to a limited degree what most who have dug in both Fremont and Anasazi pithouses already knew–that there are real differences in the pithouse architecture between these two groups. However, if we look specifically at the Escalante area Fremont pithouses, we see that they mimic the Anasazi pithouses in wall construction, hearth and some other floor feature styles.

One additional architectural feature that I want to mention is that of the antechamber. It is not included in the analysis because until the Escalante Project, no Fremont pithouses were known to have utilized antechambers, though antechambers are common in Basketmaker III Anasazi pithouses. One very distinct antechamber was found at the biggest pithouse at the Rattlesnake Point site near Escalante, however. Probable antechambers have since been noted at the big pithouses at the Dos Casas site and at the Arrowhead Hill site. These are difficult to recognize in part because, first, they are very shallow and are often eroded away and, second, looters commonly attack both ends of vent tunnels in search of the pithouse, and in the process the antechamber area is commonly destroyed.

What Does It Mean?

Here, then, is a dilemma–a conundrum in which ceramics and other material evidence are interpreted to be "Fremont" while the architecture carries many traits consistent with an "Anasazi" style. The patterning is most evident in the northern Monument and vicinity between at least AD 800-900 to 1150-1300. Is this an example of a "Freazi/Anamont" (Madsen 1982, 1989) blending of traits demonstrating the fallacy of culture-historical labels and of macroregional paradigms that perceive broader patterns of cultural cohesiveness? What behaviors are being manifest here that might inform on social identity?

We can begin with the recognition that while they may have had the same genetic roots (Carlyle et al. 2000; O'Rourke et al. 2000), behavioral patterns manifest in the archaeological record indicate that by the AD 800s and 900s, Fremont and Anasazi culture histories were quite distinct, as was their cultural 'clothing' (an argument repeated time and again beginning with Rudy [1953],

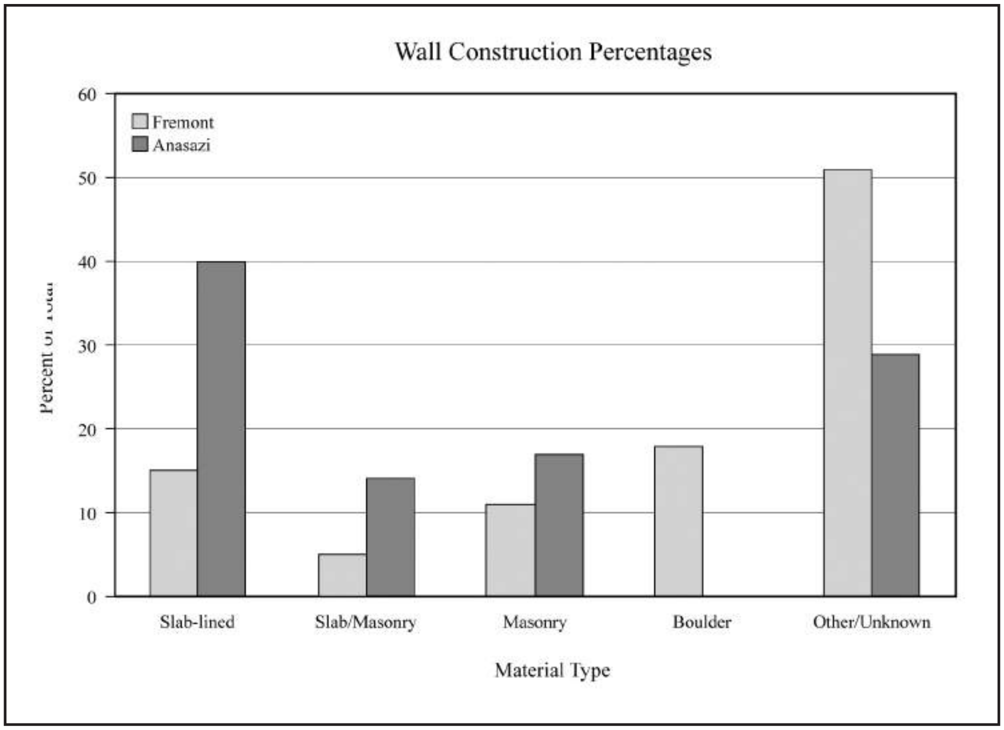

Figure 3. Wall construction techniques in the study area

Wormington [1955], and Jennings [1956]). These were two culturally distinct, possibly ethnically distinct, farming groups. Further, for several hundred years there does not appear to have been *significant* (i.e., archaeologically prominent) interaction, though there unquestionably was interaction taking place (see McDonald 1994); neither does there appear to have been an overlapping of territory such that, in any one time or place, one group was the majority and the other a minority in a complex interface setting. However, beginning in the AD 800s at Roadcut, we begin to see some hints of possible trait sharing - with an otherwise generic, seasonal Fremont pithouse that contains Anasazi traits–a slab-lined hearth and possibly with some jug-shaped interior pits–very tentative evidence indeed, and clearly a time period in need of more careful research. But by AD 1000 at the other Escalante area sites (and at the time when Geib (1996) also noted the boundary dissolution between the Fremont and Anasazi) the conundrum summarized above is more obvious.

It is difficult to tease out any sort of blending of adaptive strategies (e.g., Geib et al. 1999; McFadden 1997, 2000) at this time, and its relevance to the issue of social identity may be unquantifiable in any case, because both Fremont and Anasazi farmed the lowlands, and logistically foraged the uplands. If an individual from one group joined the other, they may have had to change the level of intensity or certain methods in which they were trained in either farming or foraging, but the change was probably not radical and they still knew how to do both.

It is hard to argue with the ceramics and other non-architectural evidence in the Escalante region which demonstrates a firm commitment to both the passive and active styles and forms found throughout the Fremont region (see Endnote 5), but I believe the Escalante Fremont devotion to an Anasazi architectural style is not completely sincere. At the Escalante area sites the slab-lined and occasional masonry-backed walls, the slab-lined hearths, the wing-walls, deflectors, vent tunnels, and the use of antechambers are all similar to though not exact copies of Anasazi forms to the south and southwest (vent shafts appear to be a later introduction, in the AD 1100s). However, there are no benches or pits reminiscent of the clay-capped floor basins at the various Escalante Fremont sites, like those often found in many Virgin Anasazi pithouses (nor, for that matter, of larger floor vaults, loom holes, or other significant floor features sometimes found in Anasazi pithouses, but not examined during this study). With greater distance from the Escalante drainage, these

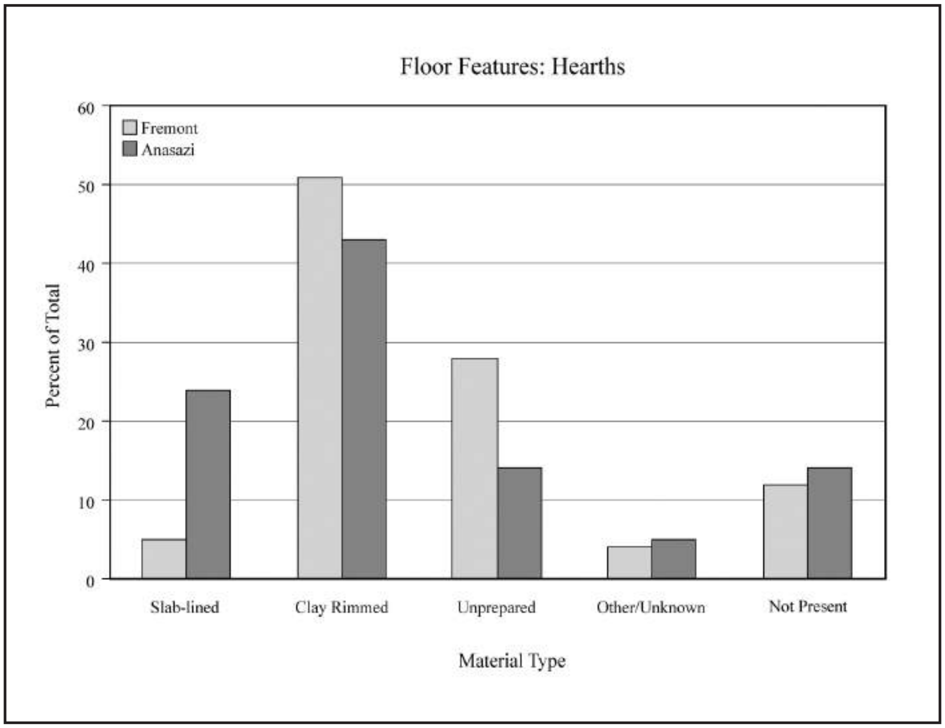

Figure 4. Hearth construction techniques in the study area

traits dissipate; hence, the use of only sporadic slab and masonry pithouse walls at Bull Creek, or crude "slab" walls at some Huntington area sites.

Richerson and Boyd (1992) identified two modes of cultural transmission that might inform on the reasons behind this expansion of certain Anasazi architectural traits. One mode is *guided variation*, which involves social learning and information transmission from generation to generation, with allowance for individual innovation and change, through experimentation, to fit ones own particular needs. The other mode is *biased transmission*, which involves imitation or copying of behavioral traits, either by rational choice because it is the social norm, or because one believes that the particular behavior will achieve some otherwise desired result. Many of the Fremont Escalante region traits, and by extension those elsewhere on the northern Colorado Plateau, are unlikely to be the product of local innovation, but rather of an imitation of particular architectural traits used by the neighboring Anasazi. The cultural transmission, then, is selective or biased, with the basic Fremont social substratum as seen in most passive and active material culture styles remaining the same. Certainly the architectural traits being copied are very functional, and seeing how slab-lined and masonry walls effectively hold back soft sands, or how a properly constructed ventilation tunnel and deflector system improved the airflow and decreased the smoke in a pithouse, would be good motivation to adopt those attributes.

Accepting that architecture is a passive style or form of communication, for the Escalante Drainage Fremont to have altered their own intrinsic pithouse vernacular style by copying some aspects of Anasazi pithouse architecture may be a symptom not only of the general boundary dissolution that occurred, but more specifically a behavior informing on a process of possible acculturation occurring in the Fremont-Anasazi interface at this critical time. If so, given what we know it is reasonable to suggest that the acculturation process was only in the initial stages and that the Escalante Drainage Fremont, and to a lesser degree Fremont living elsewhere along the broad interface zone, were effectively maintaining their own cultural identity as manifest in most other material culture remains.

Though the data is still equivocal, a slightly more radical interpretation is that some intermarriage was occurring. This would require a more complex form of acculturation wherein the individual being assimilated into the host social unit must not only change his/her cultural patterns to those of the host social unit, but also begin a

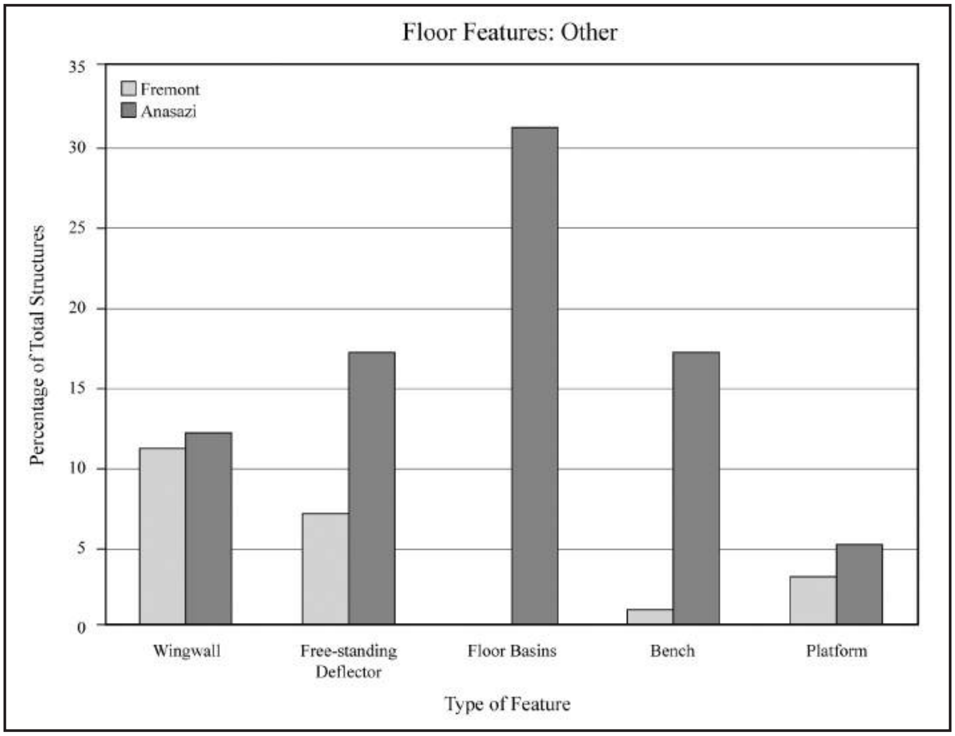

Figure 5. Other floor features in the study area

process of participation in those cultural patterns. If so, we might infer a matrilocal system in which Anasazi men (the pithouse builders) married and moved in with Fremont women (the potters). This would make some sense if the ideology of the maternal lineage were maintained, and hence the lack of kivas with certain ceremonial features (possibly floor vaults and clay-capped features, and a "sipapu," etc.) normally found in the Anasazi area. At a broader level, such intermarriage and cultural assimilation may have contributed to the sudden architectural change elsewhere in the Fremont area, with the appearance of surface roomblocks and other surface habitation and storage structures, as well as the transition to quadrilateral pithouses and more intensive use of ventilation tunnels in the Fremont core area. This is all probably stretching the interpretation too far at present, but it is an issue that should be examined in the future.

As a final note, I submit that the boundary dissolution between the Fremont and Anasazi, proposed at AD 1000 by Geib, actually began at least a century earlier, by about AD 900. After this time Fremont architectural complexity and style change is evident in the archaeological record (Talbot 2000), though certainly the changes increase dramatically in the AD 1000s. Around the AD 900s is also the approximate time that the changes begin in this specific hinterland zone. Beyond the Roadcut and possibly Barnson sites we have little information for architectural styles in this zone prior to AD 900, but to the north (e.g., Metcalf et al. 1993; Greubal 1998; Talbot 2000) Fremont architecture was very simple and lacking the details and diversity present to the south among Basketmaker and Pueblo I Anasazi, or so it was until after AD 900.

There are still many questions. What were the factors mitigating social, economic, political, or even ideological change after AD 900? Were there increasingly mutualistic relationships and decreased competition? Were lands and resource zones shared, and what were the means of conflict resolution? Were goods more openly exchanged, and did such exchange create a medium for other communications and associations? Were they indeed intermarrying? Clearly there is much to be learned, and architectural analyses should be an integral part of the search.

Summary

While vernacular architecture is primarily passive in style, it is by no means static. Changes can and do occur through local innovation, but

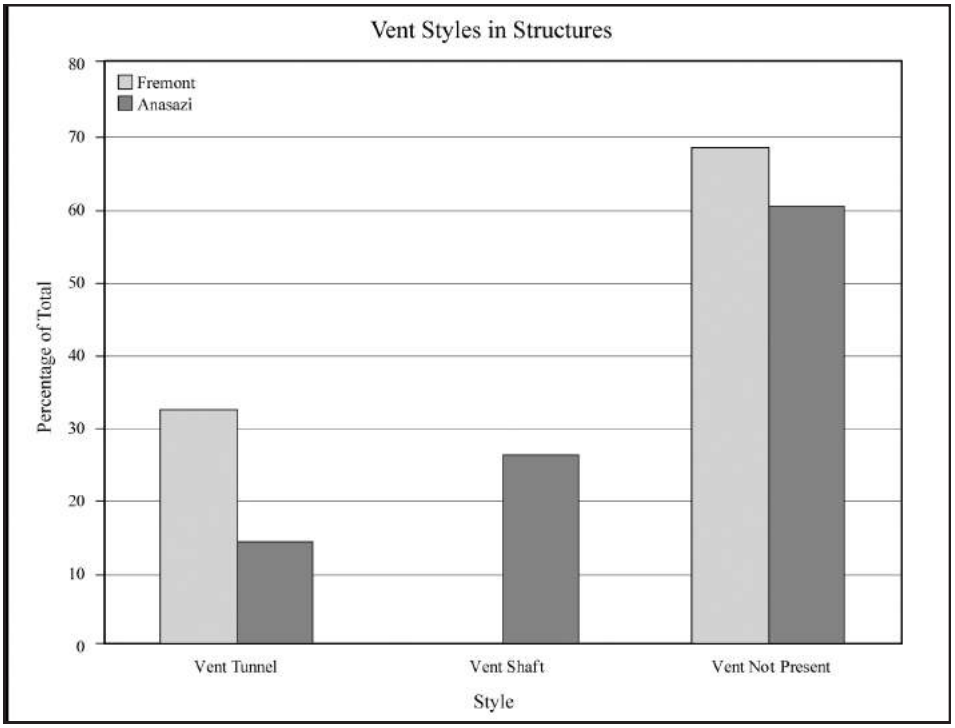

Figure 6. Ventilator construction styles in the study area

often the more rapid and radical shifts come when a cultural group is exposed to new ideas. At the same time most architecture probably is not specifically intended to convey ethnicity, but by its very nature and by people doing things the way they have learned to do them over generations, it conveys exactly that. The style expresses to the native group a sense of place and community, while to a non-native it communicates a different heritage and traditions that say "*you are a foreigner*" (Sackett 1990:37). Distinctions in Fremont and Anasazi architecture generally say that very thing. They attest to two social groups, each with its own commonalities in traditional architectural style. Whether these were distinct ethnically, ideologically, or perhaps even linguistically cohesive social groups we do not yet know, but clearly both Fremont and Anasazi groups in this interface zone are parts of larger traditions with distinct culture histories. It then appears that along this Fremont-Anasazi interface, perhaps as early as AD 900, at least some Fremont groups began to adopt new ideas in architecture that markedly altered traditional styles in the archaeological record. This may have been a simple copying of styles, or something more socially intimate, such as intermarriage. Whatever the cause, in so doing a traditional cultural barrier of sorts was lowered, and these two previously distinct cultural groups began a period of more interesting interpersonal contact, making the work for us as archaeologists considerably more fun.

Author's note: An earlier version of this paper was presented at the 67th Annual Meeting, Society for American Archaeology, Denver, Colorado, March, 2002.

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Notes

Endnote 1

The names that various prehistoric Puebloans ascribed to themselves are, of course, unknown. The term "Anasazi" is a Navajo word that means "old enemies" or "enemy ancestors" (see Richard A. Ambler, *The Anasazi: Prehistoric People of the Four Corners Region* [Flagstaff: Museum of Northern Arizona, 1989]; also see Charmaine Thompson, "The Anasazi: Who Were They?" pp. 3–18 in *Of Earth, Stone, and Corn: The Anasazi and Their Puebloan Descendants* , eds., Marti L. Allen and Shane A. Baker [Museum of Peoples and Cultures Popular Series 2, Provo, Utah, 2000]). Not surprisingly, then, modern pueblo groups such as the Hopi and Zuni prefer their own names ascribed to their ancestors, and in deference to those preferences, many archaeologists in recent years have taken to referring to the Anasazi with the more neutral label of "Ancestral Puebloan." Anasazi as used in this paper refers to the archaeological tradition and/or time period of the same name, and not as an identifier of ethnicity.

Endnote 2

Style is central to much of archaeological research; stylistic descriptions are an integral part of any discussion of artifacts, features, patterns, etc. Often style has been used as a metaphor for ethnicity, if not explicitly then at least implicitly. In the past two decades debate has centered on the nature of style - what it might or might not represent. An excellent though now slightly dated review of the debate is presented in Shennan (1989). This includes consideration of the more active forms of style by Wiessner (1989), what she refers to as Emblemic and Assertive styles. I have selected here a third, more passive form termed Isochrestic style for reasons discussed in the text and below, but primarily because architecture in general, and pithouse architecture specifically, is for the most part a passive form of style transmission.

James R. Sackett has been the chief proponent of Isochrestism. The approach was developed in response to a historic leaning toward iconologic interpretations of style–for example, the decorations applied to a ceramic vessel, which are then interpreted as active messengers of cultural variability. Sackett's approach goes deeper, with the realization that functional attributes–the materials, form, shape, etc–of that same vessel are equally representative of stylistic variability that can project social identity, even if that was not the purpose of those attributes, and that these form a vernacular style that underlies cultural identity. Sackett (1990:33) briefly explains it in the following way:

> "....isochrestic variation [is a term] from the Greek which literally translates as "equivalent in use" and which connotes in essence that there is more than one way to skin a cat.
>
> Style enters the picture when we see that the artisans of any given fraternity (or sorority) are aware of only a few, and often choose but one, of the isochrestic options potentially available to them when performing any given task, and that the choices they make are largely dictated by the technological traditions within which they have been enculturated as members of the social groups that delineate their ethnicity. These choices tend to be quite specific and consistently expressed within a given group at a given time, although they are subject to revision as a result of changes in its patterns of social interaction (and concomitant exposure to alternative isochrestic options) with other groups. Isochrestic variation in material culture that is socially bounded in this manner is consequently diagnostic or idiomatic of ethnicity, and it is such variation that we perceive as style. The likelihood of unrelated groups making similar combinations of choices is as remote as the number of potential options is great. Hence each social group or unit of ethnicity tends to possess its own distinctive style, and the overall degree of stylistic similarity represented by two groups' material cultures taken as wholes can be regarded as a direct expression of their ethnic relatedness."

Endnote 3

This is exemplified in Madsen and Simms' (1998) treatise on the Fremont. They posit that the "Fremont" referred to and examined over the last century should be considered a complex of behaviors that occurred across time and space, rather than a cohesive 'people':

> "Boundaries and traditions exist not only between cultures but within them. Plasticity and change are also features of cultures, and of individuals and groups

within them. The need to categorize tends to treat cultures, variants, and the like as autonomous social units, thus making it difficult to explore interaction, fluidity, and dynamism in any other terms. The approach we take here in exploring behavior highlights the contexts of selection to which people were subjected but does not replace whatever ethnic, linguistic, or other boundaries may have been present among people. Rather we presume many of these boundaries are archaeologically undetectable and suggest that failure to come to grips with this is one reason why we have struggled so unsuccessfully to define the Fremont people. It is also why we tend to transform our archaeological categories into social ficture" (P.322).

Of course, the very title and focus of my paper deals with an interface between the Anasazi and Fremont, which are treated as "autonomous social units," and the discussion thereafter leans toward the identification of certain architectural styles that I believe may be evidence of the interaction between those social units. When social groups with related but still distinct culture histories such as those examined here overlap and/or begin to interact, the material culture within the contact zone may cursorily appear to someone removed from the context, such as the archaeologist, as a merging or melting pot of traits that defies classification (for example, see Madsen 1982; 1989). But such merging often has the potential to be archaeologically detectable and should not be ignored. Similarly, I do not agree with the dismissal of decades of study into material culture patterning as a means to "explore behavior." Nor do I struggle to "define" the Fremont, or make such a definition my end goal. I recognize that human behavior is variable, but that it is the patterns in the archaeological record that provide the test of paradigms and theories, and it is to those patterns recognized by the pioneers in Fremont research over many decades that my conceptualization of "Fremont" adheres.

Archaeologists struggle to understand the mechanisms behind the transmission of artifact and other styles across time and space (e.g, Bettinger and Eerkens 1999; Cameron 1995; Gunnerson 1969; Jennings 1978; Simms 1995, to mention a few). In this paper I lean somewhat on the concept of biased transmission (Boyd and Richerson 1985; Richerson and Boyd 1992) as a possible explanation for cross-cultural copying of the mostly passive styles communicated through architecture. But I emphasize that such styles usually have a cultural heritage of their own, being taught and learned from generation to generation within a larger social milieu that displays congruity and uniformity through regionally similar patterns, and identified by convenient labels such as Anasazi and Fremont. Madsen and Simms (1998:259) believe that applying labels such as these "fails miserably in defining a people, who... are not easily described or classified." But then most of us realize that these are not labels of people, but labels of regionally coherent patterns in the archaeological record–patterns that imply a similar cultural trajectory and participation in macroregional behaviors and material cultures that are distinct from others in the region. As Fremont culture history has been worked out over time, archaeologists have occasionally focused on more specific patterns in material remains variability, which has resulted in numerous variant schemes (see Madsen 1989 for a critique). As satisfactory or unsatisfactory as we now see them to be, those variant schemes were never meant to represent "people." Instead they were, in a sense, attempts to define specific "contexts of selection." In much the same way, the behavioral perspective can restructure the data at any level that it deems applicable to search for patterns that inform on behavioral and stylistic variation, but it is quite another thing to dismiss entirely the broader patterns that are rooted so firmly in hard archaeological data.

Of particular concern is Madsen and Simms' declaration that "There are, in fact, only three things common to all these (Fremont) people: they grew maize or knew someone who did, they made or traded for pottery and they were not Anasazi...." (P. 259). Their justification leans heavily on variability of style across space and time in Fremont material remains. This issue has been addressed more recently by Talbot et al. (2005). One confusing pronouncement presented by Madsen and Simms as historical "fact," and addressing specifically pithouse architecture (since that is my current topic), should suffice to illustrate the problem with such untested generalizations. In referring to the late Fremont period, they state:

> "Significantly, there are actually very few things that distinguish even this crystallized Fremont. Pithouse villages and farming are found over large areas of the United States about this same time and are not very useful in distinguishing the Fremont from other groups. Since pithouses had been used in the Great Basin and Colorado Plateau during the Archaic, they do not necessarily identify either agriculture or "sedentism" but, rather, indicate greater tethering or redundancy in the structure of mobility. Even within the Fremont area, the form and construction techniques of both habitation and storage structures are so varied as to preclude useful classification" (p.262).

This generalization falters in several ways, but three in particular: 1) It is true that pithouse villages and farming are found over large areas of the United States at about this same time. But it is also true that regionally distinct forms of site layout, structural types and functions, agricultural technologies, and even genetic forms of maize are commonly used by archaeologists to define archaeological traditions. For nearly a century Fremont architecture, settlement patterns and subsistence strategies, in concert with other well-described material culture characteristics, have been used to distinguish the Fremont from other groups. 2) It is true that pithouses do not necessarily identify agriculture or sedentism. However, greater tethering and redundancy in the structure of mobility are strongly associated with the introduction and expansion of agriculture across the Southwest, and with more stylistically formalized pithouses and pithouse villages, with increased storage capacity and a shift from a risk management to a risk buffering strategy. 3) Archaeologists have been classifying Fremont architecture for decades, and as early as the 1930s and 1940s were recognizing specific patterns in form and construction technique that inform on structure and site function, and that identify regional differences and commonalities. Certainly some researchers have gone to categorical extremes, creating pigeon-hole typologies that obscure rather than inform, but a blanket statement that uses this artificially created variability in architecture to dismiss general classifications backed up by long-recognized patterning in the physical data is incorrect and misleading. A more careful look at architectural studies shows: 1) clear temporal and spatial patterns in the development of Fremont architecture; 2) clear categories of structural types and functions; and 3) clear methodologies demonstrated in construction techniques that are wide-spread and that are persuasive in their implications for cultural identity (see Talbot 2000 for a detailed review; also Talbot et al. 2005).

The Madsen and Simms approach would have us believe that the archaeological tradition labeled as "Fremont" since the 1930s does not exist, that there is no regional uniqueness or recognizably distinct heritage evident in the material record, that stylistic variations cannot be subsumed under a larger areal vernacular, or that past regional patterning studies based on thorough, painstaking examination of countless sites across space and time over the last century are meaningless. Under those presumptions any possible ethnic, linguistic, material culture, or other boundaries indeed become archaeologically undetectable, and the prehistoric world is reduced to a mishmash of localized behavioral "complexes." Ironically, such a presumption may be the more dangerous social ficture!

Endnote 4

It is not uncommon to find confusion between the labels 'vent tunnel" and 'vent shaft.' The names each describe well their respective constructions. Ventilator tunnels are long, often relatively shallow appendages to pithouses which can run for up to three or four meters away from the structure. They are always dug as a trench, and are sometimes large enough to have functioned as entryways (e.g., such as the Big Flat, Rattlesnake Point, and other Escalante area sites), though there is definite spatiotemporal variability in this regard. Ventilator shafts are almost always very constricted tunnels that exit a structure horizontally, but then very quickly angle into a vertical shaft and small opening usually located not far outside the structure walls. The distinction is critical for the Fremont in particular, because with a couple of questionable exceptions, vent shafts do not occur in the Fremont region (see Talbot 2000), whereas they became very common throughout much of the Anasazi area, in particular as pithouses became deeper and took on more formal characteristics of kivas.

Endnote 5

Figurine fragments typical of Fremont styles, though somewhat crude, were found at several of the project area sites. In addition, Geib (1996 chapter 6), following Gunnerson (1959:23), has pointed out the significant difference in ceramic wall-forming techniques used by Anasazi and Fremont potters. Geib notes that at least post-AD 850 Kayenta Anasazi ceramics are formed by lapping the coils onto the vessel exterior, while Escalante River Basin Fremont lapped the coils onto the vessel interior. In fact, the latter trend seems to be consistent for the Fremont as a whole, at least until the introduction of corrugated pottery into the Fremont area after AD 1050, which required coils overlapping onto the vessel exterior (Lane Richens, personal communication 2002). Pending a more intensive regional examination of Fremont ceramics, this bolsters the argument for distinct Fremont and Anasazi cultural identities. In some cases, such as in questions of similar temper sources being used by Fremont and Anasazi groups (e.g., Coulam 1991) the wall-forming technique is likely to be much more informative than temper.

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Hopi Perspectives on the Archaeology of Grand Staircase-Escalante National Monument

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ABSTRACT

This paper presents an overview of evidence linking the ancient occupants of GSENM with the Hopi Tribe. Support for such a link comes from linguistic, demographic, and ceramic evidence, as well as petroglyphs, oral tradition, and historical accounts. We advocate a perspective on cultural affiliation that emphasizes emic social groups like clans rather than etic units such as culture areas. In light of the strong ties between ancestral occupants of the monument and the Hopi Tribe, we suggest that the tribe be closely involved in decisions about cultural resource management in GSENM.

Keywords: Hopi, cultural affiliation, oral tradition, clan

Introduction

This paper provides an overview of Hopi land use, ancestral ties, and cultural concerns relevant to Grand Staircase-Escalante National Monument (GSENM) and neighboring areas, summarizing an extensive literature search, site file searches, and ethnographic interviews with Hopi consultants (Bernardini 2005a). The Hopi Tribe asserts cultural affiliation to GSENM, but the connections between the ancient occupants of this territory and the modern Hopi Tribe have been obscured in some ways by the manner in which cultural affiliation has been investigated by archaeologists. We highlight the ways in which different social frameworks (e.g., clans vs. culture areas) and fieldwork strategies can produce substantially different interpretations of the archaeological record, and emphasize the importance of incorporating emic social categories and traditional knowledge into archaeological research on cultural affiliation. Evidence of Hopi ties to ancestral populations of GSENM is evident in linguistic, demographic, and ceramic evidence, as well as petroglyphs, oral tradition, and historical accounts.

Contemporary Hopi Lands and Settlements

The Hopi are a federally recognized Indian tribe occupying a reservation in northeastern Arizona, part of a territory they have used for more than a millennium (Adams 1989). The current boundaries of the Hopi reservation, which have contracted since their original establishment in 1882, encompass only a small portion of the territory once occupied and used by Hopi ancestors (Ellis 1974). The Hopi Tribe has issued a formal claim of cultural and ancestral affiliation to the Fremont, Kayenta, and Virgin Anasazi culture groups of southern Utah (Hopi Tribal Council Resolution H-70-94) and considers all archaeological sites attributed to these prehistoric cultures to be Hopi Traditional Cultural Places, or "footprints" of Hopi ancestors.

Hopi Social Organization

Hopi social organization is comprised of a number of interlocking groups (Connelly 1979:539), including named villages, clans, and religious societies, and unnamed households, lineages, and phratries. Villages are largely politically autonomous, although some are joined through ritual dependency in a mother-daughter village relationship (Connelly 1956).

Lineages, although they are unnamed and often not coresidential, are the fundamental units in Hopi kinship (Eggan 1950:19; Whiteley 1988). Lineages are grouped together into matrilineal clans, composed of people united through the female line who live in the same village and are thought to be descended from a common ancestor. Each Hopi clan has one or more wu'ya, or totem, that provides it with a name and a symbolic association to a plant, animal or meteorological phenomenon (Eggan 1950; Lowie 1929). Clans are grouped together into exogamous phratries based on common origins or migration experiences. The importance of the phratry lies in the transmission of the control of ceremonies, with "partner" clans assuming the ceremonial duties of shrinking or recently extinct clans.

Hopi Migration Traditions

Hopis conceptualize both contemporary and prehistoric identity primarily in terms of clan affiliation, and contemporary Hopi culture is explicitly conceived of as the cumulative product of the "gathering of the clans" at Hopi (Courlander 1971; Dongoske et al. 1997, 603; Fewkes 1904; Nequatewa 1967). Hopi migration traditions explain that clans occupied several villages in sequence over the course of their migrations, leaving a trail of ancestral sites termed a migration pathway. Migration pathways were non-linear because as clans moved they merged with other clans, fissioned, and moved laterally or even in spirals relative to the location of the Hopi Mesas, each making independent decisions about when and where to move. Each clan traces its own unique history of movements from village to village until its arrival at Hopi, accounts that stretch back into the distant past (Courlander 1971; Fewkes 1900; Malotki 1993; Mindeleff 1891; Stephen 1929; Voth 1905; Yava 1978).

As part of their pact formed with the deity Ma'saw when they emerged into this Fourth World, Hopis vowed to place their "footprints" as they migrated in search of Tuuwanasavi, the earth center on the Hopi Mesas. These footprints now comprise the archaeological record, including petroglyphs, potsherds, ruins, shrines, and other material. Ancestral Hopi territory includes any area marked by Hopi footprints. The Hopi do not view these archaeological sites as "abandoned." Instead, they view them as still occupied by the people who lived there and as important reminders of the spiritual responsibility Hopis have to the land.

Ancestral Places

Important places on the Hopi landscape are not just limited to traditional archaeologically defined "sites" like pueblo ruins. Shrines, springs, eagle nests, and natural features like mountains are part of the footprints left by Hopi ancestors, and many of these places have been, and continue to be, visited by later generations of Hopis. These features are considered footprints because they were used by Hopi ancestors to deposit or collect culturally significant materials, and rights of use to these places have been passed down along clan lines through time. In her research of Hopi land use, Ellis (1974:221, 262; see also Adams 1989:25) observed that "When the people emigrated, they continued to claim and use many shrines, springs, eagle nests, and other natural resources and sacred spots formerly possessed in areas formerly occupied and claimed by no others until the Navajo arrived and spread throughout the area. Because Hopi ceremonial life is exceptionally full, these areas are frequently visited today for whatever uses or rites they have been remembered." From a Hopi perspective, "these places are considered as "belonging" to the group which has historic claim to them, and these claims are renewed through rituals which commemorate the historic events which gave basis to the claim. Prayer feathers used in the rituals are deposited at these places as evidence of the claim," (Sekaquaptewa 1972:242-243).

Archaeological Perspectives on Hopi-GSENM Ties

Archaeologists have conceptualized the link between southern Utah and the "puebloan" area of Arizona in a number of different ways. What is significant for this study, however, is that the majority of researchers find sufficient evidence for either a direct or indirect (e.g., through an intermediate area like the Kayenta region) flow of people from southern Utah southward into the population that is today known as the Hopi Tribe.

Archaeological investigations into the identity of prehistoric populations of southern Utah has been conducted using two primary frameworks: 1) language groups, and 2) culture areas. There are theoretical and methodological concerns with both frameworks, especially the latter, but because they dominate the archaeological literature conclusions about cultural identity cannot be understood without them. Each of these frameworks, and the links between populations in GSENM and Hopi that have been drawn from them by researchers, will be discussed in turn below.

Language Groups

Linguistic groups, which sometimes, but not usually, correspond to culture areas, have been used to classify prehistoric populations in southern Utah and northern Arizona. The Hopi language is classified as one of three branches of the northern Uto-Aztecan language family, which also includes Numic (including Shoshonean and Ute), and Takic. Given the linguistic similarities between Hopi and Numic (e.g., Shoshonean) languages, they probably stem from a common linguistic ancestor, and some scholars suggest that at least part of the original core of Hopi population was "of Shoshonean stock" (Ellis 1951:150, 1967:36). By this, these scholars do not mean that Hopi language or culture is derived from the historically known Shoshonean population, but that the Hopi language derives from a Numic linguistic base that is referred to in shorthand as "Shoshonean." Because Shoshonean speakers are thought to have entered the Southwest from the west, initially through northeastern Nevada and into Utah, the ties between Hopi and Numic languages indicate a northern origin for a portion of the Hopi Tribe's population.

Assertions of "Shoshonean" (i.e., Numic) linguistic origins for Hopi clans can also be found in Hopi traditional knowledge, such as statements in some clans' histories that when they reached Hopi they had been away for so long that they spoke other languages like Pauite or Shoshone (Courlander 1982:41). Yava (1978:82) and Auguh (1999) specifically state that the Snake and Horn clans from the north were Shoshonean speakers. Clans then "earned the right to speak Hopi after they arrived" at a Hopi village (Kuwanwisiwma 2001).

Other scholars emphasize the presence of Keresan words in Hopi ceremonies and songs as evidence that the Hopi also incorporated a significant Keres speaking population, another language associated with areas to the north of Hopi. The songs of the Snake-Antelope, Flute, Wüwüchim, Mamzrau, and Singers societies are said to be in Keresan (Parsons 1936:555; Stephen 1936:261 n1, 578, 713). Alexander M. Stephen stated that the Snake (including Snake-Antelope society), Sand, and Flute clans spoke the same language as the people of Laguna Pueblo, namely *Hopaqlavayi*, which means "Northeast talk" (Stephen 1936:713-714, 718), interpreted to mean "Keresan".

Parsons (1936:554) locates ancestral Keresan speakers "at *Toko'nabit*, near the junction of the San Juan and Colorado Rivers"; Ambler (2002) would extend the territory of ancestral Keresan-speaking populations to the Kanab and Virgin Anasazi areas. Ellis (1971:69) thinks that some of the pre-A.D. 1300 Hopi immigrants speaking "Northeast talk" could have come from the Navajo Mountain areas, others from the Upper Chuska Valley, Montezuma Valley, and Mesa Verde regions (the latter being in her view the Keresan heartland).

Thus, both linguistic evidence and Hopi traditional knowledge trace Hopi ancestors back to Keresan and "Shoshonean" speaking populations living in northern Arizona and southern Utah before A.D. 1300. Ute accounts provide support for this scenario, stating that the "*muukwitsi*" (the Ute term for the ancient puebloan residents of Utah) of southern Utah were different groups of people, not just one. Some anthropologists (e.g., Goss 1968:34) interpret such statements to indicate that there were linguistic divisions among the archaeological cultures of Kayenta, Virgin, and Fremont living in southern Utah, some of whom later moved to Hopi (see below). Ellis (1971:85) infers the Shoshoneans to have been in the majority, or "at least dominant," in this proto-Hopi population given that theirs is the language that persisted.

Culture Areas

Culture areas, as used in archaeology, are territorially bounded units intended to contain a population with a distinctive material culture – that is, particular traditions of house building, pottery production, burial practices, etc. Despite growing criticism of archaeological culture areas as units of prehistoric cultural identity (Speth 1988; Bernardini 2005b; Duff 2002), debates over the definition and significance of the Fremont culture area, for example, have continued long after such debates were abandoned by researchers working elsewhere in the Southwest. Though we advocate the use of clans, rather than culture areas, in efforts to link prehistoric and contemporary Native American populations, it is necessary to grapple with them to understand archaeological conclusions about cultural relationships.

Significantly, GSENM appears to be a transitional zone between archaeologically-defined cultural groups (Figure 1). Madsen (1998) sees the Monument as a middle zone populated by hopelessly tangled groups of "Freazi" or "Anamont" who shared characteristics of populations to their north and south. Others (e.g., Geib 1996:113) see a clear early boundary between Fremont and Anasazi groups, which later changed from a "relatively marked discontinuity in material remains to one that was spatially continuous." As Madsen (1997:8) notes, this "transition/border between the two groups lies almost entirely within the monument," making GSENM a theoretically interesting but challenging case study for assessing identity.

Regardless of how southern Utah populations are classified, a majority of researchers find evidence for either a direct or indirect (e.g., through an intermediate area like the Kayenta region) flow of people from southern Utah southward into the population that is today known as the Hopi Tribe (Figure 2). These movements include cyclical migrations between the Kayenta/Virgin Anasazi and Fremont areas, sequential movements from southern Utah to the Kayenta and Virgin Anasazi areas, thence to Hopi, and direct movements from southern Utah to Hopi.

Fremont

Although there is some debate about how specifically the destination(s) can be pinpointed, most scholars agree that the people living in the Fremont area moved south beginning in the A.D. 1100s, joining puebloan groups in northern Arizona. Although the Fremont area is now occupied by Shoshonean groups, Wormington (1955:187) notes that "there is no evidence directly linking the later Shoshoneans and the Fremont people…diagnostic Fremont traits are lacking and pottery and most projectile points are different… there is every reason to believe that [the Fremont] moved out of the area." As Madsen and Simms (1998:319) point out, "there remains a gap in the archaeological record between the end of identifiable Fremont material culture (A.D. 1250-1450) and the earliest material remains associated with historic [Shoshonean] groups such as flat-bottomed "flower pot" vessels and twined seed-beaters, which occur no earlier than A.D. 1650…this raises the possibility that these remains represent a relatively recent movement of people into the region, a possibility with which we concur" (see also Berry and Berry 2003:143-144).

As for specific destinations of the Fremont migrants, Wormington (1955:187) considers it "most probable that the Fremont people moved south and eventually lost their identity among the Pueblo people…where this amalgamation took place is not known, but…they must have been aware of the presence of people in northern Arizona since they used trade pottery from that area. If they continued moving directly south they would ultimately have reached the Hopi country…

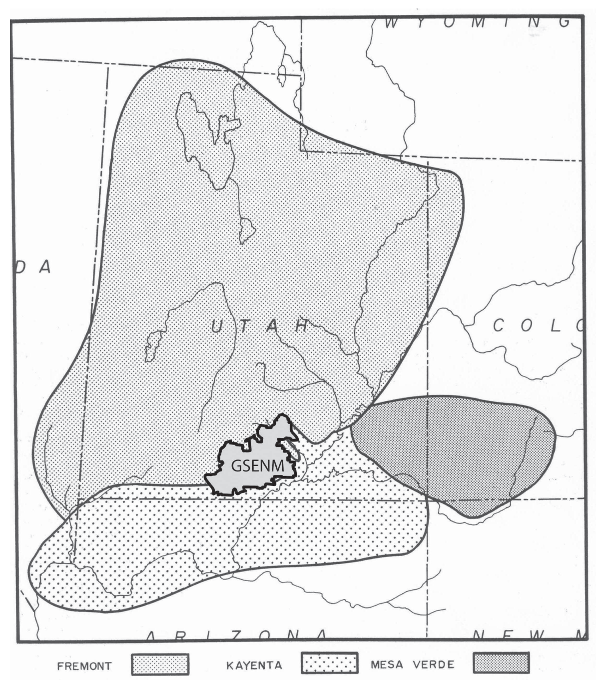

Figure 1. GSENM boundary superimposed on Jennings' (1978) map of Fremont, Kayenta-Virgin, and Mesa Verde cultures.

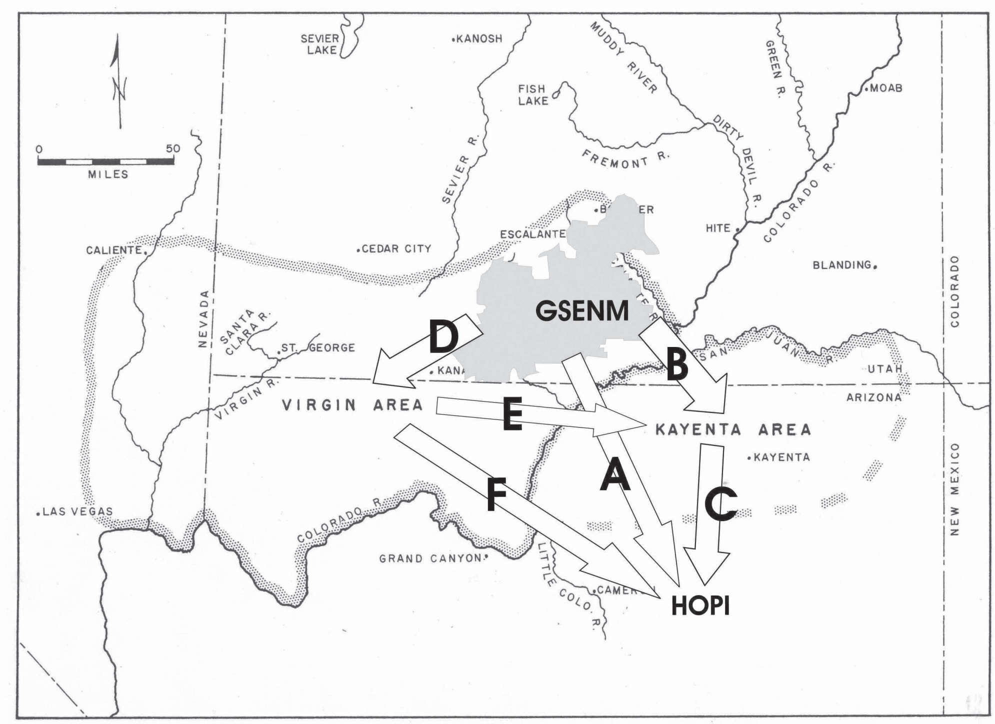

Figure 2. Population movements connecting the GSENM area of southern Utah to Hopi (base map from Aikens 1966: Figure 1).

if both the old residents and the newcomers spoke Shoshonean dialects, which is not unlikely in the case of the Fremont, rapport might have been… easily established."

Kayenta and Virgin Anasazi

Archaeologists have long speculated that the Fremont received influence and/or immigrants from the Kayenta and/or Virgin Anasazi region of Arizona, a connection which may have led some Fremont groups to emigrate to the Kayenta/Virgin area after A.D. 1100 (e.g., Lister 1964). The Coombs Site (Lister, Ambler, and Lister 1959) is the most famous example of a probable Kayenta outpost; interaction between local Fremont populations and Kayenta immigrants at sites like Coombs could have established relationships that Fremont groups later used to gain entry into villages in the Kayenta heartland. As Spangler (2000:404) and others have pointed out, however, early statements about identity were made primarily on the basis of a single artifact class, ceramics, and "not on any significant differences in adaptive lifeways." Further, most of the pottery recovered in the Fremont area was grey utility ware, with "ethnic" distinctions made primarily on the basis of temper. For example, Gunnerson (1969) classified plain gray sherds as Virgin Series North Creek Gray, while Lister (1964) classified some of the same gray pottery as Kayenta Series Tusayan Gray. Reanalysis of this material using contemporary ceramic types would likely resolve much of this type of confusion.

Petroglyph styles have also been cited in support of a Kayenta intrustion into GSENM. The Eastern Kayenta style described by Schaafsma (1971) for the area east of Kanab Creek dates to the late Pueblo II period and contains geometric forms similar to those found in the House Rock Valley but which have no antecedents in southern Utah. Steward (1941) recorded examples of this Kayenta-style rock art in the eastern Grand Staircase area.

More recent work has continued the debate over Kayenta vs. Virgin Anasazi origins for intrusive agricultural populations. As Geib, Collette, and Spur (2002:379) state: "that the Anasazi occupied the Kaiparowits Plateau is beyond doubt… but were they Virgin or Kayenta Anasazi?" The debate continues to revolve around interpreations of plain grey pottery. Researchers working on the Kaiparowits Plateau argue that pottery recovered there belongs primarily to the Virgin Anasazi tradition based on raw material differences, but also distinctions in vessel finishing, surface treatment, and possibly design styles (Spurr, Geib, and Collette 2004:30). These researchers also see differences between Kaiparowits Plateau and Kayenta stone tool reduction, masonry construction, settlement layout, and interior features, leading them to "favor a model of expansion out of the west from the Grand Staircase… if Anasazi populations from south and east of the Colorado river…were using the…Kaiparowits Plateau, it was probably via logistical hunting forays" (Spurr, Geib, and Collette 2004:30, 377).

In contrast, others (e.g. Lyneis 1996; McFadden 1998) see evidence for a Kayenta expansion onto the Kaiparowits Plateau and Glen Canyon areas at the expense of Fremont people. Researchers working in the nearby Piute Canyon region also conclude that immigrants were "typical Kayentans…the Marsh pass locality would be the most logical homeland, given the large PI populations in that area and its proximity to upper Piute Canyon" (Ambler, Fairly, and Geib 2004:9). Lyneis (1996:23) concludes that "it is widely accepted that from A.D. 1050 to 1250, the intrusive Kayenta communities north and west of the Colorado River maintained close relationships with the Kayenta heartland." An important piece of evidence linking southern Utah populations to the Kayenta region is pair of woven cradles with geometric designs, one recovered from Kiet Seel in Tsegi Canyon, the other from San Juan County, Utah. The decoration is so similar between the two cradles that "the two might have been made by the same woman" (Fewkes 1911:29).

Regardless of whether immigrants moved into GSENM from the Kayenta region, the Virgin region, or both, these population movements have implications for the ultimate fate of the Fremont population. As ethnographic observations demonstrate, emigrating populations tend to move only to known destinations, with the amount of information possessed about a destination varying directly with the likelihood of it being selected among a set of known options (Brown and Sanders 1981; Bernardini 2005b). There is consensus that population movements into southern Utah happened in the 11th and 12th centuries, and that GSENM began to be depopulated soon after A.D. 1100. At most, then, only about a century would have separated the entrance and exit of immigrants into the monument area; thus, ties to places of origin would still be fresh. It is therefore most likely that many residents of GSENM returned to villages in the Virgin and Kayenta regions of northern Arizona. This is significant for the current study because, as demonstrated below, each of these areas has strong connections to Hopi.

It should first be noted that a formal declaration of cultural affiliation has been made linking the Kayenta Anasazi with Hopi (a finding that Kayenta is "affiliated with Hopi, reasonably believed" [Wozniak 1996]). One line of evidence supporting this link is demographic patterns; the depopulation of the Kayenta region in the late A.D. 1200s coincides with marked population increases in the Hopi region. Colton (1960:109), for example, notes that "while the regions about Navajo Mountain, the Tsegi Canyons, much of Black Mesa, and the Moenkopi drainage were being depopulated, the Hopi pueblos of Oraibi, Old Shungopovi, Old Mishongnovi, Old Walpi, Chuckovi, Hoyapi, Sikiatki as well as other pueblos in the Hopi area, show active building periods. The same is true of the five great Hopi Pueblos in the Jeddito Valley – Kokopnyama, Nepshoptanga, Chakpahu, Kiwaiku, and Awatobi – which flourished with a total population well over three thousand people." Ellis (1951:221) concurs that "the picture…is one of the direct Hopi ancestry being the people of the Tsegi and Hopi territory." Dean (2002:157) also concludes that "the bulk of the Kayenta population joined closely related groups of the Tusayan branch in the Hopi Mesas and Homol'ovi areas of the middle Little Colorado drainage."

Direct GSENM ties to Hopi

At least three scholars refer specifically to parts of GSENM as sources for some Hopi immigrants. Ellis (1967:36) sees a nucleus of Hopi population stemming from "a combination of Shoshonean-speaking peoples who moved to the Hopi Mesas before A.D. 1300 or before from three areas: one group had been living in and around the Hopi Mesas; the second group came from Kayenta (Marsh pass); *the third group came from small sites in Utah, northwestern Arizona north of the Grand Canyon*, and the Moapa area of Nevada" (italics added). Both Schroeder (1965:53) and Euler (1964:380) feel that in the twelfth century occupants of the Virgin River and Johnson

Bench/Paria Plateau areas moved to the Kayenta district, from whence essentially the whole district moved to Hopi by A.D. 1300.

Summary of Archaeological Links Between GSENM and Hopi

When addressing the issue of Hopi population sources, most scholars agree that the Hopi have an ancestry "so mixed that we might speak of Hopi country as a melting pot" (Ellis 1967:36). Although different emphases are placed on the relative contributions made by people from different areas, the information presented above demonstrates significant population movements from southern Utah to Hopi.

Oral Tradition Evidence

Hopi clans preserve traditional knowledge about use of GSENM by ancestral Hopi populations who lived in the area or traveled to there to hunt or collect resources. Since the earliest recordings of clan migrations by anthropologists, Hopis have stated that after emerging from the *Sipapuni* "some of our people traveled to the north, but the cold drove them back" (Fewkes 1894:107). Tables 1 and 2 summarize the clans whose traditional histories associate them with the Fremont area, GSENM, and southern Utah.

Badger Clan

The traditional knowledge of the Badger Clan traces the movements of its ancestors through GSENM (Kuwanwisiwma 2004). The Badger Clan symbol is most commonly represented in petroglyphs as a badger paw. It may also be significant to note, with respect to symbols associated with the Badger Clan, that there is a Butterfly lineage of the Badger clan (Stephen 1936:520, 1072 n4).

Fire Clan

According to Wilton Kooyahoema (2004), Fire Clan member, the Fire Clan traces its ancestry through GSENM. During its migrations, the Fire Clan traveled together with the Kokop, Spider, and Snake Clans. Although the migration traditions recount no specific placenames within GSENM, they do mention nearby areas that place ancestral Fire Clan members at least within reasonably resource-acquisition distance of GSENM. For example, both the Fire and Bearstrap Clans are mentioned as living at Tokonavi [Navajo Mountain], 100 km southeast of GSENM, in the Snake Myth recorded by Voth (1905:35). The Fire Clan's connections to Kawestima [Navajo National Monument], 200 km southeast of GSENM, were revealed during the Oraibi split of 1906. Members of the Fire Clan were prominent among the Hostiles faction, who ultimately left Oraibi. During the split, Tawakwaptewa, leader of the Friendlies, said to Yukioma, leader of the Hostiles "The Fire Clan and its affiliated clans can return to the cliffs at Kalewistima [sic, Kawestima] from where they came…Take all your people from Oraibi…You say you came from Kalewistima. Very well. Return to Kalewistima [Kawestima] and leave us in peace" (Courlander 1971:197). Yava (1978:112, 149) relates a similar quote by Bear Clan people: "You Masauwus (the Fire Clan was also called the Masauwu Clan) and you [Water] Coyotes, if you can't live in peace, if you can't stop disrupting everything, go back to your own village in Kalewistema. That was where the two clans had come from, Kalewistema, those cliff ruins near Kayenta."

Hopi Name	English Glossary
Tsu'ngyam	Rattlesnake
Tuwangyam	Sand
Kuukutsngyam	Lizard
Aawatngyam	Bow
Tepngyam	Greasewood
Paaqapngyam	Reed (Bamboo)
Hospo'ngyam	Roadrunner
Hoongyam	Arrow
Kastinngyam	Katsina
	Fire
Isngyam	Coyote
Kokootngyam	Burrowing Owl
Piqösngyam	Bearstrap
Masilenngyam	Flute
	Deer
Honanngyam	Badger
Oomawangyam	Cloud
Honngyam	Bear

Table 1. Clans with traditional ties to the Fremont area (Kuwanwisiwma 1999; Hamilton 1999, cited in Anyon 1999:24; Ferguson 2001:97-98).

Hopi Name	English Glossary	References
Honanngyam	Badger	Kuwansisiwma 2004
	Fire	Kuwansisiwma 2004; Kooyahoema 2004
Masilenngyam	Flute	Ferguson 1998: 82; Lewis 2004
Tepngyam	Greasewood	Ferguson and Dongoske 1994: 27; Kuwansisiwma 2004
Tsu'ngyam	Snake	Secakuku 2004
Alngyam	Horn	Curtis 1922: 78-79
Kookyangngyam	Spider	Hermequaftewa (cited in Ferguson 2001: 95); Ferguson 1998: 91; Ferguson and Dongoske 1994: 26-27; Kuwansisiwma 2004; Turner 1963: 22; Voth 1905: 27-28
Paaqapngyam	Reed	Ferguson and Dongoske 1994: 26
Tsöpngyam	Antelope	Fewkes 1894: 106
Tuwangyam	Sand	Polingymptewa 2004
Piqösngyam	Bearstrap	Kuwansisiwma 2004
Kastinngyam	Katsina	Kuwansisiwma 2004

Table 2. Clans with traditional ties to GSENM and southern Utah.

Flute Clan

The Horn, Flute, and Snake clans have strong associations together in Hopi migration traditions, so much so that Fewkes (1897:307) hypothesized that the ancestors of these clans lived together as two phratries, the Horn/Flute and the Snake. Stephen (1936:718) further notes that "all the songs of the Snakes and the Antelopes are Laguna or… Hopa'klavia'yi, Northeast talk. Pottery of the Flute clan can be identified by the sunflower (Ah-kui-si) design, which is another of the clan's marks, and which is used in Flute ceremonies and on masks. It is important to note that the sunflowers from the Kidder and Guernsey cache that were curated in the Peabody Museum were recently repatriated to Hopi through NAGPRA on the basis of their connections to the Flute Clan; these flowers are now stored in the Flute Clan house in Walpi.

The Flute Clan is also associated with Maa-hu, the cicada (Lewis 2004). Malotki (2000:68) also notes that Len, or Flute, society members have the cicada as a totem, and that "whenever they intend to play their flutes and engage in ritual prayer, they put their totem on top of the [kiva] ladder, where it flutes for them." Lewis (2004) also mentioned Horn, Flute, and Deer petroglyphs in southern Utah which demonstrate the presence of ancestral Flute Clan homesteads.

Horn Clan

In a fragmentary migration account, Curtis (1922:78-79) records that "the Horn people were living in the north, and wishing to find a better country they moved southward across the Colorado River, and arrived at Tokonabi [sic, Tokonavi] where people already were living." In a synthetic migration account compiled by James (1974:30), the Horn Clan is also described as having lived with the Snake Clan at Tokonavi .

Greasewood Clan

The Greasewood Clan, along with Bow and Reed (Bamboo), are said to have migrated "from Wupatki to the Little Colorado Rive and up the Grand Canyon northward into Utah and Colorado" (Ferguson and Dongoske 1994:27). Leigh Kuwanwisiwma, Greasewood Clan, Bacavi village, notes that early on and into historic times the Hopi have visited the Grand Staircase area, in part for trade with Paiutes (Kuwanwisiwma 2004). A compilation of Hopi place names from the Greasewood Clan and several other Hopi clans includes a number of locations along the Utah/Arizona border which indicate ancestral use of areas near GSENM, including:

- *Yamaqpi*, Lee's Ferry. The best crossing place of the Colorado River, long known to the Hopi. The modern maintained trail from the south side of the canyon was the original Hopi-Paiute trail.
- *Patukya*, spinning top. Refers to Mexican Hat, Utah.
- *Pökanghoyat*, the war twins (aka the Navajo twins). Two rock formations side by

side in the town of Bluff.

- *Pivanmuru*, Tobacco Hill. Mt. Trumbull, located on the Paiute trail. Still visited regularly by Hopis.
- *Pavayoykyasi*, place of the rainbows. Arches National Monument. This place name is specific to the Greasewood and Bow Clans.
- *Navipvösö*, "two big canyons coming together within which there are many alcoves." Refers to the area from Blanding (?) north into the Glen Canyon National Rrecreation area, near Bullfrog crossing, just across from Navajo National Monument. This is also a place name specific to the Bow and Greasewood clans.
- *Tokonavi,* Navajo Mountain. This is a term like Palatkwapi, an time period as much as a geographic region. Includes Paiute Canyon, Qatoya, which connects with Flute Canyon (Tsegi canyon). A rock formation in this canyon is a snake diety.
- *Tsayava*, "small river". Kanab creek - a modern place name coined by the Hopi Cultural Preservation Office.
- Rainbow Bridge, a crossing point for Hopi travelers and location of a Hopi shrine.

Spider Clan

The Spider Clan and its phratry-mate the Bearstrap Clan (Eggan 1950:65) trace their origins into Utah (Ferguson and Dongoske 1994:27; Kuwanwisiwma 2004; Turner 1963:22). The basic Spider Clan migration tradition was recorded by Voth (Voth 1905:27-28) and is consistent with the summary of Andrew Hermequaftewa to the Bureau of Indian Affairs in 1955 (cited in Ferguson 2001:95), who stated that after the Hopi clans emerged into the Fourth World and receiving spiritual instructions from Maasaw, "it was time to move on, and we began to move in different directions. Some of our people went north, as far north to a place where there is snow and cold all the year round. Another group went south, as far as they could go. The Spider clan went north and the Bear clan went south, and the other groups went off in different directions." Contemporary Hopi cultural advisors continue to describe how the Kokyangyam (Spider clan) migrated as far north as the frigid area where corn would not grow before arriving in the Four Corners area and the Hopi Mesas (Ferguson 1998:91; Ferguson and Dongoske 1994:26).

Reed Clan

Ferguson and Dongoske (1994:26) record that the Paazqpngyam (Reed Clan) also migrated northward into Utah.

Snake Clan

Because of the Snake Clan's association with the Snake Dance, the ceremony most heavily attended by non-Hopis and most thoroughly documented by anthropologists, documented traditional knowledge of the Snake Clan is more abundant than almost any other single Hopi clan.

Although most accounts focus on Snake Clan villages in the Tokonavi area (see below), there are also references to areas north of the Colorado River, in southern Utah. For example, Fewkes (1923:500) notes that the Snake Clan "migrated to the Hopi country from the north or from former habitations in the cliffs on the San Juan River and its tributaries." At the Hopi village of Walpi in the 20th century, the placement of agricultural fields around the village reflected the direction of origin of clans in the village; Snake fields were to the north and west (Stephen 1936:853), supporting their claims for northern origins.

In an interview conducted for this paper, Alph Secakuku (2004), Snake Clan, Shipaulovi Village, noted that there were pockets of Snake people on both sides of the Colorado River. The Snake Clan homeland covers the area bounded on the west by Bryce Canyon, on the east by the Hovenweep National Monument, on the north by Capitol Reef National Park and the Green River, and on the south by Tokonavi. As Snake Clan people moved south toward Hopi they occupied villages leading southwest to Wupatki. This area includes the Fremont and Kayenta archaeological culture areas. According to Secakuku, there is no Snake Clan knowledge about the Virgin River/Muddy River/Kanab area (the Moapa archaeological culture area), and Secakuku suggests that this area may have been occupied by a different group of people. Snake Clan members continue to make a pilgrimage to a ruin in southern Utah near GSENM, but the exact location could not be released for this report.

Petroglyph Evidence

Petroglyphs are one of the primary media through which Hopi ancestors signaled their presence on the landscape. A recently published inventory of Hopi clan symbols at the Tutuveni petroglyph site (Bernardini 2009) provides a resource with which to identify potential Hopi-affiliated icons. The more than 5,000 clan symbols at Tutuveni represent a "Rosetta stone" of sorts for Hopi clan symbols; although Tutuveni does not provide an exhaustive inventory of Hopi clan icons, confidence in the interpretation of a petroglyph as Hopi-affiliated can be increased if it can be linked to a symbol at Tutuveni.

Hopi clan symbols have been previously identified in Glen Canyon National Park, immediately adjacent to the monument's eastern boundary. Here, Turner (1963) concluded that ancestral Hopi groups left "footprints" in the form of sites and petroglyphs, then later returned to revisit some of these ancestral places. Hopi clan symbols have been identified in a number of other areas of southern and central Utah, including Flute and Deer Clans near Vernal, Utah (Anyon 1999:48), Snake and Bear Clan symbols in Capitol Reef State Park (Harold Polingyumptewa, 2004), and Sand Clan symbols near Moab (Anyon 1999).

A systematic review of petroglyph symbols in GSENM was beyond the scope of this chapter. An electronic search of the Utah State Division of History site files and consultation with archaeologists working in the monument (Matthew Zweifel, personal communication, 2008; Marietta Eaton, personal communication, 2008) nevertheless resulted in the identified of a number of GSENM sites with likely Hopi icons. While this list is certainly not exhaustive of petroglyphs in the Monument with Hopi affiliations, it indicates a strong cultural connection between the two regions.

- 42Ga1543 near the confluence of Boulder Creek and the Escalante River contains sets of badger and bear tracks.
- 42Ka5157 is a large rock art site with a Greasewood Clan symbol.
- 42Ka1500 is large rock art site on the Paria River at the confluence with Deer Creek containing a Maasaw-like figure and potential katsina figures.
- 42Ka1808 near Johnson Canyon contains a Maasaw-like figure and rows of corn plants.
- 42Ka1576, the South Fork Indian Canyon rock art site, includes rows of katsina-like faces.
- 42Ka6145, the Big Bird site, includes a Greasewood Clan symbol.
- 42Ga2103, the Weaver Panel rock art site, contains an anthropomorph with Hopi-style hair-whorls.
- 42Ga0038, the Hundred Hands site, contains hundreds of hand prints in an alcove, identified by CRATT members as an important Hopi footprints site.
- 42Ka5724, the Middle Trail site, contains a number of possible kachina petroglyphs (McFadden 2003) just south of GSENM boundary along the "Middle Trail" - a route with pecked hand holds which crosses "The Dive" portion of Buckskin Gulch, a tributary of the Paria River. A series of petroglyphs, including Bear Clan symbols, is located on both sides of the Middle Trail, in addition to a Pueblo IV period camp site with Jeddito Yellow Ware sherds.
- 42Ka1526, Catstair Canyon, has a Maasaw-like pictograph.
- 42Ka4426, the Mansard Site, includes numerous bear track symbols.
- Site 42GA3461 contains at least one petroglyph symbol with clear similarities to a clan symbol of an extinct Hopi clan pictured at the Hopi shrine of Tutuveni (Figure 3a). Hopi cultural advisors interpreted this as the symbol of the Patalatsi, a water insect, associated with the Water Clan.
- Site 42GA3274 and Site SH9109 contain several bear paw symbols that match Bear Clan symbols at Tutuveni (Figure 3b).
- Site SA9016 contains a rug or textile motif also found near the Hopi village of Awatovi that has been identified by Hopi consultants as a probable clan symbol of an extinct clan (Figure 3c).
- Site 42GA3938 features a probable Ma'saw anthropomorph.

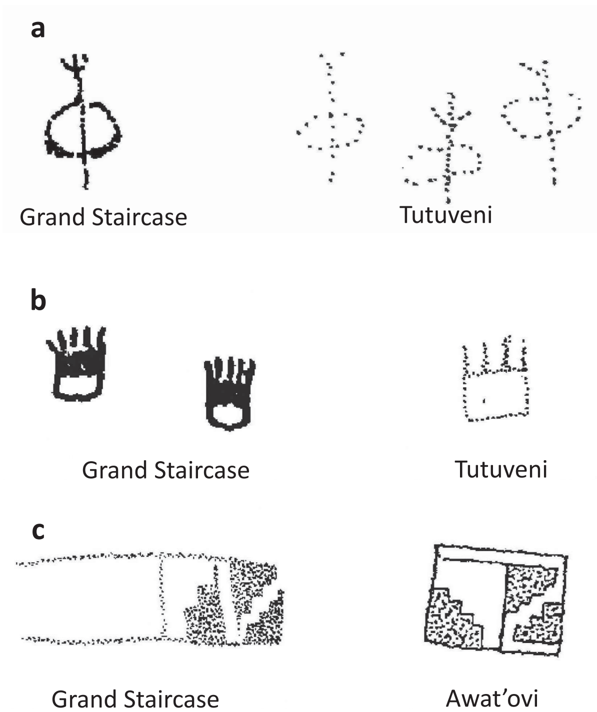

Figure 3. (a) Petroglyph elements from Panel 2 at Site 42GA3461, Escalante Canyon, Utah, and Tutuveni; (b) Petroglyph elements from Panel 3 at Site 42GA3274, 25 Mile Canyon, Utah and Site SH9109, in Piute Canyon, Utah, and Tutuveni; (c) Petroglyph elements from Site SA9016, Paiute Canyon, Utah, and Site S24-142-98, near the Hopi village of Awatovi.

- Site 42GA1876 contains a possible Sun Clan symbol.

Jeddito Yellow Ware

Pottery has been one of the most distinctive aspects of Hopi material culture since ca. A.D. 1300, when the residents of Hopi villages began making Jeddito Yellow Ware (JYW) vessels. Archaeologists have long felt confident in assigning the production of JYW to the Hopi Mesas region (e.g., Fewkes 1919), largely because the ware is so abundant at Hopi sites, an inference confirmed through compositional analysis (Bernardini 2005b; Bishop et al. 1988). This conclusion is significant, since it means that any JYW found away from the Hopi Mesas must have been obtained either directly or indirectly from Hopi potters. A number of archaeologists have identified JYW on sites in southern Utah (e.g., Baldwin 1944; Geib, Collette, and Spur 2002; Lindsay 1976; Mueller et al. 1968; Schaefer 1968; Spangler 2000), but there is some disagreement over how to explain its presence.

Some suggest that JYW in Utah reflects Hopi trade with Paiute groups, but JYW is never found in association with Paiute-Shoshoni pottery (Lindsay 1967:35), and most of the JYW is utility ware, which is not likely to be widely traded (Wormington 1955:189). Further, with very few exceptions, most JYW finds in GSENM predate A.D. 1400, likely before Paiute groups had entered the region. A more likely explanation is that JYW results from the revisitation of ancestral shrines and villages by Hopi individuals who had moved to the Hopi Mesas (McFadden 2003:21). Interpretation of small sites with JYW as temporary Hopi camps is supported by the small number of sherds they contain, the lack of structures other than an occasional fire pit, and site locations in the open on the canyon floor (Longacre 1970:137; Long 1966:65). The distribution of sites containing JYW reveals that JYW covers much of the territory between the Hopi Mesas and GSENM (Figures 4 and 5, see also Table 3). This distribution suggests trips by late prehistoric, protohistoric, and historic Hopi populations from the Hopi Mesas to GSENM, most likely for a combination of hunting, gathering resources, and revisitation of ancestral villages, shrines, springs, and eagle nests.

Historical Observations

Many explorers, missionaries, trappers, and military expeditions traveled through southern Utah and GSENM in the historic period, some of whom recorded observations about the archaeology of the area and speculated about its prehistoric occupants, and recorded statements from members of other tribes. Many of these accounts link the prehistoric population in southern Utah to the Hopi Tribe, or "Moki" (aka Shenemos, Moquis), as the Hopi were then known.

Statements by Euro-Americans

John Wesley Powell observed a number of ruins during his initial decent of the Colorado River and subsequent survey. He observed structures he identified as kivas, and commented that "the people in the Province of Tusayan… are, doubtless, of the same race as the former inhabitants of these ruins" (Powell 1875:228). The diary of Frederick Dellenbaugh, a member of Powell's sec-

Figure 4. Location of sites with Jeddito Yellow Ware pottery. See Table 3 for the key.

ond expedition, contains a number of references to archaeological sites attributed to the ancestors of the "Moki." For example, Dellenbaugh (1991:79) writes "There had been people here before any white men, for Steward found an artificial wall across and indentation if the cliff, the first work of the ancient builders we had encountered. It was mysterious at the time, with South-western ruins having then not been discovered with one or two exceptions. We ascribed this wall, however, to the ancestors of the Moki (Hopi)."

At about the same time as Powell's trip, Captain F. M. Bishop's journeys in Utah were being recorded in a series of letters published in the Utah Pantagraph newspaper. Bishop (1947:250-231) wrote, "It is a noticeable fact that these ruins are found almost the entire length of the cañon, from Greene River City to Callville. They are scattered along the valley of the Uintah, back to the foot of the mountains; abound along the valleys of the Great Salt Lake, Utah Lake, and in all the valleys leading to the great Cañon of Colorado. There is a tradition among the Shenemos, or the Moquis Indians, to the effect that their tribes once lived over this entire country, and that disease and war have finally reduced them to the little handful now living in the "Seven Cities" of northern Arizona, which seems quite probable." The "Seven Cities" referred to are identified by Powell (1875:202) as Oraibi, Shipaulovi, Mishongnovi, Shongopovi, Tewa (Hano), Walpi, and Sichomovi.

Map #	Location	Comment	Reference
1	Kaibab Plateau	Two C14 dates in mid 1600s, PII and historic Hopi ceramics at C:13:010, the Furnace Flat site	Spangler 2000:652
2	Kaiparowits Plateau	JWY sherds found on two sites: 1 bowl rim at 42KA4572 and four fragments including one mid 1300s rim from a single dipper (or small bowl) from 42KA4827	Geib, P., J. Collette, and K. Spurr 2002:278
3	Kaiparowits Plateau	Two Jeddito Black-on-yellow sherds form a single site	Fowler et al. 1959:349
4	Kaiparowits Plateau	Forty sherds of Jeddito Black-on-yellow, Jeddito Corrugated, and Homolovi Corrugated form campsites at Kane Wash, Last Chance Creek and Escalante River desert, the Escalante River, the Kaiparowits Plateau, and the mouth of Hall Creek.	Lister 1964:62
5	Fiftymile Mountain	Two Jeddito Black-on-yellow sherds	Gunnerson 1959a:349
6	Paria Canyon	Three Jeddito Corrugated sherds, from at least two jars, dating from the mid-late 1300s through the early 1400s; and four Jeddito Black-on-yellow sherds, ca. 1350-1450, probably from at lesat three different bowls. All from site 42KA5724, associated with site 42KA5723, a petroglyph site containing possible kachina masks	McFadden 2003
7	Paria Plateau	Twelve sherds of Jeddito Black-on-yellow from NA 10,154, a rockshelter	Mueller et al. 1968
8	Shivwits Plateau	Three Jeddito Blck-on-yellow sherds from A:16:14	Baldwin 1944:14
9			
10	Red Rock Plateau	Twenty sites with Jeddito and Awatobi yellow ware sherds	Lipe 1967:313
11	Rainbow Plateau	“Sherds and whole vessels of Hopi pottery	Long 1966:365
12	Glen Canyon	“Occasional fragments of Jeddito Yellow Ware and Awatobi Yellow Ware”	Adams et al. 1961:24, 55
13	Glen Canyon	Jeddito Yellow, Homolove Corrugated, and Awatobi Corrugated	Fowler et al. 1959:566
14	Glen Canyon	194 sherds of Jeddito plain, fourty-five sherds of Jeddito corrugated, seven sherds of Jeddito Black-on-yellow	Fowler et al. 1959:566
15	Glen Canyon	Small numbers of JYW sherds on surface of Grimm site, the Barren Flats group, Forked Stick Alcove, and site 42SA568 of the Ledge Ruin group	Lipe et al. 1960:6
16	Glen Canyon	Fourteen Jeddito Corrugated sherds, recovered from layer 6 and the surface of the Grimm Site (42SA637)	Lipe et al. 1960:19
17	Glen Canyon	One Jeddito Black-on-yellow ladle fragment from Barren Flats Group (42SA588, 42SA559, 42SA531, NA6518)	Lipe et al. 1960:125
18	Glen Canyon	One Sikyatki Polychrome sherd from Forked Stick Alcove (42SA413, NA6153)	Lipe et al. 1960:131
19	Glen Canyon	Thirteen JYW sherds from Ledge Ruin Group (42SA566, 42SA567, 42SA568)	Lipe et al. 1960:138
20	Escalante Desert	Three sherds of early Pueblo IV Jeddito Black-on-yellow	Fowler et al. 1959:204
21	Navajo Mountain	Three-four JYW sherds near White Mesa and at Red House	Morss 1931:15
22	Navajo Mountain	Four Jeddito Black-on-yellow sherds were found on the surface of Upper Desha Pueblo. Thirty-two sherds of Jeddito Plain recovered from excavations at Cactus Rock Pueblo (NA 7544)	Lindsay et al. 1968:182
23	Kayenta area	Twenty sites with JYW in Long House Valley between Tsegi Canyon and Black Mesa	Adams 1989:25
24	Kayenta area	JYW from Inscriptions House ruin	Adams 1989:25
25	Monument Valley	Eleven sites with JYW	Neeley and Olsen 1977:72
26	Cummings Mesa	JYW sherds, kachina-like mask pictograph at NA 7960	Ambler et al. 1964:12
27	Cummings Mesa	JYW at NA7961	Ambler et al. 1964:95
28	Hopi Buttes	Seven sherds each of Jeddito Black-on-yellow and Sikyatki Polychrome were found at three sites. “A few Jeddito Black-on-yellow and Sikyatki sherds were also found at the summit of Chimney Buttes, but this site... was probably a shrine.”	Gumerman 1988:55
29	La Sal Mountains, Utah	Awatovi and Jeddito Yellow wares from eleven sites (42GR3, 69, 75, 76, 78, 102, 122, 144, 182, and 184)	Lindsay 1976:35
30	Near Cisco, Utah	Cave/rockshelter containing “Jeddito Black-on-yellow and Jeddito Tooled”	Lindsay 1976:35

Table 3. Map key to accompany Figure 4. Note that site 27 is not shown on Figure 4.

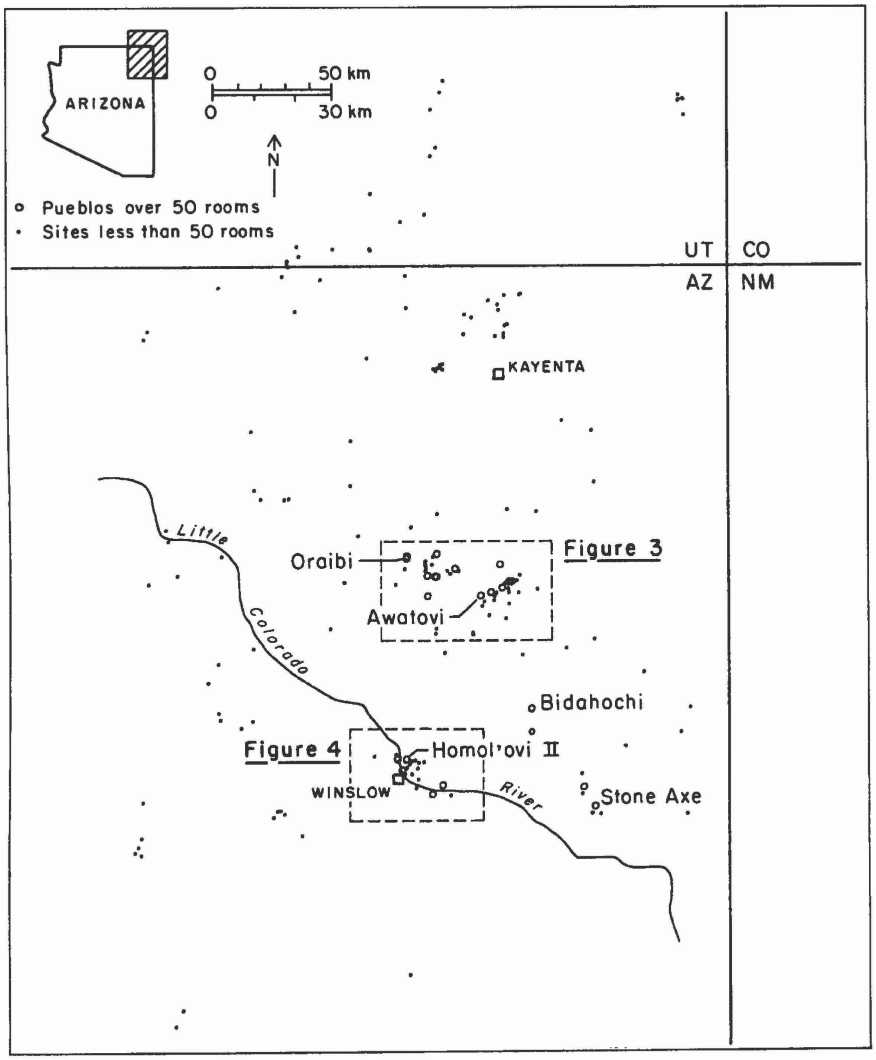

Figure 5. Distribution of JYW sites in Arizona and Utah (reproduced from Adams, Stark, and Dosh 1993: Figure 2).

Statements from Other Tribes

Edward Palmer recorded statements from members of the Paiute Tribe in the mid-1800s to the effect that "they were once slaves of the Moquis who once lived in what is now known as Utah. The Indians from the North waged war upon them and drove them all across the Colorado River, the Moquis agreeing to never cross the river" (Heizer 1954:3). Barber (1877:592) also records Ute traditions in which they "claim to be the descendants of the race which conquered the builders of these pueblos. They evidently believe that the architects were ancient Moquis, and if asked who originated these ruins will invariably answer "Moquitch"." Four Southern Paiute informants interviewed by Pendergast and Meighan (1959:139) stated that pictographs and petroglyphs in Utah were manufactured by the former inhabitants of the area, the Mokwits (equated with the Hopi), and that these people "moved away and went south into Hopi country." Both Kayser (1965:83) and Goss (1968:30) record statements by Ute informants stating that Ute people observed the muukwitsi speaking a language that the Utes could almost understand, and that these muukwitsi went south and west to become the modern Hopi.

The terms used by the historic-period Native American occupants of southern Utah also show that these groups regard the Hopi as the ancestral occupants of this territory. The Ute (including Utes, Southern Paiutes, and Chemehuevis) refer to both the prehistoric Anasazi and the modern Hopi with the same term, "muukwitsi" (Goss (1968:29-

30; Pendergast and Meighan 1959). Goss (1968:30) emphasizes that "this reference to the Hopi as the muukwitsi is not a generic application to all pueblo peoples. Other pueblo dwellers are designated by a variety of terms…The people of Taos, the northernmost Taoan pueblo, are singled out to be called "sakwakawitsitsi" or "bluebirds." It is only the Hopi that have been singled out and called "the dead one" and been equated with the prehistoric Anasazo of Yutish territory." Members of the Southern Ute tribe "all spoke familiarly and unhesitatingly of the Moquitsu (plural of Moqui) and their ruins in what is now Southern Ute country" (Kayser 1965:82).

Northern Ute informants also "unanimously referred to the Puebloid village remains in northeastern Utah as /muku=ci/ Hopi dwellings. One informant said, "There used to be lots of them up here. Sometimes we'd find pieces of their pottery, sometimes their old grinding stones which we take and use." She also said, "The /muku=ci/ went back down south a long time ago when they found there were a lot of other Indians coming in" (Smith 1974:15). Finally, Southern Paiute in the Moapa valley of northwestern Arizona and northeastern Nevada also make reference to ancestral Hopi populations. Hayden (1930:86) was informed that "the southern Paiute in the Moapa Valley have a tradition that the builders of the pueblo villages in the Valley went to Arizona and were the ancestors of the modern Hopi."

Conclusions

This overview has presented a number of lines of evidence, including petroglyphs, ceramics, clan migration traditions, and historical observations, that document the Hopi Tribe's claim of affiliation to cultural resources in GSENM. In the process, we have illustrated the ways in which different social frameworks (e.g., clans vs. culture areas) can clarify or obscure links between ancient and modern social groups. The persistence of the culture area approach in southern Utah – exemplified by the continued debate over the definition and boundaries of the "Fremont phenomenon" – has complicated research into cultural affiliation in the area. When questions are framed in terms of culture areas, research is directed at finding prehistoric "tribal" equivalents to modern Native American groups. If, however, it is recognized instead that modern tribes like Hopi are composed of heterogeneous groups with distinct histories, research may be more productively directed at tracing the histories of certain groups back to particular areas of the Southwest. In this paper, we have attempted to combine Hopi traditional knowledge with archaeological data to demonstrate the connections of a number of Hopi clans to GSENM. In light of these strong ties, the Hopi Tribe feels that it should continue to be a full participant in the development of plans to manage cultural resources on the monument.

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The Southern Utah Oral History Project: A Record of Living with the Land

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ABSTRACT

The Southern Oral History Project began in July 1998 soon after Grand Staircase-Escalante National Monument (Monument) was established and the Bureau of Land Management decided to gather oral histories documenting historical lifeways and land use information in the surrounding communities. Local citizens in the small communities in Kane and Garfield counties of southern Utah that border the Monument manifest great interest in documenting and preserving the cultural history of the area. Funding for the project came from BLM. Grand Staircase-Escalante National Monument and Utah State Historical Society staffs entered into a partnership to carry out the project with Kent Powell of the Utah State Historical Society manager for the project. The aim of the oral history project is to preserve some of the memories and culture of long-time residents of the area. Preserving cultural history through oral history collection allows communities to endure by continuing to retell their stories, building bridges between the past and present, and enabling local residents and visitors to the Monument and surrounding communities to engage in the area's unique culture.

Keywords: oral history, cultural history, collection, preservation, Grand Staircase Escalante National Monument, land use

Introduction

Oral history is defined as a primary document of historic information collected in a personal interview setting with an individual who has witnessed or participated in an historical event or series of events (Oral History Association, 2003:Introduction). The goal is to collect and preserve that individual's first hand information and make it available for future researchers.

Oral history is an individual's personal perspective and narrative account of past events, and includes spoken memories, commentaries, songs, poems, and recollections. The interview is a structured conversation or dialog between at least two individuals, an interviewer and an interviewee, about particular or significant aspects of the past.

The interviews of the Southern Utah Oral History Project (SUOHP) are conducted based on the Principles and Standards of the Oral History Association (OHA) which adheres to procedures insuring "the production and preservation of authentic, useful and reliable primary source material." (OHA, 2003:5) In general, the interview is conducted with critical inquiry in mind, and with an understanding of the subjective character of the oral history method. Initial memory questions relax the interviewee and help to set the mind and focus on the interview subject. From there, the interviewer's questions and the interviewee's responses often construct each other.

The focus of the Southern Utah Oral History Project is to preserve and communicate culture, provide information and transcripts to the public and build partnerships with federal, state and local communities. Through oral history collection, information about people and land use during much of the twentieth century is preserved. Collection, processing and distribution of oral histories encourage communities to begin or continue to enhance their oral history collections, to tell their origin story, and provide a medium for new generations to connect to the past.

By highlighting the culture of long time residents of the southern Utah area, a growing number of locals and visitors to the region are able to connect to and understand the exceptional culture and lifestyle of the area. The culture and lifestyle of the past is also a record of hard work, sacrifice and faith which is reflected in thought and action by the people who live there today.

In this particular project the interviewees are long time residents of communities surrounding the region now known as Grand Staircase-Escalante National Monument. The project area covers approximately 9166 square miles (an average 1.2 persons per square mile) with 1.96 million acres comprising Grand Staircase Escalante National Monument within Garfield and Kane counties in southeastern Utah.

Interviewees lived and worked in the following geographical regions: Aquarius Plateau, Sevier Plateau, Paunsaugunt Plateau, Kaiparowits Plateau, Kaibab Plateau, Pink Cliffs, Escalante Mountains, Circle Cliffs, and the Escalante Desert.

The communities of the Project are Boulder, Escalante, Henrieville, Cannonville, Tropic, Bryce, Antimony, Panguitch, Hatch, Alton, Glendale, Orderville, Mt. Carmel, Kanab, and Big Water. (approximate total population of all towns listed 8,900.)

Peripheral areas, communities and ghost towns included in the Project are Pipe Spring, Moccasin, Fredonia, The Arizona Strip, Johnson Canyon, Paria Town, Wooden Shoe, Yellow Creek, Loseesville, Berryville, Adairville, and Widstoe.

In addition to recollections, perspectives on past events, and a discussion of life ways, collecting first hand information on land use and adaptation to landscape was of particular interest because of the rugged and isolated nature of the region. The nature of the region combined with human ingenuity and faith defined success.

Methodology

Interviewing and Editing Process

Interviewees were initially chosen through word of mouth recommendations, calls by telephone, or personal introductions. Ranchers, farmers, herders, miners, hunters, trappers, loggers, and their families who have traditionally used the land are identified. Potential interviewees are prioritized by community with final selection based on knowledge of the subject area, age, and the database collected to date.

The interviews are conducted at a site agreeable to the interviewees. Each interview is conducted for approximately one hour using state of the art equipment provided by the Utah State Historical Society. Video and digital video recordings were also made in lieu or concurrently with the audio recordings.

During the early stages of the Project a Sony cassette recorder was used. From 2001 to the present a Sony Walkman Digital Audio Tape-Corder (DAT) has been used. A cassette copy is made of the DAT recording. The cassette tape is used with a Sony Stereo Playback transcription machine and transcribed into a Microsoft Word document. Each oral history is transcribed based on an established transcription format for the project. The time to transcribe a one hour interview takes an average of five hours.

Once the oral history is transcribed an editing period begins. The document receives a primary edit by the transcriber. A copy is then printed and sent to the interviewee allowing them to assess the transcribed interview for errors, deletions, or to make clarifying additions. Along with a copy of the transcription for edit, the interviewee receives a letter of thanks for their participation in the project, instructions for the edit process, a copy of the photograph that will be included in the final copy, and a "Deed of Gift" form (Appendix A) which is signed and dated if the transcription is accepted. In addition, the cassette tape copy of the oral history is usually sent along to assist in the editing process and then for the interviewee to keep. Handwritten edits are made directly to the draft transcription. The interviewee edit process may take from one week to several years to complete and be returned. After returning the transcription to the SUOHP, editing changes are incorporated, providing the integrity and tenor of the interview is maintained. The transcription is then processed into a final version, bound by volunteers at the Utah State Historical Society and distributed to repositories throughout the project region, Grand Staircase-Escalante National Monument and Utah State Historical Society Library.

Storage of Collection

Five copies of each transcription are made. Two copies, one bound and one unbound, are given to Utah State History and to Grand Staircase Escalante National Monument to be cataloged and stored in their library or collection. The unbound copies may be used to make additional copies as requested by patrons. Bound copies are cataloged and stored at Utah State Historical Society's Research Library located at 300 Rio Grande, Salt Lake City, UT 84101 and at the Main Office of Grand Staircase-Escalante National Monument, 190 E. Center St., Kanab, Utah. As stated earlier, one bound copy is also given to the interviewee. All transcriptions are in the process of being uploaded to the Utah State History website: http://history.utah.gov and the Bureau of Land Management website: http://www.ut.blm.gov/monument/cultural-index.php

The audio collection is cataloged and stored to the proper standards at the library of the Utah State Historical Society's Utah History Research Center. A list of the collection may be viewed on the website: http://history.utah.gov. All audio and video recordings created during the Project are public property and available, as needed. Some of the recordings have been converted to WAVE files and then burned on CDs.

Equipment Used

- Sony© Walkman Digital Audio Tape-Corder (DAT) recorder
- PDP-95 digital tape
- Audio-Technica© microphone with base
- Omni Directional mini microphone with clothing clip
- Mini DVC recorder, XL1 camera
- Sony© cassette recorder
- Maxell UR-60 minutes normal cassette tapes

Results

- 234 interviews recorded which include 15 follow-up interviews of selected subjects. See Appendix B
- 28 video tape recordings. See Appendix C
- 51 Supplemental Material Folders, including personal histories, diaries, legal papers, songs, town histories, manuscripts, ledgers, and newspaper articles. See Appendix D

Applications

Presentations of the Southern Utah Oral History Project

- "Learning from the Land Symposium," Southern Utah University, Cedar City, Utah, June, 2006.
- "Grand Staircase-Escalante National Monument Science Forum," Grand Opening; Social Science paper presentation, Escalante Interagency Visitor Center, Escalante, Utah, June, 2005.
- Grand Staircase-Escalante National Monument; Summer Lecture Series, a free audio-visual presentation for the public, GSENM Visitor Center, Cannonville, September 2004 and September 2006.

Publications and projects based on materials from the Southern Utah Oral History Project

- Higher Ground Radio Documentary Project; A youth radio series based on a collection of interviews done by the Southern Utah Oral History Project (1998-2002). In a cooperative effort with the Utah Division of State History and City Academy Charter School directed by Suzi Montgomery, the Documentary Project is about taking a youth radio program, adding the voice of an old Southern Utah rancher and mixing it with a teenager's perspective. The Documentary Project aired live on Loud and Clear, Salt Lake City's only all-youth radio program. The process explores our community, local radio stations and ultimately learning the art of documentary storytelling while gaining a unique perspective on Utah's ranching history.
- Higher Ground Radio Documentary Project website: http://www.highergroundlearning.com/-HGLv2.0/programs/radio1.html
- Deseret Morning News, "Living with the Land; Southern Utah Oral History Project Provides a Peek at the Past," April 21, 2006, reported by Carma Wadley.

- Garfield Insider, "Beauty: Our Land… Our People," feature article series based on excerpts from oral histories, November 10, November 18, November 25, 2005, written by Marsha Holland.
- Decade of Discovery: Grand Staircase-Escalante National Monument, 10th Anniversary Report 1996-2006, "Oral Histories."
- Human Geography: Interpretive exhibit on regional pioneer history located at the Grand Staircase-Escalante National Monument Visitor Center, 10 Center Street, Cannonville, Utah.

Other projects

- Everett Ruess/Escalante Canyons Arts Festival: Production of CD in which a compilation of excerpts from oral histories by local residents who recall the travels of Artist/Adventurer Everett Ruess in the 30s, presented to Ruess Family and made available for wider use promoting the cultural history and goals of the Festival.
- Escalante Heritage Festival: Video and audio recordings of Heritage Festival's music, cowboy poetry, and plays which depict historic events from the area to be archived at the new Heritage Center.
- Escalante Heritage Center: Interpretive presentation of "The Cream Cellar Route" based on photos and history of the Escalante Region.
- Ebenezer Bryce Heritage Festival (Tropic, Utah): Poster presentation of the Southern Utah Oral History Project and demonstration of "How to Conduct an Oral History Interview."

Discussion

It was a love of the life ways woven with a deep faith in self and God that kept people persevering with the uncertainties of living on the land. Cowboying, herding, farming, mining, road building, trapping, hunting, and logging on the land kept men away from their homes and family for weeks or months at a time. Women, too, relied on their knowledge of what the land could provide to heal and grow their families. They used their wits to deal with isolation, capitalizing on the tight knit communities to preserve food and produce clothing, bedding, soap, candles for light, and other necessities to survive. Socializing revolved around Sunday church meetings, picnics, and music with weekly dances and singing. Entire families would travel hours by buckboard or horseback to attend these gatherings.

The communities of the Project area have remained relatively isolated since settlement with populations varying little since the turn of the twentieth century. Minor fluctuations occurred in response to world events such as the World Wars, 1918 flu epidemic, mineral booms and advancement of transportation and technology which affected not only the population, but community economies. The patchy distribution of populations throughout the project area reveals not only distinctive habits, dialects and methods unique to that area, but also a common fabric distinctive to a broader world (Applied Biomathematics: Introduction).

Truly, there is no taming such a rugged and isolated landscape and the oral histories tell this story well. Flash flooding would instantly wash away a season's worth of labor, the land, and the means of irrigation. Drought would leave grazing land so poor and stock too weak to be trailed that cattle would simply die on the range. And there were times when huge snowfalls would leave a young herder trapped with three thousand head of angora goats on the range for a month using only his innovation and skill to survive the snowy seclusion. Fence lines have been strung over boulders, along cliffs, and through washes, created out of whatever raw materials could be found nearby. The building of grist mills, waterwheels for power production, mobile lumber mills, and coal mine operations were able to provide the basic necessities to settle and live. Cash was rarely exchanged. Dictated by what the land could offer the successes of the thin economies which developed were enabled only by innovation, and the modified integration of new technologies and transportation methods.

Continuing to improve access to the collection via local repositories, libraries and online is essential to the communication of culture which the Project aims to preserve. The communication of culture through oral history enables communities to retell its story not only as individuals but as a whole, adding meaning to the struggles for life and enduring settlement (Miggins, 1992:1). The many visitors, eager to intimately experience the intense beauty and remote nature of the region, engage more thoroughly in the unique culture that defines the communities bordering on the Monument, both directly and indirectly, through expanded access to the collection. Repositories have been created or are being used to house copies of the transcriptions so that local residents, visitors and academics may access and research the collection. To date the following regional locations retain all or part of the Southern Utah Oral History Collection: Boulder Town Library; Escalante Town Library; Grand Staircase-Escalante National Monument Visitor Center, Cannonville; Kanab Public Library.

Building partnerships has been an essential aspect of the Southern Utah Oral History Project and is key to the success and longevity of the Project. Through the collection of oral histories of local residents, cultural and heritage groups such as Sons of the Utah Pioneers and the Escalante Heritage Center can partner with the Project to further their goals of preservation, collection and interpretation of local history. In addition, collaboration with Utah State History and the Bureau of Land Management/Grand Staircase-Escalante National Monument has strengthened perspectives on the cultural and heritage resources available in and around the Monument (GSENM, 2006:20).

Conclusion

Collecting oral histories has proven to be an exceptional medium in which to preserve and communicate the culture of the region. Since the oral histories have been collected, transcribed, edited and produced, many of the interview subjects have passed away, but their story has been preserved. It is through these personal accounts certain patterns, themes, methods and habits emerge that reflect the necessities required to live with the land. Whether through reading a transcription or listening to a recording, people have an opportunity to connect, through language and a record of actions, with a fading culture.

Acknowledgements

Major funding for the Southern Utah Oral History Project came from the Bureau of Land Management. Utah State History and Utah Humanities Council have provided additional funding.

Dr. Kent Powell, Field Service Coordinator for Utah State History Research Library, Salt Lake City, Utah, and his staff provided important expertise and resources to enable the Project to produce and protect the collection of the Southern Utah Oral History Project.

Acknowledgement must also be given the local residents and community leaders whose trust and stories were invested with the Southern Utah Oral History Project to preserve history for future generations.

Past and Present Staff

1998-2001:
Three paid interviewers, three community volunteer interviewers, Utah State History volunteers and paid staff, contracted transcribers.

2002 to present:
One paid interviewer and transcriber, Utah State History volunteers and paid staff.

Trained and Paid Interviewers

- Jay Haymond: SUOHP 1998-2000; received his Bachelor's and Master's Degree from Brigham Young University and Ph.D. from the University of Utah. His dissertation was on the History of the Manti-LaSal National Forest. He taught History at Dixie College before earning his Ph.D. He served as head of the library at the Utah State Historical Society and oversaw the Historic Preservation Office. While in charge of the library, he established the Oral History Program. Jay was instrumental in establishing Utah's Place Names Program and establishing the Historic Trail's Consortium.
- Suzi Montgomery: SUOHP 1998-2001; currently Executive Director of Higher Ground Learning - a creative learning center in down-

town Artspace that specializes in innovative and experiential curricula, including Radio Documentary. This program develops academic skills in students such as writing, editing, researching, interpersonal communication, organization and prioritizing, gets them involved in their community and imparts the importance of listening and sharing with others.

- Marsha Holland: SUOHP 1999-present; Bachelor's Degree in History from the University of California, Davis (1999). Marsha has worked on the Southern Utah Oral History Project since 1999 as an interviewer. She began as the lead historian for the Project in 2001, interviewing subjects, transcribing interviews, and securing additional funding sources. Marsha is instrumental in marketing the collection as a resource to communities bordering Grand Staircase-Escalante National Monument.

Community Volunteer Interviewers

- Margaret Shakespeare: Resident of Tropic, Utah, trained volunteer interviewer.
- Karin Barker, Resident of Henrieville, Utah, trained volunteer interviewer.
- Gael Hill: Resident of Escalante, Utah, volunteer interviewer.

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Appendix A: Deed of Gift

UTAH STATE HISTORICAL SOCIETY
ORAL HISTORY PROGRAM

INTERVIEW AGREEMENT AND DEED OF GIFT

I hereby give to the Utah State Historical Society the tapes and transcriptions of the interview/interviews recorded on ____________________ and grant the Utah State Historical Society the right to make the tapes and transcriptions available to the public for such educational and research purposes that are in accordance with the policies and procedures of the Society's Utah History Information Center.

NARRATOR ____________________

ADDRESS ____________________
____

SIGNATURE ____________________

DATE ____________________

INTERVIEWER ____________________

ADDRESS ____________________
____

SIGNATURE ____________________

DATE ____________________

Appendix B: List of Oral Histories Completed

1. Adair, Ella Wilson
2. Alvey, Arnold
3. Alvey, Iona Peterson
4. Alvey, Karen Jepson
5. Alvey, Ladell
6. Alvey, Melvin
7. Alvey, Rella Shakespeare
8. Anderson, Ann
9. Barney, Othello and Roxie L.
10. Barton, Berdell
11. Bee, Roland
12. Behunin, Veda
13. Brems, Robert
14. Brinkerhoff, Ora
15. Brown, Worth
16. Brueck, Vaydes Johnson and Supernaw Enid Johnson
17. Bushnell, Iris Smith (2)
18. Campbell, Vane
19. Carroll, Norman Glendale
20. Carroll, Velma Brinkerhoff
21. Chatterly Shoenfeld Mangum, Leola
22. Chamberlain, Lavell
23. Chynoweth, Jack (4)
24. Chynoweth, Mae
25. Chynoweth, Mary Etta
26. Clark, Lester
27. Clark, Sheldon
28. Cottam, Doyle
29. Cox, Twila Campbell
30. Cram, Norman
31. Crawford, Afton (Aunt Dee Riding)
32. Crofts, Bessie
33. Crofts, Lincoln C.
34. Crofts, Lucy
35. Crofts, Rex
36. Davis, Larry

37. Davis, Melda
38. Demile, John
39. Demile, Alan
40. Esplin, Verene
41. Evans, Ardis J.
42. Fearon, Sue
43. Feltner, Glenda Twitchell
44. Feltner, Hobart
45. Francisco, Charlie (2)
46. Francisco, Evadean (2)
47. Fullmer, Mona
48. Gardner, Ray
49. Glazier, Claud M.
50. Griffin, DeLane
51. Grose, Charles Kenneth and Eva
52. Haas, Helma
53. Hall, Heber
54. Hall, LaFair
55. Hamblin, Ina
56. Hansen, Alta Mae
57. Hansen, Paul
58. Haws, Idona
59. Heaton, Delila B.
60. Heaton, Florence
61. Heaton, Fred
62. Heaton, Grant
63. Heaton, Ramona
64. Heaton, Vard
65. Henderson Sisters – Schafer/Twitchell
66. Heybourne, Maryllis
67. Hill, Ian Thomas
68. Isaacson, Edith
69. Jackson, Norman
70. Jackson, Val
71. Jake, Rachel
72. Jake, Verdell E.
73. Jepsen, Fey
74. Jepsen, Neal (2)
75. Johnson, Adeline
76. Johnson, Calvin
77. Johnson, Grant S.
78. Johnson, Golden and Roxanne
79. Johnson, Joseph Smith
80. Johnson, Lanard
81. Johnson, Lowell
82. Johnson, Lynn
83. Johnson, Nan
84. Johnson, Parley
85. Johnson, Zelma
86. Jolley, Dale
87. Jolley, Rachel
88. Joseph, Elizabeth
89. Judd, Cleone
90. Judd, LeRoy
91. Judd, Myrtle
92. Judd, Myrtle w/Oscar
93. Judd, OraNell
94. Judd, Vaughn A.
95. Latham, Darryl
96. Leach, Trevor
97. Leach, Trevor (follow-up)
98. LeFevre, Dell
99. LeFevre, Gladys
100. LeFevre, Lamar W.
101. LeFevre, Mac (2) + Salt Gulch Video
102. Liston, Jan
103. Liston, Louise Nixon
104. Liston, Neal
105. Liston, Stan
106. Littlefield, Sarah Ott
107. Luker, Monte
108. Loya/Gubler/ Opal Spencer/ Edith Issaacson
109. Lyman, Ivan
110. Lyman, Kirk
111. Lyman, Truman (2)
112. Lyman, Lincoln
113. Mace, Evelyn Young
114. Mace, Ronald G.
115. Mackelprang, Bessie (3)
116. Mangum, Don (2)
117. Mangum, Louise
118. McAllister, Laura
119. McFarland, Dorothy
120. McInelly, Twila
121. Mecham, Clint
122. Mecham, Lowell
123. Mecham, Marian
124. Mecham, Malen (2)
125. Mecham, Stan (2)
126. Meeks, Vard
127. Moore, Lula Chynoweth
128. Moore, Ruby (3)
129. Morgan, Corris Swapp
130. Ormund, Burns
131. Ott, Bob and Mira
132. Ott, Wallace
133. Othello, Barney
134. Ott, Rella and Janet, Helma Haas
135. Palmer, Orval

136. Parsons, Alice Heaton
137. Pollock, Afton
138. Pollock, Larvin
139. Pollock, Lonnie
140. Porter, Ben
141. Porter, Velma (Boulter)
142. Poulson, Neta
143. Richards, Nyle
144. Richards, Thomas
145. Riding, Bob
146. Rider, Delmer and Georgia
147. Riggs, Don
148. Riggs Gladys
149. Riggs, Virgil
150. Robinson, Darl
151. Robinson, Wayne
152. Rogers, Mavis
153. Rose, Irving
154. Rose, Viola
155. Roundy, Elaine
156. Roundy, Jerry (2)
157. Roundy, Sheree
158. Schow, Corine
159. Shafer, Rhoda Henderson
160. Shakespear, Dixie (2)
161. Shakespear, June
162. Shakespear, Obie
163. Shingoitewa, Sam
164. Shoenfeld, Leona Mangum Chatterly
165. Smith, James Welker (Jim?)
166. Smith, Jim
167. Smith, Thayne
168. Smith, Thayne and Jo
169. Sorenson, Elbern
170. Spencer, Addie
171. Spencer, Dale O.
172. Stock, Arma (2)
173. Swapp, Corris
174. Supernaw, Enid
175. Syrett, Carl
176. Syrett, Jean Bybee
177. Tait, Rena Chamberlain
178. Tornbom, Bill
179. Twitchell, Desmond
180. Twitchell, Gretha Henderson
181. Wintch, Betty
182. Wintch, Dean/ Joe Hughes
183. Wintch, Kent
184. Young, Charlotte
185. Young, Clifton
186. Young, Royce
187. Anderson, Ann Mangum
188. Brooksby, Lyle O.
189. Chynoweth, Nellie Smith
190. Clark, Wilford
191. Condie, Vernon
192. Hall, Horace
193. Heaton, Hester
194. Mary Henrie (1)
195. Judd, Oscar
196. Lamb, Lorene Crawford
197. Ramsay, Clair
198. Smith, Bart
199. Spencer, Vernon
200. Williams, Dwight (Place Names)
201. Willis, Myron
202. Willis, Sears
203. Williams, Dwight
204. Thompson, George
205. Mecham, Clint (2)
206. Feltner, Hobart, CCC Henrieville site
207. Griffin, Clem
208. Henrie, Mary (2)
209. Miller, Sandra Lyman
210. Marshall Talbot, Eva
211. Twitchell, Virgil
212. Perme Twitchell, Levena
213. Spencer, Vernon
214. Crofts, Everetta Heaton
215. Bryce Canyon Park: Mission 66
216. Fotheringham, Vera
217. Houston, Dorothy
218. Schow, James (Cal) & Martha
219. Ott, Louise
220. Dodds, Rebecca Workman
221. Mayo, Warren
222. Penny, Rob
223. Asay, Aaron
224. Descendents of Ebenezer Bryce
225. Bryce, Ebenezer
226. Black, Dora
227. Losee, Dan
228. Davis, John Henry
229. Church, Afton Heaps
230. Miller, Howard
231. Shakespeare, Kelly
232. Gomez, Allen

*Appendix C: Video List**

Digital and VHS
Videographer- Suzi Montgomery
Taped from December 2000- June 2001

1. Velma Brinkerhoff Carroll
2. Lavell Chamberlain
3. Rena Tait Chamberlain **
4. Elbern Sorenson **
5. Lanard Johnson **
6. Bessie Mackelprang **
7. Golden Johnson, Roxanne Chynoweth Johnson and Lula Chynoweth Moore
8. EvaDean Francisco
9. Ian Hill
10. Clayton Carter
11. Arnold Alvey
12. Burns Ormond
13. Alice Alvey
14. Truman Lyman
15. Iona Peterson Alvey
16. Charlotte Heaton Young
17. Nabbie and Claude Glazier
18. Women of the West- Group interview/ Bryce area
19. Charlie Francisco, Don Mangum
20. Twilla McInelly
21. Louise Liston
22. Stan and Jan Liston
23. Jan Liston
24. Otello and Roxy Barney
25. Delmer and Georgia Rider
26. Lavina and Vard Meeks
27. Nan Johnson
28. Marvin Alvey

*Appendix D: Supplemental Material Folders****

1. "Songs Mother Sang" manuscript. Collection of poems, songs, and thoughts associated with the Charlotte Heaton Young.
2. Hall, Heber H. Abstract of thesis and dissertation, other writings
3. "The Life Story of Joseph S. Johnson and Agnes Ford Johnson"
4. Typescript, 82 leaves
5. "Growing up at Moccasin" by Fred E. Heaton
6. Hogan, Goudy. Autobiography from Utah Historic Records Survey Federal Writers' Projects WPA., Mabel Jarvis, St. George (Utah), 21 leaves
7. "History of Jedediah Grant Adair" by Jedediah Grant Adair, 10 December 1934
8. "Beloved Kanab Women Dies [Josephine Hogan Adair]" from Kane County Standard Vol. 3 typescript
9. "Life History of Mary Josephine Hogan Adair" by Miriam Bergetta Adair Covington, typescript
10. "An Autobiography" by Ruhanna Udair 14 January 1889, handwritten photocopy
11. "William Wallace Adair" told to Wilma Adair, June 1939, typescript photocopy
12. "History of Emeline Baldium," handwritten photocopy
13. "History of Eliza Estella Adair Watts" and "History of Miria Adair Watts Bulkley" typescript.
14. "George Washington Adair" as told to William Wallace Adair to Wilma Adair, April 1940.
15. "Diary-Joseph Smith Johnson" (1936) typescript
16. "Diary-1936 Joseph Smith Johnson, Jr." typescript
17. Agnes Ford Johnson oral history interview by Kent Johnson, 29 November 1986, Kanab (Utah)
18. Esther Ford history prepared by children, 1936. 68 leaves
19. "Among My Memories: A Life History and Stories of John Henry Davis, Frontier Cowboy, Missionary-Polygamist, A Good Husband & Father A Friend to the Indians, Rancher & Civic Leader" by Afton Pollock

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* Videos are stored at the Utah State Historical Society and are available upon request to view or copy. List compiled by Marsha Holland, Historian, Southern Utah Oral History Project, Tropic, Utah
** Indicates those videos reviewed by scene.
*** Collection stored at the Utah State Historical Society Research Library.

20. Living history interviews, Vol. 1 1992, Kanab High School. 44 interviews

21. "A Life History and Stories of Sam & Emily Pollock" compiled by Afton Pollock (n.d.) 107 pages

22. Chamberlian papers: family directory and activity book

23. Virgil Riggs history by Virgil Riggs, (8 November 1999), 5 leaves

24. "Adventures with Wild Cattle" by Quinn Griffin in *Western Horseman* (July 1990)

25. Esplin, Lucy Chamberlain. Autobiography, "The Story of My Life"

26. Esplin, Henry Cox. "A few experiences in the life of Henry Cox Esplin as related by family members," n. d.

27. Moccasin and Her People" compiled by Jennie H. Brown and Nora M. Heaton, n. d.

28. Griffins video interview by Suzi Montgomery, Fifty-mile Mountain, 15 January 1999

29. Robinson, Wayne. Grazing rights: Legal papers

30. Robinson, Wayne. Grazing rights: correspondence

31. Robinson, Wayne. Grazing rights: An Invitation for Participation in Western Heritage Foundation.

32. Robinson, Wayne. Grazing rights: "Romance of a Church Farmhouse or A History of Johnson, Kane County, Utah, by Adonis Finlay Robinson, n.d.

33. Robinson, Wayne. Grazing rights: "The James R. and Janet M. J. Ott Family" compiled by J. Bevan Ott, August 1996

34. Robinson, Wayne. Grazing rights: Grand Staircase-Escalante National Monument Presidential Proclamation, Draft Resolution 4 prepared by mayors and city councils of Alton, Antimony, Big Water, Hatch, Henrieville, Kanab, Panguitch, Tropic (Utah)

35. Robinson, Wayne. Grazing rights: Miscellaneous histories

36. "History of Tropic" manuscript, n.d.

37. "The Village of Tropic" manuscript, n.d.

38. "Historical Events of Tropic Town," n.d.

39. "Autobiography of Andrew Janus Hansen," 1852-1932, 1969

40. "Orderville: Heart of the United Order," n.d.

41. "It Happened Around Here," compiled by the Bryce Valley High School Students, 1973

42. "History of Orderville," n.d.

43. "70 Years of 'Valley Highs' Reunion Yearbook," 1996

44. "Salt Gulch Boy: His Horses, and his Dogs, 1922-1936," pt. 1 [life of Heber H. Hall]

45. "'About Me' Life Sketches of the William Wesley Pollock Family," compiled by Afton Pollock, n.d.

46. "A Life History and Stories of Sam & Emily Pollock," n.d.

47. Pahreah Co-op Store ledger, ca. 1890s [photocopy]

48. *The Cope Courier*, v. 5, no. 1, August 1975

49. "The Section," by Amy Carroll Stark

Formative Period Settlement Patterning in the Northern Grand Staircase-Escalante National Monument

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ABSTRACT

The Formative Period (AD 1-1300) in Grand Staircase-Escalante National Monument (GSENM) is particularly characterized by agriculture, substantial dwellings, long-term storage facilities, pottery production, and is considered a period when mobile hunters and gatherers became more sedentary and socially complex. Archaeologically, two separate cultures (Fremont and Anasazi) are recognized on GSENM. Within the Monument, Fremont material culture extends from the Escalante drainage basin to the Kaiparowits Plateau and Pink Cliffs, and represents “a long-lived local adaptation that began in the Archaic Period and continued as an identifiable entity until contact with the Anasazi during Pueblo II times” (McFadden 2000:1). Early survey and research within GSENM resulted in a model for Formative Period settlement patterning which reflects “generally” defined site types consisting of upland slab-lined pithouses with storage facilities and limited activity lowland sites, suggestive of varying subsistence strategies (McFadden 2000). This apparent patterning led to a Formative Period settlement model suggesting that the Fremont practiced a pattern of “seasonal mobility,” with warm months spent living in camps or brush shelters while farming in the lowland canyons, while fall and winter periods were spent in the uplands, where pinyon, firewood, and big game were available.

Between 1999 and 2004, the BYU Field School of Archaeology carried out an excavation and survey project designed to test the proposed settlement model. Sixteen sites were chosen for methodical testing and/or excavation, while large sections within GSENM, representing areas known to have high site potential (Baker et al., 2001), were selected for intensive survey. 582 sites, of which 93 had been previously recorded, were identified during these inventories. The information obtained from these sites, in combination with the data collected from the 16 site excavations, has greatly broadened our understanding of Formative settlement strategies within GSENM.

Keywords: archaeology, formative, fremont, settlement

Dating Aboriginal Rock Art by XRF Chemical Analysis

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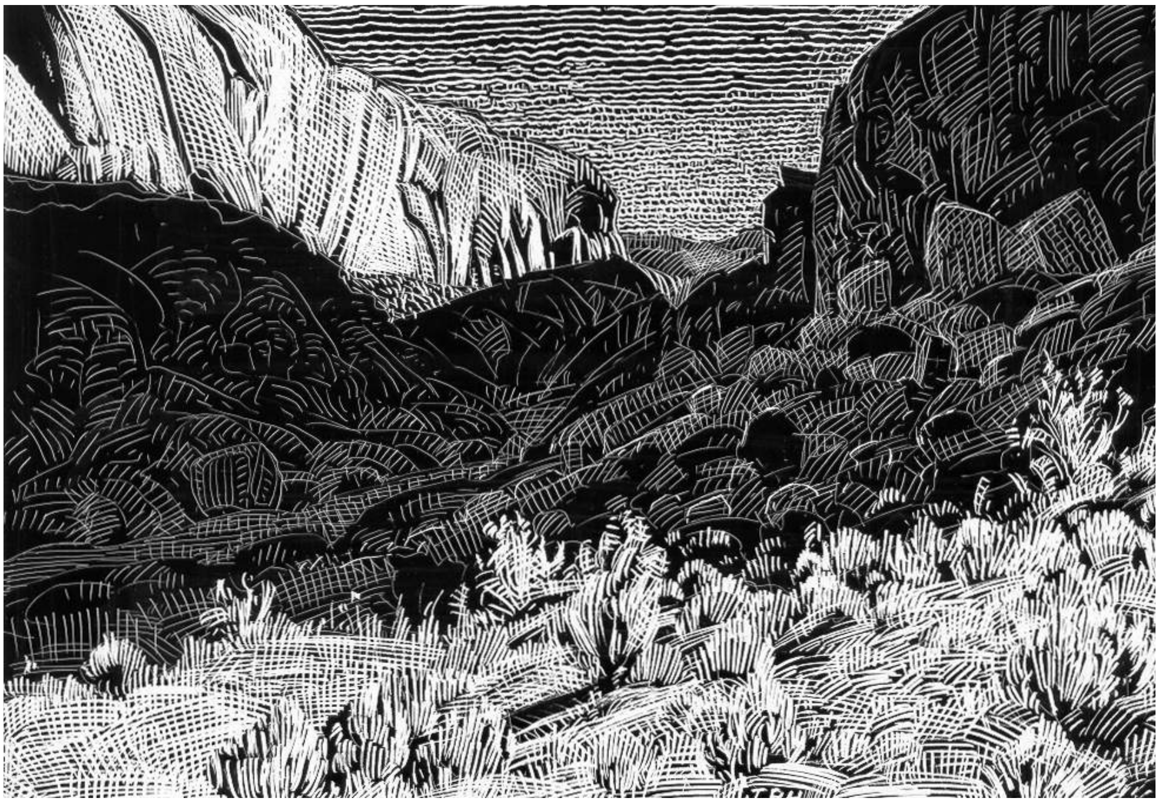
ABSTRACT

Desert varnish (DV) is a natural dark coating that slowly accumulates on rock surfaces in arid environments. Pecking away DV surfaces by ancient artists created the images that are commonly called petroglyphs. Subsequent repatination of the rock surfaces with DV suggests a method for dating: (1) measure the x-ray fluorescence (XRF) spectra of the DV-covered glyph and the surface of a separate piece of bulk rock, and (2) subtract the bulk spectrum from the glyph spectrum. With corrections for self-absorption in the DV layer, the chemical composition of the glyph DV may be determined. These results were compared to a calibration series based upon dated rock surfaces from alluvial fans, Pleistocene lake shores and basalt flows. The ultimate accuracy depends upon these dated surfaces and is approximately ± 30%, improving as the database grows. There was good age agreement from petroglyphs at archaeology sites dated by other methods. The portable XRF caused no damage to the petroglyphs.

Keywords: desert varnish, petroglyphs, x-ray fluorescence

Social Sciences



"It's not what you find...it's what you find out."

– David Hurst-Thomas –

Grand Staircase-Escalante National Monument Front Country Visitors' Characteristics, Monument Management and Community Services Impressions, and Expenditures in the Monument Area

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ABSTRACT

This paper presents data collected from a study conducted during the 2004 visitation season on front country visitors to the Grand Staircase-Escalante National Monument (GSENM). Part of the study's purpose was to provide baseline information on visitors' characteristics, satisfaction with GSENM management efforts, impression of nearby communities' visitor services, and visitor expenditures in those communities as well as economic impacts to Kane and Garfield Counties from those expenditures. Visitors to the GSENM come from throughout the United States and the world. They tend to appreciate GSENM management efforts but would like to see improvements in areas such as signage and information dissemination. They were also pleased with visitor services in communities in the Monument area but would value some improvements such as a diversity of dining establishments. In the GSENM area, visitors from Utah spent an average of $74 per person on their trip compared to $200 for visitors from other states and $274 for international visitors.

Keywords: front country visitors, visitor characteristics, social science survey research, outdoor recreation, recreation resource management, importance-performance analysis, IMPLAN

Introduction

The purpose of this project was to gather data from front country visitors to the Grand Staircase-Escalante National Monument (GSENM). The study was conducted by research scientists and students affiliated with the Institute for Outdoor Recreation and Tourism (IORT) at Utah State University. This study was funded by the Grand Staircase-Escalante National Monument, Bureau of Land Management (BLM). The main objective of this study was to provide baseline data concerning front country recreation uses and the interaction between visitor uses and other Monument values.

The Monument was designated to protect nearly 1.9 million acres of southern Utah in a "primitive, frontier state" and to provide outstanding opportunities for scientific research and education (U.S.D.I. Bureau of Land Management, 1999). To meet these goals, it is critical to protect the natural conditions of the Monument. At the same time, however, traditional uses are acceptable as long as they do not conflict with the primary purposes of the Monument. Recreation is one of the most pervasive of these traditional uses.

Visitor intercept surveys were administered at developed sites in the Front Country zone and at key dispersed use areas in both the Front Country and Passage zones of the Monument. Three slightly different versions of intercept surveys and one mail survey were developed and administered during 2004. The surveys were designed with five goals in mind:

1. Collect baseline data of visitor characteristics and use patterns for the purpose of long-term monitoring of recreation use trends.
2. Collect visitor expectation and satisfaction data useful for long term monitoring to help BLM managers understand visitor interests and preferences, and the reasons visitors do what they do.
3. Collect data on visitor images of the Monument and knowledge of scientific research results to provide baseline data for long term evaluation of informational and educational messages at visitor centers and waysides, and through community education programs.
4. Collect data on the relationship between tourism, visitor and hospitality services, and local community development.
5. Identify Monument site use levels using GIS maps and compare use with management zones.

The purpose of the following paper is to report research findings on certain visitors' characteristics, satisfaction with GSENM management efforts, impression of nearby communities' visitor services, and visitor expenditures in those communities. The complete report addressing all research objectives, *A Front Country Visitor Study for Grand Staircase-Escalante National Monument*, can be accessed at http://extension.usu.edu/iort/html/professional/april2006.

Study Site

On September 18, 1996, President Clinton exercised his presidential right granted through the Antiquities Act of 1906 and designated nearly 1.9 million acres in southern Utah as the Grand Staircase-Escalante National Monument (GSENM). The GSENM is the first national monument to be administered and managed by the Bureau of Land Management (BLM) and became the first national monument in the BLM's new National Landscape Conservation System. The GSENM contains many outstanding natural features including sandstone canyons, arches, desert terrain, and riparian areas on the Colorado Plateau. GSENM is very remote; it was the last place in the continental United States to be mapped (U.S.D.I. Bureau of Land Management, 1999). The Monument is surrounded by a number of other federally managed, specially protected lands including: Glen Canyon National Recreation Area to the southeast, Capitol Reef National Park to the northeast, and Bryce Canyon National Park to the northwest, all units within the National Park System; the Dixie National Forest to the north and west, and the Paria Canyon-Vermilion Cliffs Wilderness Area on the Utah-Arizona state line, managed by the BLM. Other major visitor attractions near GSENM are Grand Canyon National Park, Zion National Park, and Lake Powell within the Glen Canyon National Recreation area.

GSENM itself is made up of three distinct physiographic regions: the Escalante Canyons in the northeast portion of GSENM, the Kaiparowits Plateau making up the middle portion of GSENM, and the Grand Staircase in the southwest portion of GSENM. Each of these regions contains extraordinary historical, cultural, and geological features. It is from the names of these physiographic regions that GSENM gets its name, Grand Staircase-Escalante National Monument. Unfortunately, the name can be misleading and visitors may come looking for an actual "grand staircase" on a human scale. The "grand staircase" is actually geological, made up of the Chocolate, Vermilion, White, Gray, and Pink Cliffs as they ascend in elevation from south to north across the western side of the GSENM, and can only be seen if one looks north onto GSENM from around the Highway 89 area just north of the Arizona-Utah border.

The intent behind the designation of this vast area of land was to protect it in a "primitive, frontier state" and to "provide outstanding opportunities for scientific research and education" (U.S.D.I. Bureau of Land Management, 1999: iv). At the time of the designation, the BLM had never before been given the responsibility of managing a national monument. With the designation, the BLM became responsible for managing the area for recreation as well as most other traditional uses. Due to this added responsibility, the managers of GSENM felt it was important to support research that would help them understand how to best manage the area for both front country and backcountry recreation visitors.

In 1999, a backcountry visitor use survey was conducted by Dr. Mark Brunson and Lael Palmer through the Institute for Outdoor Recreation and Tourism (IORT) at Utah State University. One focus for this survey was to examine recreationists' relationship with a newly designated national monument (Palmer, 2001). Since this backcountry visitor baseline data had been collected, it was also important for the BLM to conduct a study which would contribute baseline data on front country recreation visitors.

According to the BLM, approximately 600,000 people visit GSENM every year, and recreational use is increasing. BLM managers believe that most visits occur in the Front Country and Passage zones, which comprise only about 6% (116,372 acres) of the Monument at the periphery and along major transportation routes. The management plan for GSENM calls for a continuation of this concentrated visitor use pattern. The concentration of visitors on a relatively small portion of GSENM can help managers meet the dual goals of providing recreation while protecting most of the area from many recreational impacts. The success of the zoning strategy, however, is dependent on understanding and monitoring visitor use patterns and perceptions of crowding, understanding the relationship between visitor behavior and the natural environment, and using information and education to increase visitor appreciation for GSENM and to reduce visitor impacts.

Background Literature

The social sciences lag behind the biophysical sciences in providing data that are relevant for ecosystem-based management (Lee, 1993; Blahna, 1995). In the past, research on recreation use in protected areas has been hindered by narrow, site-specific data collection efforts which have proved to be of marginal value for protected area planning and management (Borrie, McCool, & Stankey, 1998). Furthermore, while backcountry recreation experiences have been widely studied (Hammit & Cole, 1998), few research efforts have focused on dispersed, motorized recreation activities. Likewise, we know that recreation experiences can be enhanced by the presence of biological or cultural resources (Knight & Gutzwiller, 1995; Wang, Anderson, & Jakes, 1996), but little or no research has specifically examined these interactions on the Colorado Plateau or compared the interests and values of visitors to dispersed and developed sites. Visitor interaction with local communities is also a key concern for Monument staff, but there are few large-scale studies of these interactions. Through the use of the front country visitor surveys, baseline data was collected in order to examine these issues.

There are also large gaps in our understanding of the link between science literacy and informational and educational programs of protected areas. Science literacy is a critical element of positive environmental attitudes, and behavior and enhancement of scientific literacy among the public is a primary objective of the Monument. Yet there are very few large-scale studies of whether national monuments, parks, and other protected areas are effective in meeting this mandate. Baseline data collected through the front country visitor surveys helps also to look at this issue.

Many rural economies in the West have diversified from being based solely on extractive resource industries (e.g., grazing, timber production, and mining) to include an emphasis on service industries, especially those related to visitor and hospitality services associated with tourism. Successful communities are focusing on developing services that emphasize open space and remoteness, scenic beauty, outdoor recreation opportunities, and other amenity resources (Drabenstott & Smith, 1995). Amenity resources refer to those aspects of the rural environment in which residents and visitors alike may find beauty, pleasure, and experiences that are unique to that locale. A destination's place uniqueness can be developed and marketed to visiting tourists. Tourism, as a development industry, relies on the development and utilization of natural, historical, cultural, and human resources in the local environment as tourist attractions and destinations. Tourism creates recreational uses for natural and human-made amenity resources and converts these into income producing assets for local residents, thus contributing to the local economy and community development (Willits, Bealer, & Timbers, 1992). Data was also collected through the front country visitor surveys that provide for a limited evaluation of and an analysis of the relationships between visitors and hospitality services provided in the "gateway" communities surrounding the GSENM.

Methodology

Research Questions

The Monument provides an outstanding setting for collecting social science data to help address the research and literature gaps identified previously and to provide baseline data for evaluating the long-term effectiveness of the zoning strategy contained in the management plan. The following paper describes results from three primary research questions:

1. What are some visitor and use characteristics associated with recreation in dispersed areas in the Front Country and Passage Zones of the Monument?
2. What expectations and preferences do visitors at developed sites in the Front Country Zone have of the management resources and opportunities of the National Monument and visitor hospitality services in the surrounding communities?
3. How much money are visitors to the Front Country and Passage Zones spending in communities located in the Monument area?

Sampling Process

A two-step sampling design was developed and implemented: a short on-site intercept survey and a more detailed mail survey. Data were gathered from visitors from late March through mid October in 2004 using a random systematic selection of sampling dates. Intercept surveys were conducted at 27 pre-determined sites within the Front Country and Passage Zones of GSENM. Surveys were conducted at five visitor centers and three overlooks adjacent to the Monument and 19 recreation sites (trailheads, scenic attractions, roads, and campgrounds) located directly on GSENM. A breakdown of sample sites by each type of location and a complete list of contact points are shown on Table 1. Visitors to the three campgrounds (Calf Creek, Deer Creek, Whitehouse) were sampled during the same time block as the respective trailheads at these locations. Visitors were approached by researchers after completing activities at each site, while campers were approached at their campsites. Researchers conducted intercept surveys in an interview style with those visitors who agreed to participate in the study.

Survey and Sampling Design

For Phase I of this study, the survey instruments and sampling design were initially developed in collaboration with Monument staff. During Phase I, the survey instruments and the sampling design were pilot tested. From the results of this first year pilot study, the survey instruments and sampling design for Phase II were developed.

Three intercept survey instruments were used in this study: recreation site in the Monument, Monument visitor center, and Scenic Byway 12 overlook surveys. These surveys contained many similar questions but differed slightly for each type of site. The last two pages of the recreation site survey included questions regarding visitors' expectations, impressions, and activities participated in while at that survey site, while the last two pages of the visitor center survey included questions regarding visitors' impressions of and satisfaction with the facility, displays, and staff at the visitor center survey site. The overlook survey consisted of the same questions asked in the main sections of the recreation site and visitor center surveys. However, a trip route mapping exercise that was included in the other surveys was omitted from the overlook survey due to the amount of time it took to complete in relation to the typical amount of time visitors actually spent at the overlooks.

The main sections of the three intercept surveys contained questions regarding group size, length of stay, residence, overall trip route (mapping exercise), activities participated in, impres-

Monument Recreation Sites				Visitor Centers	Overlooks
Trailheads	*Scenic Attractions*	*Roads*	*Campgrounds*		
Calf Creek	Devil's Garden	Burr Trail	Calf Creek	Big Water	Blues
Deer Creek	Grosvenor Arch	Cottonwood Pull-off	Deer Creek	Boulder	Boynton
Dry Fork	Left Hand Collet	Johnson Canyon Road kiosk	Whitehouse	Cannonville	Head of the Rocks
Escalante River	Paria Movie Set	Smokey Mountian Road kiosk		Escalante	
Harris Wash				Kanab	
Lower Hackberry					
Whitehouse					
Wire Pass					

Table 1. Intercept Survey Sites

sions, expectations, and satisfactions while visiting the Monument. The recreation site and visitor center surveys included a mapping exercise where the intent was to the attain the most accurate description of the respondent's trip route up to the point when the visitor was surveyed, as well as the visitor's planned trip route following the interview. During this exercise, visitors were asked to point out any sites or visitor centers they had already stopped at, as well as those they were planning to stop at and where they were planning to go once they left the Monument area.

During the intercept survey data collection effort, 1,751 visitors were asked if they would be willing to participate in a more detailed follow-up mail survey. A mailing list was compiled of all visitors who agreed to participate in the mail survey and provided an address (n = 1,148). A three wave mailing design was employed following the outline provided by Dillman (2001). A mail survey accompanied by a cover letter was sent to all visitors on the mailing list as the first wave mailing. Two weeks later, as the second wave mailing, a postcard reminder was sent to all visitors who had not completed and returned the survey sent in the first wave. About one to two weeks following the postcard reminder, another blank survey with an updated cover letter was sent to any remaining visitors who had not yet returned a completed survey.

The mail survey included more detailed questions regarding visitor characteristics, past experience, expectations, satisfactions, Monument images, and expenditures. The survey instrument itself was nine pages long and included a mapping exercise similar to the one used in the intercept survey.

Results

Survey Response

As shown in Table 1, there were 27 locations where the intercept surveys were administered. Of the 2,306 respondents contacted, 2,062 (89.4%) agreed to be interviewed (Table 2). This included 83% (n = 602) at visitor centers, 90% (n = 887) at overlooks, and 96% (n = 573) at recreation sites.

Of the 2,062 respondents who agreed to the intercept interview, 1,751 (84.9%) were asked if they would be willing to receive and complete the follow-up mail-back survey. Overall, 555 respondents were not asked if they would be willing to participate in the mail survey because they refused to participate in the intercept survey (n = 244) or they were overlook visitors who told the interviewer that they were just passing through or commuting to work (n = 311), allowing the visitor to skip the section asking for mailing information and participation in the mail survey. Of the 1,170 (66.8%) respondents who said they would be

		Monument Recreation Sites				Visitor Centers	Overlooks	Total
		Trailheads	Scenic Attractions	Roads	Camp-grounds			
Days in Sampling Period	Weekend	25	14	19	9	30	15	45
	Weekday	56	35	42	25	63	38	96
Number of Contacts		272	213	84	28	724	985	2,306
Completed Intercept Surveys	Weekend	103	66	28	17	230	264	708
	Weekday	157	139	53	10	371	623	1,353
	Total	260	205	81	27	602[1]	887	2,062
Intercept Response Rate		95.6%	96.2%	96.4%	96.4%	83.1%	90.1%	89.4%
Number of Addresses		193 (74.2%)	149 (72.7%)	61 (75.3%)	22 (81.5%)	395 (65.6%)	328 (56.9%)[2]	1,148[3] (65.6%)
Mail Surveys Returned		132	99	40	13	263	219	766
Mail Survey Response Rate		68.4%	66.4%	65.6%	59.1%	66.6%	66.8%	66.7%

Table 2. Sampling Days and Intercept and Mail Survey Response Rates
[1]One survey was missing the date it was completed
[2]Of the 887 overlook respondents, 311 were not asked if they would like to do a mail survey
[3]Of the 2,306 visitors contacted, 555 (24.1%) were not asked to participate in the mail survey because they refused the intercept survey (n=244; 10.6%) or were overlook visitors who indicated that they were just passing through or going to work (n=311; 13.5%). Of the 1,751 who were asked if they would do a mail survey, 581 (33.2%) said no and 1,170 (66.8%) said yes. Of those who said yes, 22 (1.9%) gave invalid addresses (undeliverable).

willing to complete a mail survey (581 refused), 1,148 gave the interviewer their name and a useable mailing address. Of those, 766 respondents completed and returned the survey for a response rate of 67.6% (Table 2).

Demographics

Of the 2,062 visitors who participated in the intercept survey, about 67% (n = 1,382) were males. The average age of all survey participants was 50 years. Visitors to the Monument came from throughout the United States and the world. International visitors comprised about 23% (n = 471) of the sample, and of this, 38.2% were from Germany (n = 180), 12.7% from the Netherlands (n = 60), and 9.1% from Canada (n = 43).

Of the 2,050 respondents who indicated their place of residence, 14.2% (n = 290) of the intercept visitors were from Utah, 12.9% (n = 265) from California, 5.8% (n = 118) from Arizona, 4.9% (n = 100) from Colorado, and 9.5% (n = 194) from other western states (Nevada, Montana, New Mexico, Oregon, Idaho, Washington, Wyoming, and Alaska). The rest of the visitors were from 39 other states (n = 607; 29.6%). All together, the sample included visitors from all 50 states and the District of Columbia. Of those visitors who were from Utah, 10.3% (n = 30) resided within either Kane or Garfield counties and would be considered local residents to the Monument area. The top three Utah counties represented were Salt Lake (n = 95; 32.8%), Utah (n = 35; 12.1%), and Washington (n = 33; 11.4%). Those three counties contain 60.8% of the state's population and accounts for 56.3% of in-state visitors while Garfield and Kane counties have only 0.5% of the state's population and accounts for 10.3% of Front Country visitors.

When visitors were asked how many people were in their group for the trip, 12.6% (n = 223) said they were alone, 56.3% (n = 996) indicated a group size of two, 20.7% (n = 366) said three or four, 6.2% (n = 109) indicated five or six, and 4.2% (n = 75) said seven or more. Following a similar pattern, when asked how many people were traveling in the same vehicle as the respondent, the majority (n = 1,018; 57.6%) of respondents said that there was a total of two people traveling in the same vehicle.

Respondents were also asked if this was the first time they had visited the Monument. Slightly more than sixty percent (60.6%; n = 1,062) indicated they were first time visitors. When first time visitors were asked what they expected to see and experience during their visit to the Monument area, 572 (54.5%) gave a response concerning natural features, 463 (44.1%) said landscape and scenery, and 151 (14.4%) had no expectations or did not expect anything (respondents were given the opportunity to provide multiple answers).

Knowledge of the Monument's Management Agency

Visitors were asked if they had heard of Grand Staircase-Escalante National Monument and 88.0% (n = 1,814) said they had heard of it (Table 3). Of those 1,814, 1,806 were then asked if they knew the agency that manages the Monument and 58.7% (n = 1,061) said yes (eight responses were not recorded). When those 1,061 visitors were asked to identify the agency, 74.3% (n = 788) correctly identified the BLM. In other words, only 788 (38.2%) of the 2,062 respondents had heard of the Monument and indicated they knew which agency managed it and correctly identified the BLM as the management agency (Table 3). Noteworthy is that about one-quarter of the international visitors (26.2%) indicated they had not heard of GSENM or were unsure if they had heard of it. Also noteworthy is that almost 65% of international visitors did not know which agency was responsible for the management of the Monument, while over one-third (37.3%) of the visitors from other states didn't know, and over one-fifth (28.4%) of Utahns didn't know.

Monument and Trip Information Sources

Visitors who had heard of the Monument were asked how they first found out about the Monument. As shown in Table 4, the most frequently mentioned information source for first hearing about the Monument were reports about the initial designation by President Clinton's proclamation in 1996 (20.6%), followed by maps and brochures (16.2%), guidebooks (13.5%), and friends or family (11.5%). However, 15.4% (n = 272) of the visitors gave a response other than the response categories listed on the survey. The other sources of information where visitors first heard about the Monument are organized into several general categories: clubs (n = 4; 1.5%), community (n = 21; 7.7%), do not know (n = 18; 6.6%), educational sources (n = 15; 5.5%), familiar with the area (n = 35; 12.9%), media sources (n = 51; 18.8%), miscellaneous answers (n = 6; 2.2%), Monument designation (n = 10; 3.7%), personnel in surrounding areas (n = 7; 2.6%), planning for the trip (n = 6; 2.2%), travel agency/information center (n = 20;

		Overall	***Utah***	***Other States***	***International***
Heard of GSENM?	Yes	88.0%	97.9%	90.9%	73.8%
	No/Unsure	12.0%	2.1%	9.1%	26.2%
If yes, do you know which agency manages GSENM?	Yes	58.7%	71.6%	62.7%	35.1%
	No/Unsure	41.3%	28.4%	37.3%	64.9%
Bureau of Land Management (BLM)[1]		74.3%	82.4%	73.8%	64.5%
National Park Service (NPS)		11.8%	5.9%	12.3%	19.0%
Department of the Interior		3.4%	2.0%	3.8%	1.7%
U.S. Government		2.5%	2.5%	2.6%	2.5%
Forest Service		1.9%	3.4%	1.8%	0.0%
State Parks		1.5%	0.5%	1.0%	6.6%
Other Agencies or Combined Agencies		4.6%	3.3%	4.7%	5.7%

Table 3. Knowledge of the GSENM's Management Agency

[1]38.2% (788 out of 2,062) of respondents had heard of GSENM, indicated they knew which agency managed it, *and* correctly identified the BLM as the management agency.

Information Source	Overall (n=1,761)	Utah (n=279)	Other States (n=1,141)	International (n=331)
Clinton Designation	20.6%	52.3%	17.5%	4.2%
Maps/Brochures	16.2%	3.6%	18.4%	19.3%
Guidebook	13.5%	0.4%	10.3%	35.3%
Friends/Family	11.5%	15.8%	12.0%	6.3%
Internet	6.9%	0.7%	7.3%	10.9%
Driving By/Road Signs	6.9%	5.0%	7.7%	5.7%
Magazine	4.0%	0.7%	4.9%	3.9%
Newspaper	2.9%	5.0%	2.6%	2.1%
Visitor Center	2.2%	0.0%	2.7%	2.1%
Other	15.4%	16.5%	16.5%	10.0%

Table 4. Information sources used to first find out about the Monument (respondents checked only one information source).

7.4%), travel literature/literature about the area (n = 24) 8.8%), and traveling (n = 67; 24.6%).

Interestingly, but perhaps not surprising, over half of the Utahns (52.3%) indicated they first found out about the Monument through the media blitz surrounding the original Clinton designation, compared to 17.5% of visitors from other states and only 4.2% from other countries (Table 4). Maps and brochures were not used much as the initial information source by Utahns (3.6%) compared to visitors from other states (18.4%) and countries (19.3%). Similarly, less than one percent of Utahns first found out about the Monument from internet sources compared to 7.3% from other states and 10.9% from other countries. More than one-third of international visitors (35.3%) used a guidebook compared to less than one percent of Utahns. Also, Utahns were more likely to have first heard of the Monument from friends and family (15.8%) than visitors from other states (12.0%) and international visitors (6.3%).

When respondents were asked what sources of information they had used to plan their *current* Monument trip, the largest percentage of responses were in the maps/brochures (29.1%) and guidebook (29.1%) categories (Table 5). Almost one quarter received information at a visitor center, while 23.1% utilized the internet. Other frequently mentioned sources were knowledge based on previous trips (16.3%), friends and family (12.5%), and driving by or road signs (7.4%). For this question, visitors were allowed to give more than one response as to what sources of information they had utilized. Again, for this question, visitors were allowed to give answers other than those provided on the survey and these responses (n = 325) were organized into several general categories: clubs (n = 3; .9%), community (n = 44; 13.5%); do not have any information (n = 38; 11.7%), educational sources (n = 12; 3.7%), familiar with the area (n = 28; 8.6%), media sources (n = 23; 7.1%), personnel in surrounding areas (n = 14; 4.3%), travel agency/information center (n = 80; 24.6%), travel literature/literature about the area (n = 40; 12.3%), and traveling (n = 46; 14.2%).

In planning for their trip, Utahns were more likely to find previous trip experience to the area more useful (33.5%) than visitors from other states (14.6%) and countries (7.9%) (Table 5). Also, word-of-mouth information from friends and family was an important source of information for Utahns (22.5%) compared to those living in other states (11.2%) and countries (7.9%). More than half of international visitors (50.9%) used guidebooks compared to about one-quarter of visitors from other states and 13.7% of Utahns. Similarly, international visitors (30.2%) and visitors from other states (24.0%) used internet sources for trip planning compared to only 10.6% of Utahns. Maps and brochures also appear to be important trip planning aids for all visitors.

In comparing first time visitors to repeat visitors to the Monument, there are differences evident in the sources of information where the visitor *first* found out about the Monument. First time visitors were more likely to say maps/brochures (n = 174; 19.8%) or guidebooks (n = 165; 18.8), while repeat visitors were more likely to say the Clinton

Information Source	Overall (n=1,803)	Utah (n=284)	Other States (n=1,166)	International (n=342)
Maps/Brochures	29.1%	17.6%	32.4%	26.6%
Guidebook	29.1%	13.7%	26.5%	50.9%
Visitor Center	23..8%	22.2%	24.9%	21.6%
Internet	23.1%	10.6%	24.0%	30.2%
Previous Trip Experience	16.3%	33.5%	14.6%	7.9%
Friends/Family	12.5%	22.5%	11.2%	7.9%
Driving By/Road Signs	7.4%	9.2%	8.1%	3.8%
Magazine	4.5%	1.1%	6.1%	1.8%
Government Agency Office	2.6%	3.9%	2.5%	1.8%
Newspaper	1.4%	1.4%	1.6%	0.6%
Other	18.0%	18.0%	19.8%	12.3%

Table 5. Where did you get information about he Monument to plan this particular trip? (Respondents could select more than one information source).

designation (n = 239; 37.2%) or friends/family (n = 72; 11.2%) (Table 6).

When comparing first time visitors with repeat visitors to the Monument, first time visitors were more likely to use guidebooks (n = 299; 33.3%), maps/brochures (n = 283; 31.5%), visitor centers (n = 254; 28.3%), and the internet (n = 220; 24.5%) when they *planned* their trip, while repeat visitors were more likely to rely on information from a previous trip/experience (n = 237; 35.8%), maps/brochures (n = 162; 24.5%), guidebooks (n = 161; 24.3%), and visitor centers (n = 150; 22.7%) (Table 7).

Visitation

Visitors were asked how long they were planning to stay in the Monument area. Of the 1,727 who answered this question, 87.6% (n = 1,513) were staying one day or more while the rest were only visiting from one to twelve hours. Of those staying one day or more, 29.1% indicated they were only staying one day, 20.7% indicated they were staying two days, 32.1% said three, four, or five days, 18.1% indicated they were staying 6 or more days. Visitors who indicated they were staying one day or longer, on average, stayed 3.6 days visiting the Monument. Of the 214 visitors who said that they were visiting the Monument for less than one day, 74.8% indicated they were staying for four hours or less, with the other 25.2% staying 5 to 12 hours. The average amount of hours these visitors visited the Monument was 3.4 hours.

Visitors were also asked why they were visiting the Monument area. Recreation was the primary reason by far with 77.2% (n = 1,566) of visitors providing this response. However, 57.1% (n = 1,158) of the visitors responded they were visiting for recreation but that the Monument was not their primary destination; and 20.1% (n = 408) responded they were visiting for recreation and the Monument was their main destination (Table 8).

The 1,158 visitors who said the Monument was not their main destination were asked what their main destination was. The most frequently mentioned response for this question was a tour of the National Parks (n = 370; 32.0%). Interestingly, 87 (7.5%) of the visitors responded they had no real main destination or were just traveling. The next most frequently mentioned responses were Bryce Canyon National Park (n = 70; 6.0%), southern Utah (n = 63; 5.4%), both Bryce Canyon and Zion National Parks (n = 43; 3.7%), a tour of the Southwest (n = 37; 3.2%), Grand Canyon National Park (n = 28; 2.4%), a tour of the West (n = 27; 2.3%), Capitol Reef National Park (n = 22; 1.9%), both Bryce Canyon and Capitol Reef National Parks (n = 17; 1.5%), Lake Powell (n = 14; 1.2%), and Las Vegas, NV (n = 14; 1.2%).

	First Time Visitors (n=878)		*Repeat Visitors (n=643)*	
	percent	n	percent	n
Friends/Family	12.8%	112	11.2%	72
Driving By/Road Signs	4.8%	42	9.5%	61
Maps/Brochures	19.8%	174	8.1%	52
Magazine	5.2%	46	2.5%	16
Newspaper	1.8%	16	4.4%	28
Guidebook	18.8%	165	5.3%	34
Internet	8.8%	77	2.8%	18
Visitor Center	2.8%	25	1.1%	7
Clinton Designation	11.2%	98	37.2%	239
Other	14.0%	123	18.0%	116

Table 6. Comparison of first time and repeat visitors first finding out about the Monument.

Importance-Performance Analysis

The purpose of Importance-Performance (I-P) analysis is to have visitors rank various aspects of their trip for 1) the importance each aspect is for a satisfying recreational experience, and 2) their actual satisfaction with each aspect (perception of performance). We included two broad sets of questions on the mail survey instrument: 24 items related to Monument management, and 14 items related to other visitor facilities and services in local communities and on other public lands.

Questions dealing with the importance of items related to the overall quality of visitors' recreation experience asked respondents, "How important to you are each of the following items when visiting the Monument?" Responses to this question were on a scale where: 1="Not Important," 2="Somewhat Important," 3="Important," 4="Quite Important," and 5="Very Important." Questions dealing with the overall quality of visitors' recreation experience asked respondents, "please rate how satisfied you were with the following items during your actual visit to the Monument." Responses to this question were on a scale where: 1="Not Satisfied," 2="Somewhat Satisfied," 3="Satisfied," 4="Quite Satisfied," and 5="Very Satisfied." This question also contained a "N/A" check box for respondents who had not had experience with a particular item during their trip.

Questions dealing with the importance of services asked respondents, "How important to you are each of the following services when visiting the Monument area?" Responses to this question were on the same importance scale mentioned above. Questions dealing with visitor satisfaction with services asked respondents, "please rate how satisfied you were with the following services during your actual visit to the Monument area." Responses were scored on the same satisfaction scale as the Monument recreation quality questions referred to in the previous paragraph.

Importance-Performance Analysis Summary

Below are summary I-P diagrams of the importance and satisfaction mean score ratings for all Monument management (Figure 2) and other local services and community services (Figure 3) items. The dotted lines represent the grand means for the importance (horizontal) ratings for all respondents, and satisfaction (vertical) ratings for respondents that had experience with the items in that figure. Thus, the means are just a guideline to help visually illustrate the differences between all the items on both scales simultaneously.

In the simplest interpretation of the I-P diagrams, each quadrant represents a different management implication. Items in the lower right quadrant are generally the highest because they are relatively high on the importance scale and low on the satisfaction scale, that is, management should "concentrate efforts here" (Figure 1). Items in the upper right are those that have relatively high importance and satisfaction scores ("keep up the good work"), those in the upper left are below

	First Time Visitors (n = 899)		Repeat Visitors (n = 662)	
	percent	n	percent	n
Friends/Family	13.1%	118	13.0%	86
Driving By/Road Signs	7.0%	63	8.9%	59
Maps/Brochures	31.5%	283	24.5%	162
Magazine	5.9%	53	3.2%	21
Newspaper	1.7%	15	1.5%	10
Guidebook	33.3%	299	24.3%	161
Internet	24.5%	220	20.4%	135
Visitor Center	28.3%	254	22.7%	150
Government Agency Office/Personnel	2.7%	24	3.5%	23
Previous Trip/Experience	3.0%	27	35.8%	237
Other	18.7%	168	16.9%	112

Table 7. Comparison of first time and repeat visitors on information sources for current trip.

the mean in importance but above the satisfaction mean ("possible overkill"), and those in the lower left are low on both scales ("low priority"). These interpretations are oversimplified, however, as the following summary explains.

Importance-Performance, Monument Management

The I-P questions related to Monument management included 24 items in six categories: signage, naturalness, services, infrastructure, education, and information. Note especially five items in the upper right quadrant, "keep up the good work" (Figure 2): Brochures and Maps (A), Helpfulness of Monument Employees (W), Cleanliness of Restroom Facilities (V), Conditions of Monument Trails (Q), and Safety Information (X) that have high levels of importance and satisfaction. There are three items in the "concentrate efforts here" quadrant: Monument Trailhead Markers (P), Directional Signs to Monument Destinations (O), and Wildlife related information (K). In addition to these, a more detailed analysis suggests several other areas that need management attention. For example, item J was rated low on importance and satisfaction which would suggest that, from a visitor standpoint, paleontology is not important nor done well. Given the importance of paleontology in the Monument Proclamation and science program, however, a lack of interest on the part of the public does not mean it should be downplayed by management. If anything, it suggests much more attention needs to be put on paleontology education in the future. It is also possible that the word "paleontology" was unfamiliar to some visitors, and that may have been reflected in relatively low importance rankings than if the survey had said "dinosaurs and other topics of pre-history."

There is also a relatively large cluster of items near the axis of the scale means. Many of these items are also related to natural history and signage. For example G, H, I, and L are natural history topics (history, geology, archeology, and plants), N is about signs (Directional Signs to Visitor Centers), F is about History of the Monument Area, and D is about Information about Recreation Opportunities. Thus the I-P results suggest improvements are needed most in the areas of signage, education/interpretation, and information. Changes related to the educational needs, such as new visitor centers and environmental education programs, were being developed or were newly implemented at the time of the survey, but the I-P results also suggest that better trailhead and destination information signs should also be a priority for the future. The results of this analysis should be used to evaluate the effectiveness of these management related changes in the future. It should also be noted these I-P results represent a "macro" approach, representing visitors' perceptions of importance and satisfaction with general, overall management items and not site-specific items.

	Overall	Survey Type		
		Recreation Sites (n = 568)	Visitor Centers (n = 591)	Overlooks (n = 870)
Primarily for recreation - the Monument is my main destination	20.1%	37.9%	21.8%	7.4%
Primarily for recreation - but my main destination in NOT the Monument	57.1%	56.0%	65.0%	52.4%
Primarily for business, family, or other reason; the Monument was a side trip	2.4%	3.3%	3.7%	0.8%
Working or commuting to work (over-look only)	0.1%	0.0%	0.2%	0.1%
Just passing through (overlook only)	15.2%	0.0%	0.0%	35.4%
Other	5.2%	2.8%	9.3%	3.9%

Table 8. Reasons for visiting the Monument

Importance-Performance, Other Community and Local Services

Unlike the results for the Monument management items, there is a fairly linear relationship between the importance and satisfaction scores for the 14 community service items (Figure 3). That is, as importance levels increase, satisfaction tends to increase as well. And while dissatisfaction seems to be quite low for visitors who actually used various types of services (none of the items had more than 10% of those who used the services and said they were important and also said they were only "Somewhat Satisfied" or "Not Satisfied"), satisfaction was also not very high for many services other than State, USFS, and NPS Campgrounds (C), Lodging Services (A), and Monument Visitor Information Services (N) in the upper right quadrant. Conversely, Eating and Drinking Establishments (E), Grocery and Convenience Stores (F), and Emergency Medical Services (L) seem to need the most attention based on their relatively high importance and low satisfaction scores.

Unlike the Monument management items, there are a relatively high number of items in the "low priority" category (lower left quadrant) including Privately Owned Campgrounds (D); Sporting Goods and Outdoor Equipment Stores (H); Souvenir Stores, Gift Shops and Galleries (I); and Guide and Outfitting Services (J). While this partially reflects the fact that relatively few people need or use these services, these findings, especially the relatively low satisfaction ratings, are important for local economic development in the communities. The results could reflect the relative newness of the Monument and the lack of experience of these businesses serving the number and diversity of visitors attracted by the new Monument. While national and state parks have traditionally attracted tourists to the area, the effect of the new Monument may be to hold and disperse visitors for longer periods in more communities having less experience with visitors than in the past. So for example, rather than most visitors to Bryce Canyon National Park staying in the national park campgrounds or Ruby's Inn, now visitors are also stopping at Monument sites and staying in Boulder, Escalante, Cannonville, Tropic, and other towns that had little overflow business before. This interpretation is also supported by the items located in the upper right quadrant, which identifies successful service items – Agency Operated Campgrounds (B and C), Service Stations (G), and Lodging Services (A) – all services that would be expected to have had more experience with past tourism, the pass-through type tourist, and more traditional types of visitors, as compared to sporting goods stores, outfitters, and souvenir shops in many of the small towns in the region.

Finally, the last item in the lower left quadrant "Search and Rescue Services" (M), is difficult to interpret. Very few respondents, if any, would have had experience with search and rescue services, yet there were as many who said they used this service (n=63) as said they used "Emergency Medical Services" (L) (n=74). It is possible many

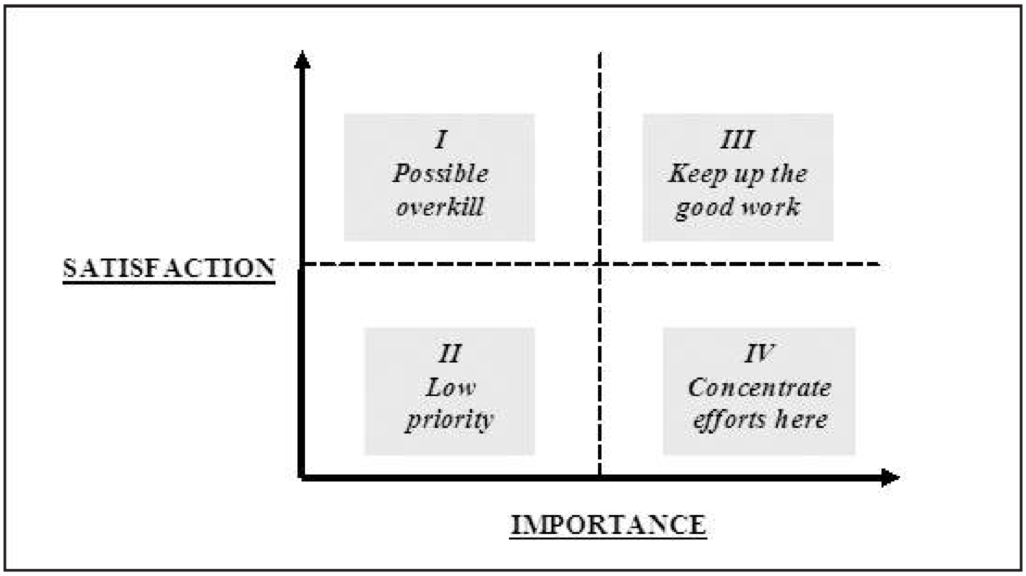


Figure 1. Importance/Satisfaction Model

of these are the same respondents to both items, and that some do not understand the difference between these two services – search and rescue operations are not offered in many parts of the U.S. and other countries. Regardless of the accuracy of response to this question, however, it is still a concern that visitors rated medical services relatively low, and Monument staff and local community officials should investigate these potential concerns.

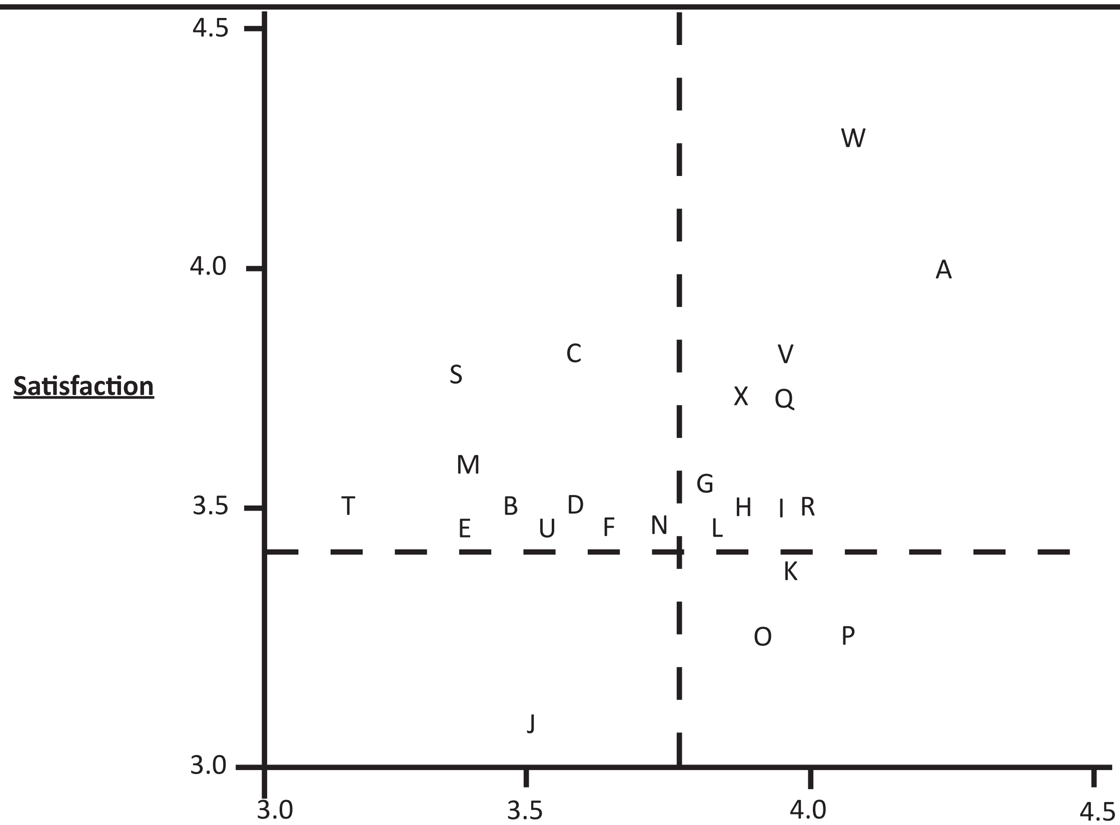
Visitor Expenditures and Economic Impact in the Monument Area

On the mail survey, respondents were asked to indicate their group's total monetary expenditure in the Monument area and surrounding communities for the trip in which they filled out the intercept survey. Eleven visitor service categories were listed (along with an "Other expenditures" category) and respondents were asked to list a dollar amount next for each. Of the 766 who returned the mail survey, 735 (95.9%) answered this question. Following are two primary sets of analysis: 1) expenditures by respondents' location of residence, and 2) an IMPLAN analysis that demonstrates the broader contribution of these expenditures to the economy and employment of Garfield and Kane Counties.

Expenditures by Respondents' Location of Residence

As shown on Table 9, total average amount spent per group in the Monument area was just under $500. Average international group expenditures ($614.90) were almost $260 more than Monument visitors from Utah ($356.14) and about $115 more than visitors from other states ($500.43). When comparing average amount spent by Utahns with visitors from other states and countries, some interesting patterns begin to emerge. Groups from other states spent about twice as much on lodging compared to Utahns, and international visitors spent nearly three times more than Utahns. Domestic visitors (including Utahns) spent more on privately owned campgrounds than international visitors. Utahns spent less on average for restaurant meals ($75.25) than visitors from other countries ($135.29) and other states ($108.57). There is a similar pattern in purchases from grocery and convenience stores with Utahns spending about $38 compared to internationals at $68 and those from other states at about $45. However, Utahns spent about $15 more for fuel than those in the other two groups. Visitors from other states spent more on souvenir and gift shop purchases ($42.05) than Utahns ($15.45) and international visitors ($29.00).

The summary statistics presented in Table 10 also show some interesting contrasts. Visitors to the Monument who reside in Utah tended to spend



Importance

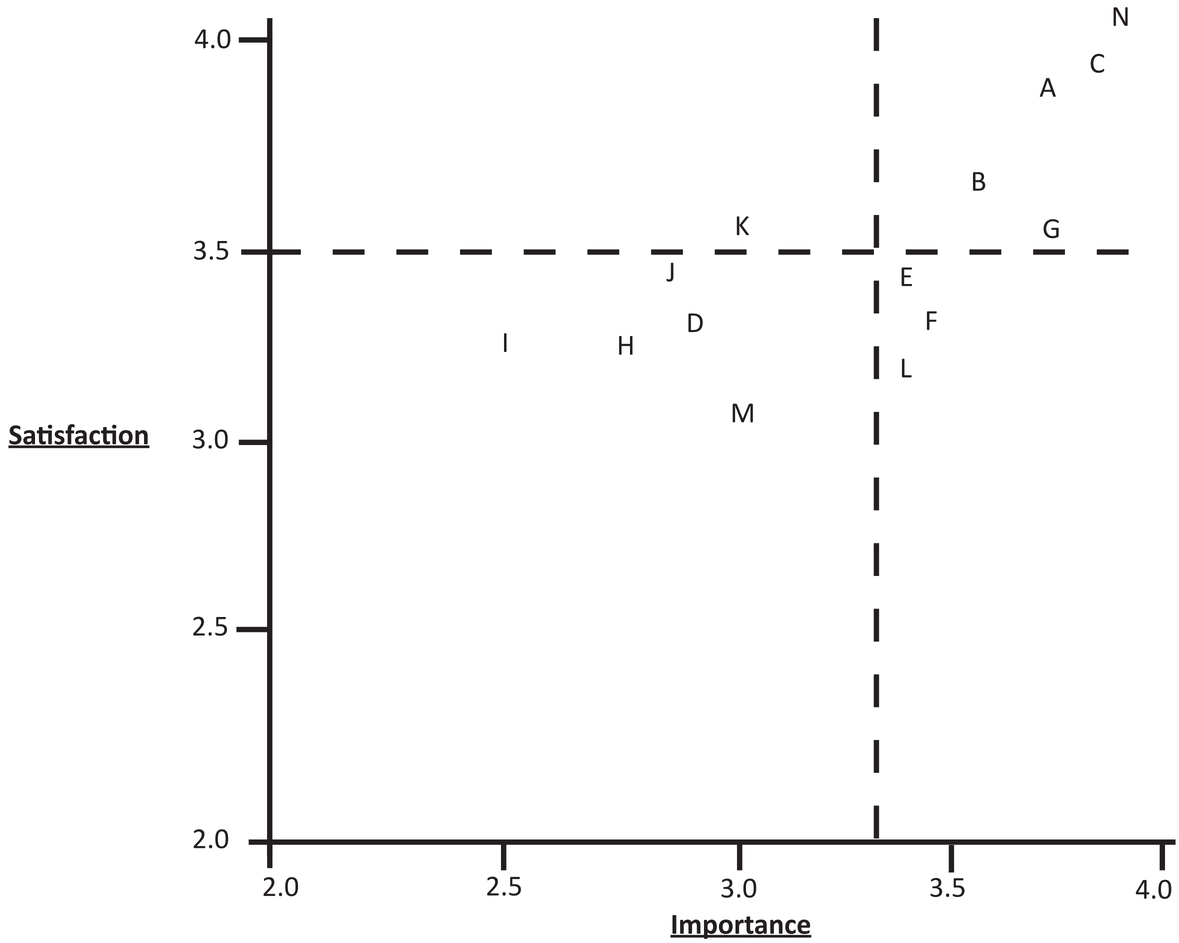
A = Brochures and Maps
B = Educational Displays at Waysides
C = Visitor Center Displays
D = Information about Recreation Opportunities
E = Educational Displays (in general)
F = History of Monument Area
G = Historic Sites
H = Geological Information
I = Archeology (prehistoric Native American)
J = Paleontology
K = Wildlife
L = Plants
M = Monument Road Signs
N = Directional Signs to Visitor Centers
O = Directional Signs to Monument Destinations
P = Monument Trailhead Markers
Q = Condition of Monument Trails
R = Condition of Monument Roads
S = Condition of Developed Campsites
T = Condition of Undeveloped Roadside Campsites
U = Availability of Restroom Facilities
V = Cleanliness of Restroom Facilities
W = Helpfulness of Monument Employees
X = Safety Information

Importance Grand Mean (3.7) and Satisfaction Grand Mean (3.4) indicated by dashed lines.

Importance Axis:
3 = Important
4 = Quite Important
5 = Very Important

Satisfaction Axis:
3 = Satisfied
4 = Quite Satisfied
5 = VerySatisfied

Figure 2. I-P Monument Management Summary Diagram



A = Lodging Services
B = Campgrounds in Monument
C = State Park, USFS, NPS Campgrounds
D = Privately Owned Campgrounds
E = Eating and Drinking Establishments
F = Grocery and Convenience Stores
G = Service Stations
H = Sporting Goods and Outdoor Equip. Stores
I = Souvenir Stores, Gift Shops, and Galleries
J = Guide and Outfitting Services
K = Local Transportation
L = Emergency Medical Servies
M = Search andRescue Services
N = Monument Visitor Information Services

Importance Grand Mean (3.3) and Satisfaction Grand Mean (3.5) indicated by dashed lines.

Importance Axis:
2 = Somewhat Importance
3 = Important
4 = Quite Important

Satisfaction Axis
2 = Somewhat Satisfied
3 = Satisfied
4 = Quite Satisfied

Figure 3. I-P Community and Other Local Services Summary Diagram

Expenditure Categories	*Overall (n = 735)*	*Utah (n = 108)*	*U.S.A (n = 528)*	*International (n = 99)*
Lodging Services	$164.29	$83.21	$167.33	$236.52
Campgrounds in Monument	$3.85	$3.79	$3.77	$4.36
State Park USFS/NPS Campgrounds	$13.37	$14.56	$13.39	$12.01
Privately Owned Campgrounds	$8.65	$6.48	$10.21	$2.73
Eating and Drinking Establishments	$107.28	$75.25	$108.57	$135.29
Grocery and Convenience Stores	$47.16	$38.18	$45.01	$68.40
Service Stations (Fuel)	$65.42	$78.64	$63.04	$63.64
Sporting Goods/Outdoor Equipment	$10.13	$9.17	$9.37	$15.29
Souvenir, Gift Shops, Galleries	$36.39	$15.45	$42.05	$29.00
Guide and Outfitting Services	$19.96	$11.57	$19.20	$33.13
Local Transportation	$0.65	$1.39	$0.54	$0.45
Other	$17.64	$18.63	$18.11	$14.07
Total Average Expenditures	$494.65	$356.14	$500.43	$614.90

Table 9. Average amount of money spent per group in Monument and surrounding area.

	Overall	*Utah*	*Other U.S.*	*International*
Median	$324.00	$212.50	$347.50	$324.00
Mean	$494.65	$356.14	$500.43	$614.90
Standard Deviation	$597.20	$455.41	$571.57	$804.51
Sum (percent of overall)	$363,565.00 (100%)	$38,463.00 (10.6%)	$264,227.00 (72.2%)	$60,875.00 (16.7%)
Respondents (percent of overall)	735 (100%)	108 (14.6%)	528 (71.8%)	99 (13.4%)
Individuals (percent of overall)	2,079 (100%)	514 (24.7%)	1,318 (63.4%)	247 (11.9%)

Table 10. Summary statistics of group expenditures in Monument area.

less on their trip (both median and mean values) than their counterparts in other states and countries. Of the 766 who returned the mail survey, 31 (4.0%) did not answer any expenditure questions, so they were eliminated from the data set, thus resulting in a sample size of 735. The total amount of money spent in the Monument area by our 735 respondents was $363,538. Utahns made up 14.6% of the respondents and contributed 10.6% to the total expenditures whereas international visitors made up 13.4% of the respondents and contributed 16.7% to the total expenditures. However a more marked discrepancy occurs when examining number of individuals that were in the respondents' groups. Respondents from Utah reported the expenditures were for larger size groups (mean = 4.8, median = 3.0) than those from out of state (mean = 2.5, median = 2.0 for both other states and international visitors). Thus, the 735 respondents gave expenditure information for 2,079 individuals (Table 10, bottom row). Expenditures for individuals traveling with the Utah respondents accounted for 24.7% of all individuals and contributed 10.6% to the total amount spent compared to 16.7% contributed by international visitors and 72.2% by out-of-state American visitors.

It is important to point out that most respondents made purchases in several service sectors and very few (if any) spent money in all sectors. As shown in the last row on Table 11, 4.2% (n=31) indicated they did not spend any money in the Monument area during that trip. An interesting finding, but not necessarily surprising, is that about two-thirds of visitors from other states and countries spent money on lodging services compared to 38.5% of Utahns. Visitors from other states were more likely to stay in privately owned campgrounds (11.4%) than Utahns and international visitors (about 5% each). The percent of visitors who spent money in restaurants and grocery stores was about the same for Utahns, international, and domestic visitors (about 75% or higher). However, while about half of the international and domestic visitors made purchases in souvenir or gift shops, less than one-third of Utahns made similar purchases (Table 11).

In order to get a more realistic estimate of average expenditures for each category, mean and median values were calculated without including respondents who indicated they did not spend any amount in the different service sectors. As shown in Table 12, of the 436 (59.3%) respondents who spent money on lodging services, the average amount spent was $277. Average expenditures for privately owned campgrounds ($91) were about $40 to $55 more than the amount spent on public campgrounds. About three-quarters of the respondents spent an average of about $131 to eat out in restaurants for a total of almost $79,000. For those who contracted with local guide and outfitting companies (7.1%), the average was $282 with a median value of $100 and a total amount spent of $14,668. The largest amount of money spent in the Monument area by visitors was for lodging ($120,753), followed by meals in restaurants ($78,848), fuel at service stations ($48,016), items purchased in grocery and convenience stores ($34,660), purchases at souvenir and gift shops ($26,743), and guide services ($14,668).

Input-Output Economic Analysis (IMPLAN)

This research was not designed to measure economic impacts of visitors to the area on local or state economies. The expenditure items, described above, were intended to provide insight into what items are purchased in local businesses by Monument visitors. However, by inputting the data into an economic analysis model, the resulting output can help further the understanding of economic relationships between tourism spending and local economic viability.

The impact that a recreation activity has on an economy is different than total amount spent pursuing that activity. A dollar spent at point of purchase moves through the economy and affects employment and income beyond area of purchase. Estimating impacts that tourist expenditures have on local counties helps inform those involved with formulating policy as to potential consequences of their decisions.

An Input-Output (I-O) analysis model was used to assess the economic impact on Garfield and Kane Counties for visitors who indicated that the Monument was their main destination. The computer model "Impact Analysis for Planning" (IMPLAN) was used as the analytical tool. That model is used for either analytical or predictive estimates for economic impacts and has been previously utilized to conduct economic impact analysis of recreation (McCoy et al., 2001).

When forecasting economic impacts using a predictive model, it is important to define whose expenditures are included, why those expenditures are more important than others, and purchase location. It is obvious there are a variety of motivations for Monument area visitation, from taking the wrong road to traveling specifically to experience the unique features of the Monument. If GSENM did not exist as a management unit, visitors would still be coming through and stopping to make purchases at local businesses. Therefore, rather than examining local expenditures of all visitors to the area, it may be of more interest to look at the local economic contribution for those who came specifically to see the Monument. In other words, treat the Monument as a tourist destination to help understand its designation effect on local county economies. This means that the analysis below focuses on those who indicated that the Monument was their main destination and they stopped in Garfield and Kane communities.

Of the 766 who returned the mail survey, 31 (4.0%) did not answer any expenditure questions so they were eliminated from the data set, thus resulting in a sample size of 735. Of these, 29 did not indicate where they stopped and 9 stopped only in Coconino County, Arizona, so these were eliminated from the data set as well. That left 697 respondents who made stops in Kane and/or Garfield counties with an average party size of 2.82 and a total of 1,969 visitors.

The expenditure data were adjusted to amount spent per person by dividing the amounts spent by

Expenditure Categories	Overall (n = 735)		Utah (n = 109)		U.S.A (n = 527)		International	
	$0	>$0	$0	>$0	$0	>$0	$0	>$0
Loging Services	40.7	59.3	61.5	38.5	38.3	61.7	30.3	69.7
Campgrounds in Monument	89.0	11.0	89.0	11.0	89.0	11.0	88.9	11.1
State Park/USFS/NPS Campgrounds	72.2	27.8	73.4	26.6	71.9	28.1	72.7	27.3
Privately Owned Campgrounds	90.5	9.5	95.0	5.0	88.6	11.4	94.9	5.1
Eating and Drinking Establishments	17.8	82.2	22.0	78.0	16.9	83.1	18.2	81.8
Grocery and Convenience Stores	24.2	75.8	21.0	79.1	24.7	75.3	25.3	74.7
Service Stations (Fuel)	12.1	87.9	9.2	90.8	12.2	87.8	15.2	84.8
Sporting Goods/Outdoor Equipment	83.3	16.7	84.4	15.6	83.9	16.1	78.8	21.2
Souvenirs, Gift Shops, Galleries	52.0	48.0	67.9	32.1	49.0	51.0	50.5	49.5
Guide and Outfitting Services	92.9	7.1	95.4	4.6	92.6	7.4	91.9	8.1
Local Transportation	98.5	1.5	99.1	0.9	98.3	1.7	99.0	1.0
Other	86.8	13.2	87.0	13.0	86.9	13.1	85.9	14.1
All Categories	4.2	--	2.8	--	4.2	--	6.1	--

Table 11. Percent of respondents who did not spend money in Monument area compared with those who spent some amount.

number of people who had expenses. The amounts were also adjusted by whether they also stopped in Coconino County. If they stopped in Garfield and/or Kane counties, the expenditures were multiplied by one. If they stopped in Garfield or Kane and Coconino, the multiplier is 0.5. If they stopped in Garfield and Kane and Coconino, the multiplier is 0.67.

Of the 766 respondents, 697 (91.0%) said that they had stopped in one or both of the Utah counties and told us how much they had spent (including $0). The 766 respondents identified their party size and/or the number of people the expenditures were for. In other words, the 766 respondents were giving us information about 2,155 visitors. The 697 respondents with the Utah stops were speaking for 1,969 visitors. So, we have per person Kane and Garfield expenditure data for 1,969 of 2,155 sample visitors or 91.4%. BLM estimates the number of visitors to Grand Staircase-Escalante National Monument in a year is 600,000. If we could have contacted all 600,000 visitors (population from which the sample is drawn), we assume that 91.4% or 548,400 would have stopped in Garfield and/or Kane counties and would be able to tell us how much they have spent.

Of those 697 respondents, 190 (27.6%) indicated that the Monument was their main destination. This is slightly higher than the results from the intercept survey respondents where 20.1% indicated the Monument was their main destination. This could perhaps be explained due to the fact that only about 7% of respondents contacted at overlook sites said the Monument was their main destination and they were less likely to indicate they would be willing to complete a mail survey than those contacted at other sites. For purposes of INPLAN modeling, that 190 sub-sample represents an estimated population 149,492 (27.3% of 548,400) who filled out the expenditure questions on the mail survey instrument, indicated the Monument was their main destination, and stopped in Garfield and/or Kane County communities. The sample of 190 has a Confidence Interval of ∀ 6.7% at the 95% Confidence Level given the response rate of 67%.

The IMPLAN model produced county-level (Garfield and Kane) databases divided into three impact categories; Industry Output, Employment, and Value Added. Industry Output is the single number in dollars, or millions of dollars for each industry. The dollars represent the value of that industry's production. Employment is the single number of jobs for each industry given as full time equivalent jobs. Value Added is the aggregate of four components; employee compensation, proprietary income, other property type income, and indirect business taxes. Employee compensa-

Expenditure Categories	Mean	Median	Range		Respondents		Sum
			Low	High	% of 735	n	
Lodging services	$277	$185	$10	$3,000	59.3%	436	$120,753
Campgrounds in Monument	$35	$16	$4	$200	11.0%	81	$2,827
State Park USFS/NPS Campgrounds	$48	$21	$2	$800	27.8%	204	$9,819
Privately Owned Campgrounds	$91	$60	$4	$500	9.5%	70	$6,359
Eating and Drinking Establishments	$131	$80	$3	$2,000	82.2%	604	$78,848
Grocery and Convenience Stores	$62	$40	$2	$1,500	75.8%	557	$34,660
Service Stations (Fuel)	$74	$50	$10	$750	87.9%	645	$48,016
Sporting Goods/ Outdoor Equipment	$61	$40	$1	$800	16.7%	123	$7,449
Souvenir, Gift Shops, Galleries	$76	$50	$2	$1,200	48.0%	353	$26,743
Guide and Outfitting Services	$282	$100	$5	$3,000	7.1%	52	$14,668
Local Transportation	$44	$30	$10	$150	1.5%	11	$479
Other	$133	$50	$3	$1,000	13.2%	97	$12,49
All Expenditures	$516	$340	$4	$6,000	95.8%	704	$363,565

Table 12. Mean, median, and total expenditures for groups who spent money.

tion is the total payroll costs including benefits. Proprietary income consists of income received by self-employed individuals. Other property type income examples include payments for rents, royalties, and dividends. Indirect business taxes include excise taxes, property taxes, fees, licenses, and sales taxes paid by businesses (taxes that occur during normal course of business but not profit or income tax).

The databases also account for the ripple or multiplier effect due to the initial increase in demand (the demand for a good will ripple through the economy until a new balance is achieved). The IMPLAN model uses three effects to measure economic impact; Direct, Indirect, and Induced effect. Direct effect is the production change associated with a change in demand for the good and is the initial effect on the economy. Indirect effect is a secondary impact caused by changing input needs of directly affected industries such as additional input needed to produce additional output. Induced effect is caused by changes in household spending due to additional employment generated by direct and indirect effects.

In running the IMPLAN model, a Social Accounting Matrices (SAM) Type multiplier was used to simulate the ripple effect. A SAM Type multiplier is considered to be a realistic indicator since it takes into account all impacts of increased sales, jobs, or salaries as well as inter-institutional transfers resulting from the economic activity. The formula for calculating the SAM Type multiplier is to sum direct, indirect, and induced effects and divide that sum by the direct effects. Based on the overall results shown on Table 13, SAM Type multipliers for Industry Output is 1.23, Employment is 1.2, and Value Added is 1.27. It should be noted that each industry sector has a unique multiplier and what is calculated above is an overall average.

IMPLAN analysis analyzes impact categories by effects in 513 industry sectors. As summarized in Table 13, a population of 149,492 visitors to the Monument as their main destination and based on the average expenditure of our sample of 190, more than $20.6 million would be directly spent in Kane and Garfield Counties in 21 different industrial sectors. This spending would directly support more than 430 additional full-time equivalent jobs with almost $10 million in employment value added on. When considering the ripple effect through the economy by adding on indirect and induced effects, the total industry output impact would be about $25.4 million in 86 sectors, employment would support more than 500 jobs in 70 sectors, and value added would increase the effect of that money by about $12.5 million in 81 of 513 economic sectors (Table 13).

Interestingly, the Utah Division of Travel Development, Department of Community and Economic Development, estimated spending by travelers in Garfield County in 2003 to be $32.5 million with 904 jobs in travel and tourism related employment; estimated spending by travelers in Kane County in 2003 was $50.4 million with 1.012 jobs in travel and tourism related employment (Utah Division of Travel Development, 2005). Those 2003 estimates by the Utah Division of Travel Development and expenditure data collected in this study suggest Monument visitor spending to account for about 25% of overall visitor spending Garfield and Kane Counties, which seems realistic considering the role of the Monument as just one of many attractions in these counties.

Another interesting feature of IMPLAN is its ability to produce some data that help characterize current economic conditions in Garfield and Kane Counties. The summary output shown for the counties in Table 14, is taken from the Output, Value Added and Employment output results. As shown in Table 14, expenditures from the nearly 150,000 Monument destination visitors would contribute about 520 or over 7% of the 6,858 full-time equivalent jobs held by Garfield and Kane County residents and nearly 6% of the counties' residents salaries, property income, and business taxes and fees. Of the nearly $400,000,000 spent in all industries, about 6.5% would be contributed by Monument destination visitors.

Again, it must be remembered this represents only those visitors who specified the GSENM as their primary destination. The Monument also contributes a greater amount to the local economies as secondary destination for visitors whose primary destination is Bryce Canyon National Park, Zion Nation Park, or other state and national attractions in Garfield County, Kane County, and Coconino County in Arizona.

Discussion

GSENM is a national and international tourism attraction. In 2004, group sizes were relatively small (average group size is 2.8 and 90% of the groups had 2 or fewer people), visit lengths were long (70% expect to stay in the Monument area for 2 or more days), and 61% of the respondents were first time visitors. Only 14% of Monument visitors were Utahns, mostly from urban areas (Salt Lake, Utah, and Washington Counties). Nearly two-thirds of the visitors were from other states and 23% were international (Germany, Netherlands, and Canada especially). This is a transient, non local, tourism-oriented clientele.

There was also a significant designation effect. 85% of the visitors made their first visit to the Monument in the eight years since designation (1996 to 2004), including nearly half of the repeat visitors. The vast majority of the visitors' primary reason for visiting the Monument area was recreation, but relatively few said GSENM was their primary destination; the major destination for most are other national or state parks in the area. And while many visitors knew about the Monument before their trip and claimed to know the managing agency, only one-third actually named the BLM.

These results indicate that GSENM is an important stop for tourists to Garfield and Kane Counties, and visitation to the Monument increased substantially as a result of its designation. But for 70% of visitors, it is actually a secondary stop along the route that visitors take to visit other more established designations like Zion and Bryce Canyon National Parks. This has both positive and negative implications for Monument management and local communities. While the Monument itself has probably not caused a large increase in the number of visitors to the area, Monument designation has clearly increased the average visitor's length of stay and expenditures in the area.

Visitors also have significant informational needs, as many are new to the Monument and they are more likely to have investigated national and state parks rather than the Monument itself.

		Direct	Indirect	Induced	Total
Output Industry Impact	Impact in Dollars	20,653,631	2,070,708	2,641,281	25,365,320
	No. of Industrial Sectors	21 (4.1%)	74 (14.4%)	83 (16.2%)	86 (16.8%)
Employment Impact	Impact in Jobs	434.8	40.9	46.1	521.8
	No. of Industrial Sectors	10 (1.9%)	52 (10.1%)	59 (11.5%)	70 (13.6%)
Value Added Impact	Impact in Dollars	9,883,993	1,105,146	1,555,766	12,544,844
	No. of Industrial Sectors	18 (3.5%)	72 (14.0%)	81 (15.8%)	81 (15.8%)

Table 13. Summary of IMPLAN model impacts.

Therefore, GSENM visitors may be more likely to have national park-type expectations for roads, information, and services. However, the very general nature of the visitors' expectations for the Monument experience may, to a great extent, be formed and influenced by the sites developed and information provided by the BLM.

Some interesting Monument management trends begin to emerge from the importance-performance (I-P) analysis. Management areas needing the most attention are wildlife, directional signs to monument destinations, and monument trail markers. Secondary areas of concern are interpretation and natural history information, signs to visitor centers, and information about recreation opportunities. And even though roads were not included in I-P analysis, it seems that this may be an informational issue as well. While the BLM has little control over some of these factors, like weather, road conditions, distances between sites, and others, these can become part of a general informational approach for the Monument. Research shows that satisfaction is often increased as visitor experiences meet their expectations. And while new roads, paving, and pullouts on the Monument may not be economically feasible or meet the goals of the Monument plan or agency mandate, better information can be provided to tell visitors the difficulties, conditions, and distances they can expect. This approach can increase visitor preparedness and satisfaction, and warning signs and information can also be used strategically to reduce visitation in primitive and outback zones. In this way, signs and information can increase visitor safety, improve experiences, reduce impacts, and generally help meet Monument zoning goals.

The I-P results for items relating to visitor services in local communities suggest that visitors would like to see improvements in certain business sectors. Eating and drinking establishments, grocery and convenience stores, and emergency medical services received high importance but low satisfaction ratings. The number, diversity, and hours of operation for these services need to be reviewed and perhaps expanded. Several other services that had low satisfaction scores but also low importance scores should also be reviewed: guides and outfitters, privately owned campgrounds, sporting goods and outdoor equipment stores, and souvenir and gift shops. Low importance ratings for these services are probably based on the relatively specific nature of the service and do not reflect the changing patterns of visitation due to the Monument. Traditional services offered before the Monument was created, such as lodging services and government campgrounds, were rated highly. Demands for certain services like outfitters and guides and emergency medical services are probably increasing. In order to meet visitor satisfaction and community development goals, local officials and business owners should evaluate and perhaps provide and advertise more of these low satisfaction services, even though some of the importance scores are also relatively low.

To estimate the economic value of Monument visitors for local communities, mail survey respondents were asked to estimate their group expenditures for the trip. Two sets of analyses were conducted: descriptive statistics of group and individual expenditures, and an input-output analysis to estimate the total effects of these expenditures in different economic sectors in Kane and Garfield Counties.

	Garfield and Kane Counties Overall	*Contribution by Monument Destination Visitors*	*Percent of Overall Contributed by Visitors*
Industry Output	$390,342,000	$25,365,320	6.5%
Employment	6,858 jobs	521.8 jobs	7.8%
Value Added	$211,639,000	$12,544,844	5.9%

Table 14. Contribution of Monument destination visitors to economic conditions in Garfield and Kane Counties.

The average amount spent per group was $495. Average expenditures for groups from Utah were considerably lower ($356) than for visitors from other states ($500), and countries ($615). This is especially significant since Utah visitor group sizes were nearly twice as large (mean = 4.8) as groups from other states and countries (mean = 2.5). Utah visitors spent an average of $74 per person, compared to $200 for visitors from other states, and $246 for international visitors. Most of this difference was due to Utahns' lower spending levels for lodging, restaurants, and souvenir shops.

IMPLAN was used for the input-output analysis. Calculations were based on an average group size of three, expenditures that were made by visitors for whom the Monument was their primary destination, and the BLM's estimate of 600,000 annual visitors. Results indicate GSENM visitors spend $20.6 million in Kane and Garfield Counties. This spending directly supports more than 430 full-time equivalent jobs with almost $10 million in employment value added. When considering the ripple effect of this money in the Garfield and Kane County economies, the total impact would be $25 million and more than 500 jobs. Value added effects increases the impact of that money by about $13 million.

Due to multiple trip destinations and other measurement factors, these figures are just estimates. We believe they are conservative estimates of the total value of Monument visitation, however. For example, as noted above, we also found there was a significant designation effect (e.g., 85% of the visitors, made their first visit to the area since 1996). So many of the Monument visitors, who may have come primarily to visit national or state parks in the area, may not have made the visit or would not have stayed in the area as long if the GSENM had not been designated. To provide more exact figures, a complete economic impact study is needed.

Conclusion

The current management plan focuses on providing information and access to relatively few sites on the periphery of the Monument. The goal is to concentrate recreational use and impacts on a small number of acres. The relatively non specific expectations and tourist-oriented character of the visitors seems to indicate this visitor management approach may be appropriate and effective. Service and overnight needs will also be important factors in visitor satisfaction, and the provision of these needs, and the relationship between Monument staff and local community service providers, will be an important future concern. It is likely there are distinct differences in the expectations and preferences of first-time and repeat visitors, and visitors from Utah compared to those from other states or countries.

To monitor visitor use trends, future research should replicate the intercept methods and use the results obtained from the initial 2004 study as representative baseline data. The mail survey results add more detail but they are essentially suggestive findings that tend to over represent relatively highly committed, interested, and longer term visitors. International and overlook visitors are also underrepresented in the mail survey results.

In general, visitors felt service workers were friendly and helpful, but information availability and visitor center hospitality could be improved. The availability and type of services seems to be the greatest concern, especially related to the lack of diversity, cost, and hours of operation. These factors may be related to the relative newness of visitor service demands in many of the Monument host communities.

One of the objectives of the GSENM management plan is to help provide economic opportunities for local communities. The BLM has responded to this charge by focusing the development of Monument visitor centers in the gateway communities of Boulder, Escalante, Cannonville, Kanab, and Big Water. These visitor information and interpretive centers, along with other local visitor and hospitality services, attract visitors as tourists who spend time and money in these gateway communities. Development at the periphery of the Monument, in the gateway communities and adjacent front country, keeps tourists more concentrated and less dispersed across the large expanses of the Monument. At the same time, economic benefits will accrue for local residents because of visitor spending in the gateway communities. Tourism development in any situation brings change along with potential positive and negative impacts. Positive impacts are often perceived as benefits, and these can benefit the economic, social, and environmental fabric of a locality or region. Negative impacts are considered costs and also affect the economic, social, and environmental fabric.

Collaborative planning and management can assist in minimizing costs while at the same time maximizing benefits, thus contributing to local community development. In order to assist in this endeavor, future collaborative research efforts working with stakeholder partners using the products from the front country surveys as baseline data should be explored. The focus would be on the collection of data for evaluating on-site and community education; examination of visitor needs, expectations, and preferences for visitor and hospitality services; analysis of the relationships between tourism, visitor and hospitality services, and local community development; and identification of other research needs.

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Learning from Contesting the Land: A Case Study of the Roads Dispute in Grand Staircase-Escalante National Monument

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ABSTRACT

The papers gathered together at this symposium celebrating the tenth anniversary of Grand Staircase-Escalante National Monument demonstrate that GSENM possesses unique scientific and historical resources that offer exceptional opportunities for research. What might be less apparent are the unique opportunities the Monument offers for social scientists who study ongoing social change. GSENM was created in a context of changing economics, demographics, and perceptions of the landscape in the West and a changing role for the federal government. Its creation was controversial, igniting and sustaining debate among a wide range of representatives from different levels and branches of government and citizens from different social, geographical, and ideological locations. These circumstances have provided a unique opportunity for a sociocultural anthropologist specializing in political anthropology to study the meaning and practice of democracy at the local level in the United States.

This paper, based on ethnographic research carried out in the Grand Staircase-Escalante region between 1999 and 2005, examines an issue that has proven challenging and controversial since GSENM was created: the management of roads on the Monument. This issue has frequently been represented by simple, two-sided images of conflict with the counties on one side and the federal government on the other. With such a simplistic portrayal, it is not surprising that such disputes often seem fruitless and impossible to resolve. My analysis approaches the dispute over roads as "current history" in order to understand how it reflects changing conceptions and practices of democracy in the United States. This paper provides a timeline of events in the dispute and interprets them from participants' points of view. It links these events and participants' commentary on them to long-term processes of change at the national level – in perceptions of the Western landscape, the role of the federal government, and the meaning and practice of democracy – and more recent regional economic and demographic shifts in the American West. This approach makes it possible to see that the dispute is not just about roads. At a deeper level, it is informed by democratic aspirations and attachment to place and it addresses more profound concerns about the ambiguous powers and weaknesses of the federal government, the meaning of democracy, and the future of the American West. The paper aims to demonstrate that ethnographic analysis can generate insight into disputes over the management of public land that will help participants find creative, effective, and democratic ways to work together to imagine and create a sustainable Western landscape.

Keywords: Grand Staircase-Escalante National Monument, public lands conflict, R.S. 2477 roads, political anthropology, democracy

Introduction

President William J. Clinton proclaimed Grand Staircase-Escalante National Monument (GSENM) on September 18, 1996 to protect its "spectacular array of scientific and historic resources." The Presidential Proclamation recognized the Monument's value for scientific and historic research and the "exemplary opportunities for geologists, paleontologists, archeologists, historians, and biologists" it would provide (Clinton 1996). In addition, it stipulated that GSENM would remain under the management of the Bureau of Land Management (BLM), instead of shifting to the National Park Service which manages most national monuments, making it the first national monument the BLM would manage and initiating a new role for the agency. To commemorate the tenth anniversary of the creation of GSENM, the second Learning from the Land Symposium has assembled papers describing some of the research that has been carried out during that period and demonstrating the foresight of the Proclamation.

Unforeseen by the Proclamation, however, is the opportunity the Monument has provided for a sociocultural anthropologist specializing in political anthropology to study the meaning and practice of democracy at the local level in the United States. GSENM has proven to be a productive site for such a study because the creation of the Monument was very controversial in Utah. President Clinton created the 1.7 million-acre Monument[1], the largest in the lower forty-eight states, in a surprise move just before the presidential election for his second term. He did not consult with local residents and Utah government officials nor inform them of his intentions beforehand[2]. He chose to proclaim GSENM from the south rim of the Grand Canyon in Arizona in a ceremony to which they were not invited. These actions angered residents of Garfield and Kane Counties, in which the Monument lies, whose lives would be affected by the new Monument. In these counties, 88.1% and 90.5%, respectively, of the land is federally owned (Goodman and McCool 1999: Table 14.1), and local residents have traditionally depended on the extraction industries of timber, mining, and livestock grazing on these lands for their livelihoods. The antipathy toward the Monument generated by these actions continues to infuse local government's and local residents' perceptions of it, making some issues affecting its day-to-day management difficult to resolve.

This paper analyzes one of those issues: the dispute over the management of roads on GSENM. Kane and Garfield Counties claim that, under the 1866 Mining Act, they have rights of way on the many unpaved roads on the Monument. The BLM has the authority, under the 1976 Federal Land Policy and Management Act (FLPMA), to develop and implement land use planning for the Monument. The dispute arises because the legal framework governing public land management specifies neither how rights of way may be identified nor their nature and extent. Nor does FLPMA elaborate on how rights of way and the BLM's management authority interact. This dispute has been arguably the most divisive and the most publicized dispute that has taken place on GSENM in the ten years since it was created, and it has implica-

[1] In 1998, the Utah Schools and Land Exchange Act and Public Law 105-335 carried out the President's intent to acquire state trust lands within GSENM, increasing its size to 1,865,420 acres (BLM 1999).

[2] In an interview that took place in 2004, after a U.S. District Court judge upheld President Clinton's use of the 1906 Antiquities Act to create GSENM, which had been challenged in a lawsuit filed by the Utah Association of Counties and the Utah School and Institutional Trust Lands Administration, former Interior Secretary Bruce Babbitt disclosed that GSENM had been created because one of the President's campaign advisors concluded that the re-election campaign needed "a dramatic environmental initiative," and that it should be "a surprise" and "done in secret" in order to "make the front page of the national press in a big splash." Interview with Charles Wilkinson and Patricia Limerick of the Center of the American West in Boulder, Colorado, April 20, 2004: http://www.centerwest.org/projects/secretaries/interviewpdf/babbitt.pdf, accessed 9/11/2007.

tions for the management of roads on public lands throughout the West. As of this writing, it has not been resolved.

I have chosen this controversial topic for my paper for two reasons. First, I want to indicate that what has been happening in the communities adjacent to the Monument in the ten years since it was created is as fascinating and significant as the research findings that natural and physical scientists, who have submitted the majority of the papers in this symposium, are reporting. In this paper, I approach the dispute over roads in the Monument as "current history," in which nothing less than the meaning and practice of democracy is being negotiated. Second, I want to show how ethnographic analysis can generate insight into disputes over the management of public land, which are often represented in simple, two-sided terms, as "conflict:" between federal and local government or between environmentalists and "anti-environmentalists." With such a simplistic portrayal, it is not surprising that such disputes seem fruitless and impossible to resolve. With a deeper understanding of the context in which a specific dispute is taking place and of the values and political ideals motivating the participants, these "conflicts" can be seen in a different light.

The specific objectives of this paper are: 1) to record the events in the dispute over roads on GSENM between 1996 and 2006; 2) to explain the significance of the events as "current history;" and, 3) to draw conclusions about the meaning and practice of democracy in the contemporary United States.

Method and Theory

This paper is based on ethnographic research carried out in the Grand Staircase-Escalante region during the summers of 1999 to 2003 and full time from September 2003 to September 2005. The analysis of the dispute over roads on the Monument draws specifically on the methods of participant observation, in-depth interviews with participants in the dispute, historical research, and content analysis of newspaper articles reporting the events described below[3].

My analysis is informed by a processual approach to ethnographic research, which treats fieldwork as "current history," or the study of "change-in-the-making" (Moore 1987). This type of approach allows the anthropologist to consider questions of agency, the extent to which people have control over the social circumstances of their lives. Anthropologist Sally Falk Moore suggests that anthropologists interested in this approach should choose for their raw data local events or processes that reveal "ongoing contests and conflicts and competitions and the efforts to prevent, suppress, or repress these" (1987: 730), because it is likely that more is at stake in these struggles than just the "foreground preoccupations" of the actors. Then, in order to begin "to see potential long-term implications in the day-to-day stuff," anthropologists must link the "foreground preoccupations" – the local events and what people have to say about them – to "background conditions," – "a variety of processes unfolding simultaneously on very different scales of time and place" – which affect local events in ways people may not be aware of or articulate (1987: 727). Local events reflect this variety of processes and therefore involve competing and contradictory ideas, actions, and causal forces. Interpretations and conclusions drawn from this type of analysis will necessarily be provisional, but will provide insight into what is being negotiated along with the "foreground preoccupations," and how social change actually comes about.

I use a processual approach for my research because I am interested in how the idea and practice of democracy is changing in the United States. There have been competing ideas of what American democracy means and how it should be practiced since the founding of the United States. For example, the Federalists, who drafted the Constitution in 1787, believed that a strong central government was necessary to protect democracy from outside threats and to guarantee individual rights, especially the right of property, in order to promote individualistic economic efforts in the short run and national wealth and power in the long. Their ideal citizen was the entrepreneur (Kemmis 1990, Rose 1994). But to ensure that the power of the federal government did not grow too strong, they built a series of checks and balances, including the division of governing powers among different branches and levels, into the Constitution.

[3] All quotations without references come from personal interviews with the author.

The Anti-Federalists, who opposed the Constitution as drafted and insisted on the addition of a Bill of Rights, believed that the greatest threat to democracy would come from a central government that grew too strong and that democracy flourished best among small, independent landowners of relatively equal means. They favored a decentralized government and institutions that promoted the development of civic virtue. Their ideal citizen was the small farmer (Kemmis 1990, Rose 1994). Both Federalists and Anti-Federalists believed, however, that an elite with talent and training should lead the nation. It was not until the "Jacksonian revolution" of 1828 that the "common man" was seen as capable of political leadership (Bailyn et al 1992). The competing ideas of the Federalists, Anti-Federalists, and Jacksonians have continued to inform laws and political institutions in the United States and the imaginings of its citizens.

Another example of how the meaning and practice of democracy has changed in the United States is the extension of voting rights over time to non-whites and women. My research considers how events on GSENM might reflect the ways American democracy is changing today as globalization and neoliberal ideology are reshaping the role the federal government plays in Americans' everyday lives.

My research contributes a much-needed perspective from the United States to a developing sub-topic in political anthropology, the anthropology of democracy. Anthropologists have only recently begun to contribute to the study of democracy, which has been undergoing a renaissance among political scientists since the end of the Cold War. Anthropologist Julia Paley (2002) argues that, because of their ethnographic methods and their attention to the viewpoints of the non-elite, anthropologists can contribute to an understanding of the ways that discourses of democracy and official democratic procedures actually play out on the ground. Most anthropological work on democracy so far has been carried out in places whose governmental systems have been undergoing a process of "democratization." Paley proposes that the next challenge for anthropologists is to study democracy in places not undergoing overt institutional change. In particular, she sees a need for an examination of the political ideals and institutions of the United States, "given that it is regularly taken as the unexamined standard bearer for the rest of the world" (2002: 271).

In my research, I do not begin with an a priori definition of democracy as a specific set of ideas or practices. I assume rather that democracy is a universal aspiration that means different things to different people in different places and at different times and is always being imagined and enacted in a particular set of circumstances. Thus, the meaning and practice of democracy is always contested and always changing. In this paper, I focus on how the participants in the dispute over roads on GSENM are imagining, enacting, and contesting democracy as they participate in the dispute, and how their viewpoints and strategies change over time to meet new conditions, transforming the meanings and terms of the debate and the meaning and practice of democracy as they participate.

The paper first describes the "background conditions" that I consider significant for understanding the roads dispute as "current history." With this perspective it becomes possible to see that the dispute is not just about roads. At a deeper level, it addresses more profound concerns about the ambiguous powers and weaknesses of the federal government and the nature of democratic government and about the future of the American West. In the second part of the paper, I provide a timeline for the dispute and analyze events from the point of view of the participants, connecting their "foreground preoccupations" to the "background conditions." In the conclusion, I draw on contemporary democratic theory to argue that the dispute over roads on GSENM is not just another "conflict over the use of public land," but democracy in action, and that GSENM in particular, and the public lands in general, are key sites for strengthening and revitalizing American democracy.

Background Conditions

In order to approach the dispute over roads on GSENM as "current history," I begin by briefly sketching the "background conditions" that are most important for my analysis. These include interrelated long-term processes of change at the national level in perceptions of the Western landscape, the role of the federal government, and the meaning and practice of democracy in the United

States, and more recent regional economic and demographic shifts in the American West.

From Vacant Territory to National Landscape: Federal Land Management Policy and the Rise of Federal Power

The dispute over who controls roads on GSENM has its origins in the 1866 Mining Act, which granted the right of way for the construction of highways over public domain lands. This Act was in keeping with a policy the federal government of the new United States of America had adopted when it first came into being in 1781. Beginning with the Land Ordinances of 1784, 1785, and 1787, Congress passed legislation to promote the orderly inventory, administration, disposal, and conveyance of title to private citizens of the vast and "vacant" public domain lands under federal ownership[4]. The purpose of this policy was to promote rapid settlement of these lands in order to strengthen the nation, secure its territory from foreign incursion, and promote democracy (Vincent et al 2004).

Federalists and Anti-Federalist agreed that the settlement and development of the "vacant" territory of the West would be good for democracy, but for different reasons. Federalists argued that "extending the sphere" would make it more difficult for factions to form. Anti-Federalists, on the other hand, felt that the expansion of agriculture into this "vacant" land would assure the continued vitality of republican principles (Kemmis 1990).

Unforeseen circumstances prevented the founding fathers' vision of a national landscape covered with a patchwork of small farms from being realized. On one hand, west of the 100th meridian, much of the land was too rugged and the climate too dry for small-scale farming. Despite the various homesteading acts passed by Congress beginning in 1862, much of the public domain remained in federal ownership.

On the other hand, the territory in the public domain increased rapidly with the Louisiana Purchase in 1803, the Oregon Compromise in 1846, and the war with Mexico in 1848, and the settlement that did occur outran Congress' attempts to regulate it in an orderly manner. As a result, Congress passed legislation that attempted to "catch up" with existing occupation and use and legitimize local management rules that had developed. The 1866 Mining Act is an example of this "catch up" legislation. Section 8 recognized whatever local solutions miners or settlers had devised for access to their property. This grant later became section 2477 of the Revised Statutes and is referred to as "R.S. 2477" in the contemporary dispute. R.S. 2477 highways played a significant role in the development of the West, as many state and county highways originated under this grant (Baldwin 1993, Vincent et al 2004).

By the late 19th century, the fact that no large areas of the West remained unsettled prompted historian Frederick Jackson Turner to announce the closing of the frontier. Jackson considered the existence of the frontier an important factor in the development of American democracy and contemplated what effects on democracy its closing would have (Faragher 1994). At about the same time, the consequences of the federal government's policy of encouraging settlement of the West were also becoming apparent. The public domain lands came to be seen as possessing "resources" which were threatened by rapid development and the idea of national management of these resources began to take hold. Congress created the first national park, Yellowstone, in 1872; in 1891, it granted the President the power (later rescinded) to establish forest reserves; and in 1906, it gave the President the power to establish national monuments. By the early 20th century, the emphasis of federal land laws had shifted from a policy of transferring the public domain lands to private ownership to a policy of retaining the remaining lands in federal ownership (Vincent et al. 2004). Western historian Richard White (1991) argues that the power of the federal government increased and took on its modern form through this process and through the development of the 19th century bureaucracies that would manage these lands and become the federal land management agencies of today.

These shifts in federal land management policy also coincided with the Progressive move-

[4] Although these lands were inhabited by native peoples with longstanding usufruct and territorial interests in the land, Euro-American settlers considered the lands "vacant," because native Americans did not have property interests, as the settlers understood them, in the land.

ment in the United States. The Progressives advocated using governmental authority and scientific efficiency to manage what was by then a flourishing national economy. The Progressive movement echoed Federalist principles and was exemplified by President Theodore Roosevelt, an ardent conservationist. However, as the federal government began to grow in power and take on more managerial functions, voter turnout began to fall. These two trends continued throughout the 20th century (Bailyn et al 1992).

Shifts in federal land management policy did not go unchallenged. They involved struggle and negotiation among the different branches and levels of government, as well as between government and citizens and between citizens with different interests. For example, Karen Merrill (2002) chronicles the struggle that ensued when the federal government first attempted to regulate livestock grazing on the public domain lands. The struggle took place between different sectors of the livestock industry (cattlemen and sheepmen), between ranchers and farmers, between the livestock industry and the federal government, between different levels of government, and within different departments of the federal government itself (the Departments of Agriculture and Interior). The negotiation process is still ongoing. The system of checks and balances built into the Constitution ensure this type of negotiation will take place. But more was being negotiated in struggles over shifting federal land management policy than the balance of power. For if, as the founding fathers believed, the policy of transferring the public domain lands to private ownership promoted democracy, then when that policy changed, the meaning of democracy would have to be renegotiated.

The public rangelands were the last of the public domain lands to come under comprehensive federal management. These arid lands were seen as unsuitable for settlement and lacking valuable resources and were generally considered "desert." Only when it became clear that the public rangelands were deteriorating as a result of unregulated livestock grazing, did Congress pass the Taylor Grazing Act in 1934 and begin the process of bringing them under federal management. Interior Secretary Harold Ickes established a Grazing Division (which became the Grazing Service in 1939) to guide this process. However, the BLM, which administers these lands today, and which emerged from a merger of the Grazing Service and the General Land Office in 1946, did not receive full authority to manage them until 1976[5].

Meanwhile, with prosperity and the proliferation of automobiles after World War II, perceptions of the public domain lands shifted again. As national parks became more developed and more crowded and national forests were harvested, undeveloped public domain lands began to be seen as "wilderness," where one could still find solitude and a landscape "untrammeled by man." The passage of the Wilderness Act in 1964 marked this shift.

The 1976 Federal Land Policy and Management Act (FLPMA) is BLM's organic act. It declared that the remaining public domain lands would be retained in federal ownership, officially ending the policy of disposal. The passage of FLPMA touched off the "Sagebrush Rebellion" among state and county governments and rural citizens in the west who wanted to take back local control of public land (Vincent et al. 2004). FLPMA also systematized and simplified the complex jumble of federal land laws that had developed as Congress had tried to keep pace with Western expansion. To systematize the management of roads on public land, FLPMA repealed R.S. 2477 and set out new provisions for the granting of various kinds of rights of way in Title V. It acknowledged rights of way for roads built prior to 1976 and gave the BLM authority to manage all other roads on lands it administered. However, it did not specify a process for identifying valid R.S. 2477 rights of way. As a result, controversy has arisen over how these rights should be determined.

Federal regulations issued to implement the provisions of FLPMA, beginning in 1979, attempted to close this gap. Initially, they provided an opportunity for state and county governments that had constructed public highways under the authority of R.S. 2477 to file maps with BLM showing the locations of highways claimed to be valid existing rights. According to county officials, Garfield and Kane Counties both produced such maps, showing the roads they claimed and considered to be part of their county transportation system. Since these initial efforts, little progress has been made in establishing an effective admin-

[5] In this paper, I refer to BLM-administered land as public land or the public lands.

istrative process for resolving R.S. 2477 disputes, due to the effect of changing presidential administrations and control of Congress on administrative law. In 1994, the Clinton Administration Interior Department proposed new regulations that would have established an administrative procedure for determining the validity of R.S. 2477 claims. The rules were never finalized because the Republicans took over Congress in 1994 and, in 1997, imposed a permanent moratorium on further Interior Department R.S. 2477 regulations (Rasband 2005).

The federal courts have also tackled the ambiguous issue of R.S. 2477 rights of way. Much of the discussion has focused on the meaning of "construction" and the meaning of "highway." Two prominent cases involving R.S. 2477 rights of way originated in Garfield County, partially accounting for local residents' heightened sensitivity to the issue. In the mid-1980s, the County's plan to improve and pave the Burr Trail (most of which now lies in GSENM) generated opposition from environmental organizations and became the subject of a case that challenged the scope of R.S. 2477 rights of way. The case resulted in a decision that was very influential in subsequent R.S. 2477 litigation (Rasband 2005)[6]. The Burr Trail dispute also became very contentious locally when some residents who had recently moved to Boulder, the Burr Trail's western terminus, organized to oppose the County's plan. Their organization later became the wilderness advocacy group, Southern Utah Wilderness Alliance (SUWA), and a key actor in the roads dispute on GSENM. The federal government sued Garfield County again in 1996, when road crews performed what they called routine maintenance at the entrance to Capitol Reef National Park without obtaining a permit from the Park Service (Rasband 2005). Despite the contributions of these significant cases originating in Garfield County, the federal courts have still not clarified the precise requirements for establishing a valid R.S. 2477 right of way.

FLPMA also directed the BLM to inventory the roadless lands it administered for possible inclusion in the National Wilderness Preservation System, which had been established by the 1964 Wilderness Act. One of the reasons that the issue of R.S. 2477 roads is so contentious is because, while these rights of way may be important to the infrastructure of states and counties, they could disqualify areas that are currently considered roadless from inclusion in the National Wilderness Preservation System (Baldwin 1993, Rasband 2005). The issue became even more contentious in Utah when wilderness advocates, who did not agree with the outcome of BLM's wilderness inventory in Utah in 1984, began to conduct their own. SUWA also played a leading role in this "citizens' inventory," adding to the antipathy some residents of Garfield County already felt toward the organization. The efforts of Utah wilderness advocacy groups prompted Interior Secretary Bruce Babbitt, in 1996 (the same year GSENM was created), to direct the BLM to conduct a new wilderness inventory in Utah. Utah, with the second-largest proportion of BLM-administered land of any state[7], has remained at the center of the R.S. 2477 debate. As a result, residents of southern Utah have a heightened awareness, if not a full understanding of the complexities, of the issue.

The creation of GSENM reflected the most recent shift in perceptions of the public lands. In 2001, the BLM created the National Landscape Conservation System to manage GSENM and fourteen more national monuments President Clinton created before leaving office, as well as the National Conservation Areas, Wilderness Areas, Wilderness Study Areas, National Historic Trails, and Wild and Scenic Rivers under its jurisdiction[8].

The New West: Economic and Demographic Shifts

The rate and character of development of the American West changed dramatically after World War II, driven by the explosive growth, first, of the defense industry and, in the 1990s, of knowledge-based industries. Urban real estate prices skyrocketed, driving "equity migration" to cheaper rural

[6] For the purposes of this paper, it is not necessary to describe the court cases mentioned and the resulting decisions in detail. This paper is more concerned with the significance that participants in the roads dispute on GSENM give them. For a detailed legal discussion of R.S. 2477 litigation, see Birdsong 2005 and Rasband 2005.

[7] Nevada has the highest proportion of BLM-administered land with 91.9% federally-owned land and 68% BLM-administered land; Utah is second with 66.5% federally-owned land and 43% BLM-administered land (BLM Public Land Statistics 1999, Vincent et al. 2004).

[8] http://www.blm.gov/nlcs/, accessed 01/03/2007.

areas. The growing work force flocked to dramatic or idyllic nearby landscapes for recreation and the many national parks, forests, and monuments attracted visitors from all over the country and the world. Soon Western rangelands were no longer "chiefly valuable for grazing[9]." Private lands were far more valuable for real estate development and public lands for their aesthetic value and for recreation (Sayre 2005). In fiscal year 2004, the BLM announced that, for the first time in its history, it had collected more from recreation receipts than from grazing fees (Billings Gazette, 7 October, 2004).

Meanwhile resource-based rural economies fell into decline as a result of decreasing commodity prices, horizontal integrations in agriculture, increasing property taxes, and opposition to federal land management policies and practices by environmental organizations. As jobs in ranching, timber, and mining declined, the main local industries became tourism, recreation, and real estate. The first two typically offer low-paid service employment, while the latter generates tax increases (Walker 2003). As a result, in many places, the "locals" can no longer afford to live where they grew up or where they work. The new industries depend on the existence of landscapes that fit the primarily urban environmental aesthetics of an imagined "pristine" nature. Local livelihoods, in contrast, depend on the existence of working landscapes that local residents experience as "home." As the rural West shifted from a resource-based production economy to an amenity-based consumption economy, the public lands became contested terrain because they help to drive both.

Since the 1990s the population of the eight intermountain states has risen three times faster than the United States as a whole (Sayre 2005). The fastest-growing parts of the West are rural, not urban or suburban areas. Newcomers are primarily urban, college-educated, middle class, professionals. The Atlas of the New West defines a "New West" county as one that is dominated by college-educated professionals or service workers (Riebsame and Robb 1997). This demographic shift changes local politics in the rural West as newcomers, whose views and lifestyle differ from the "locals," become economically dominant or the demographic majority. According to geographer Peter Walker, who studies "The New West," the clashes between "newcomers" and "locals" are more than just conflicts between cultures or ideologies. They reflect tensions resulting from "competing capitalisms that commodify nature in incompatible ways" and "an increasingly uneven development and a sharpening of class differences" (Walker 2003: 17 &18).

These economic and demographic shifts have affected Garfield and Kane Counties more slowly than the West as a whole. Jobs in ranching, timber production, and mining have declined, but the communities have not yet experienced a large influx of newcomers because they lack some of the factors that attract newcomers (e.g. airport, short driving distance to a city) (Sonoran Institute 2003a, 2003b, 2004). Except for Kanab (population 3564 in the 2000 census), none of the towns adjacent to the Monument has more than a few hundred residents (Escalante is the largest with 818), a large subdivision, fast food stores, or a mall. A majority of the residents are descendants of the Mormon pioneers who first settled the area and are proud of their pioneer heritage. Many residents still augment their income by raising livestock and identify with a culture and lifestyle they associate with ranching. They welcome tourism if it brings more jobs, but they don't want to become "another Moab."

These "background conditions" – changing perceptions of the public lands, a changing role for the BLM in administering these lands, and changing local economies and demographics – have created economic and social uncertainty among those who live adjacent to GSENM, as well as differences of opinion locally, nationally, and within the BLM itself about how GSENM should be managed. The history of conflict over roads in the region and the way that GSENM was created also predisposes many local residents to be on the defensive where roads on the Monument are concerned. It is in this context of unfolding processes and uncomfortable emotions that I begin to analyze the "foreground preoccupation" with roads on GSENM.

The Case Study

Table 1 is a timeline of events in the dispute over roads on GSENM since its designation in

[9] Text of Taylor Grazing Act.

1996	
September	Grand Staircase-Escalante National Monument created
October	Garfield and Kane Counties grade R.S. 2477 claimed roads in GSENM, Wilderness Study Areas (WSA), and lands being considered for WSAs.
	Federal government files trespass actions against the counties.
1997	Congress imposes moratorium on Interior Department R.S. 2477 regulations.
1998	
November	Draft Monument Management Plan released
December	Kane County and BLM reach tentative agreement of roads in GSENM (later breaks down).
1999	
November	Final Monument Management Plan Signed
2000	
February	Monument Management Plan goes into effect
March	Governor Leavitt announces massive lawsuit to determine R.S. 2477 road ownership. (Suit was never filed).
December	Monument Manager Kate Cannon and Kane County Commission reach agreement on road numbering system for roads within GSENM
2001	U.S. District Court Judge Tena Campbell rules against R.S. 2477 highway claims asserted by Garfield, Kane, and San Juan Counties in 1996 case.
2003	
January	Interior Department publishes final regulations on “disclaimers of interest.”
April	Memoradum of understanding between the State of Utah and Department of the Interior on State and County Road Acknowledgment.
August	Kane County officials remove BLM signs from roads in GSENM claimed by the County.
November	Kane County officials receive Grand Jury subpoenas.
2004	
February	U.S. District Court Judge Tena Campbell reaffirms 2001 ruling.
	General Accounting Office finds Utah MOU illegal.
2005	
February	Kane County begins installing signs on Class D county roads.
March	Utah State Legislature passes H.B. 264 to clarify State’s position on public land issues.
April	BLM Utah State Director gives Kane County two weeks to remove signs or face legal action.
June	Case referred to U.S. Attorney for Utah
September	Kane County passes an ordinance opening all roads in the county to ATVs unless closed by the county
	10th Circuit Court of Appeals reverses 2004 Tena Campbell decision.
October	Environmental groups file suit against Kane County for enacting road ordinance.
November	Kane County files suit against Interior Department challenging transportation and water planning in Monument Mangement Plan
2006	
March	Outgoing Secretary of the Interior Gale Norton signs new guidelines for resolving R.S. 2477 rights of way.
October	Rep. Steve Pearce introduces H.R. 6298, proposing a process for determining R.S. 2477 rights of way.
December	Kane County rescinds ATV ordinance and announces intent to remove ATV-open decals.

Table 1. Timeline for road dispute in GSENM.

1996. We have already seen that FLPMA initiated the debate over who controls roads on public land due to its incomplete treatment of the question of existing rights of way. But it is clear from the following discussion that the creation of GSENM, the subsequent development and implementation of a management plan for the Monument, and local reactions to these events have heightened public awareness of the issue and added a sense of urgency to the need to resolve it.

The purpose of a timeline is to represent events in the order they happened. What a timeline cannot represent is how different people experience and interpret the events. In this section I present the timeline from the point of view of different participants in the dispute – Kane and Garfield Counties, BLM, the Interior Department, environmental organizations, local residents, and those from outside the area – and explain why they may hold this point of view by connecting it with personal experiences and the "background conditions" just described. I also show how the viewpoints and actions of participants illustrate recurring themes that can be linked to democracy. The themes that are most prominent in the data are: 1) order versus disorder; 2) rule of law versus lawlessness; 3) legitimacy; 4) transparency; 5) balance of power; 6) voice and inclusion; 7) participation; and 8) transformation. Finally, I demonstrate that participants do not hold fixed positions, but alter their viewpoints and strategies, their alliances and oppositions, to meet new conditions. By doing so, they transform the meanings and terms of the dispute and the meaning and practice of democracy as they participate.

1996

When President Clinton proclaimed GSENM, residents of adjacent towns who objected to the way the Monument was created showed their displeasure immediately in a variety of ways. In Escalante, figures of President Clinton and Interior Secretary Bruce Babbitt were hung in effigy. Kanab held a "Loss of Rights" rally where attendees wore black ribbons of mourning. The town was decorated with black balloons and many businesses shut down (Salt Lake Tribune [SLT], 19 September 1996: A7).

Local residents later articulated a number of reasons for these displays of opposition. The comments of two Utah officials reflect the idea that in a democracy the federal government should not have too much power and there should be balance of powers among the levels of government. Mayor Brent Mackleprang of Fredonia, Arizona, located just across the border from the new Monument, declared that, "The Constitution was not written up for one man to have that much power" (SLT 19 September 1997: A7). Utah Senator Orrin Hatch asserted, "I have never seen a clearer example of the arrogance of federal power" (Maddox 1996: A5).

Complementary to the idea that the government should not have too much power for democracy to work, is the idea that the people should have a voice and that government should solicit and consider the voices of its citizens in decision-making. One Kanab resident expressed this idea by saying, "I think it was the way the Monument was created that created a lot of feelings within the community, because the citizens of Garfield and Kane Counties and the local officials were totally left out of the loop."

She told a story about the Kane County Commissioners' efforts on behalf of their constituents at the time the Monument was created that reinforced the bitterness local residents felt on being excluded. The press had leaked rumors about an impending action, so two of the commissioners flew back to Washington D.C. to try to get more information. (Her emphasis is in italics.)

> So the three county commissioners, two of them went back East, and they talked to all of our congressmen and senators – Hatch and Bennett – neither one of them – they were Republicans, knew anything about it. Bill Orton, who was a Democrat, who was our local Congressional Representative, did not know anything about it. He was not in the loop either. On the day, *on the day* that the Monument was declared – and that was at the South Rim, and that was by invitation only – on that day our commissioners – Judd and Carroll – were in Leon Panetta's office. Now Leon Panetta himself… They knew there was going to be a Monument, but *nobody knew* what the proposed boundaries were going to be, and what was going to be entailed exactly ...
>
> Out of frustration, Joe Judd said to the office girl there, in Leon Panetta's office, 'We

need to be able to take something home to tell our constituents.'

Her answer to him was: 'Do people live there?' So that shows a certain amount of ignorance for what was involved back there. Okay, that's our two commissioners. This is on the actual day that it was declared. Those two commissioners were flying home. Meanwhile, the third commissioner was Steve Crosby, and he went to the South Rim. Now, representing Kane County, he couldn't get past the checkpoint. So there was a *lot of bitterness*. And I only give that story as an example because that was the example that generated a tremendous amount of bitterness. And nothing to do specifically with the people that are there now. But because of the way that it happened, it helped to create a lot of bitterness.

Not only had the local citizens been excluded, their elected representatives had been rebuffed. She went on to link feelings about the Monument with feelings about "background conditions": changes in the local economy.

Because you have to realize, the bitterness was there, not only because of the way it was done, but also because Kane County was placing a lot of hope on Andalex[10] and jobs for our economy. Because the mill[11] had shut down – they had gone from three shifts, to two shifts, to one shift, to no shift – and all those cutbacks we felt in the schools, we felt in the local economy. And so there were people holding on, hoping that they could get a job out there. So you have to kind of put it all in perspective. And this is just after, we also had another outfit here that was mining uranium out there on the Arizona Strip, and they got out of price there for a little while and they shut down – Energy Fuels it was called. They got shut down and that was a hundred employees. And you stop and think about all of the employees in this area, whether you're for or against lumber, whatever it is, the point is, it had a disastrous effect on the local economies. So if you take the background on all of these, and you just build on those, I mean that was just kind of like the last blow.

In Escalante and Boulder, ranchers were having a hard time dealing with increasing numbers of hikers who visited the red rock canyons where their cattle grazed. The hikers sometimes confronted the ranchers or left negative remarks about the cows they encountered in the trailhead registers for the BLM to read. Ranchers' line shacks had been burned and their cattle shot without those responsible ever being identified. Gates were regularly left open, costing ranchers much effort to round up stock that had wandered where it wasn't allowed to be. Ranchers feared the new monument would bring both more hikers and tighter regulation of their livestock operations, making it even more difficult to make a small profit. Supporters of the Monument promised it would bring more jobs in tourism, but the ranchers, timber workers, and miners knew those jobs would not pay as well as their former professions, nor would "cleaning toilets," as they often referred to those jobs, bring them the satisfaction that hard work and producing something tangible had.

Another reason that local residents were apprehensive that the new Monument would increase economic hardship was because, in the recent past, two other national monuments had been created in the region, which had later become national parks, from which all resource extraction was prohibited. In 1923, President Warren G. Harding proclaimed Bryce Canyon, which borders GSENM on the west, a national monument. It became a national park in 1928 and livestock grazing was gradually eliminated (Newell and Talbot 1998). Capitol Reef National Park, which borders GSENM on the north, also started out as a national monument, proclaimed by President Franklin D. Roosevelt in 1937. In 1969, in the last hours of his administration, President Lyndon B. Johnson, used the Antiquities Act to increase the size of the Monument by 600%. In 1971 Congress made Capitol Reef a national park and initiated the process of eliminating livestock grazing. The process is not yet complete (Frye 1998).

These fears and uncertainties about personal and community futures are the local face of the declining rural resource-based production economy. Those experiencing these seemingly inexorable and uncontrollable changes in their

[10] She is referring to Andalex Resources Inc., a Dutch-owned company that held leases for coal on the Kaiparowits Plateau at the time GSENM was created.

[11] She is referring to Kaibab Industries, a lumber mill in Fredonia, a few miles across the Arizona border from Kanab.

lives can discuss the effects of "economics," "free trade," and "globalization," and can understand their experiences in these terms. But they also want to understand them in terms that might grant them some control over the circumstances of their lives. The Monument represents the advance of the new, amenity-based consumption economy into southern Utah. While local people can't do anything about globalization, they feel they might be able to do something about the Monument. While they may not be aware of it, by contesting the creation and management of GSENM, they are also reacting to the effects on their daily lives of globalization and the shifting regional economy and a federal government they perceive as exercising and expanding its power to promote the national and regional economy at their expense. In the discussion that follows, it is important to keep in mind that the anger provoked by what local residents see as the undemocratic way the Monument was created and anxiety about the viability of the local economy and culture continue to infuse and heighten emotional tension in the roads dispute on the Monument.

In October, after GSENM was created, Garfield and Kane Counties sent out road crews with bulldozers to grade R.S. 2477 claimed roads within the Monument, including roads in Wilderness Study Areas (WSAs) and proposed WSAs[12]. In response, SUWA, having developed into an organization of substantial size and funding, sued the counties for illegal actions and the BLM for failing to protect the areas. Later that month, the federal government sued the counties for trespass (Rasband 2005). The resulting court cases dragged on for nine years, but turned out to be crucial in the ongoing R.S. 2477 debate.

Garfield County Commissioner Louise Liston explained the county's actions in this way:

> We've been debating and fighting over [this issue] for a long time, and maybe the courts will have to decide. We've been harassed, threatened, and intimidated by federal officials for working on those roads. Maybe it's time to find out who they really belong to (Gorrell 1996).

The Counties accomplished two things with this action. First, like many of the local residents, they expressed their opposition to what they perceived as the undemocratic way that GSENM had been created. Their action also asserted local power, reminding the federal government how attenuated its power is in rural areas. Second, they made a statement that could not be ignored, hoping to provoke a decision from the courts about R.S. 2477 roads. While these messages may seem contradictory, they illustrate that the balance of power between the different levels and branches of the American government and between the government and its citizens is a delicate one that is constantly being negotiated in a variety of ways.

In response to the counties' actions, U.S. Attorney Scott Matheson, representing the position of the federal government, asserted:

> There is a right way and a wrong way for the counties to assert their road claims. The course they have followed is the wrong way because it violates our fundamental commitment to the rule of law. We obviously feel the need to assert the claims of the federal government in the face of their outright defiance. The counties should pursue their road claims within our legal framework, not bulldoze first and litigate later (Gorrell 1996).

In fact, there was no "right way" and "wrong way" and no "legal framework" for the counties to "pursue their road claims." The comments of the U.S. Attorney are an example of the way we talk about the federal government as if it were a coherent, unified entity that is orderly and produces order, when, in fact, the federal government is composed of different branches and departments that may be pursuing different ends and may interact in ways that produce unforeseen and unintended effects. The latter view of the federal government is consistent with a new approach to the anthropology of the state that deconstructs the conception of "the state" as an integrated, autonomous entity that dominates another called "society." It focuses instead on how the idea of the state is constructed through discursive practices of representation and interpretation and the everyday activities and routines of state bureaucracies, and how the idea of that state serves to conceal relations of power and forms of discipline in day-to-day life (see, for example, Sharma and Gupta 2006).

Spokespersons for environmental organizations who commented on the counties' actions reinforced the U.S. Attorney's characterization

[12] San Juan County also participated in this action and the subsequent litigation.

of the federal government as keeper of "the rule of law" by describing the actions taken by the counties as disorderly and lawless. "The counties are acting like spoiled, rotten children desecrating our national monument." And, "I am increasingly alarmed by this rash of lawless behavior" (Gorrell 1996).

This initial event set up a three-way dynamic between the federal government, Garfield and Kane Counties, and environmental organizations, principally SUWA. Initially, the Counties and the federal government were in opposition and SUWA opposed both. This dynamic shifts throughout the timeline as participants in the dispute alter their viewpoints and strategies and their alliances and oppositions to meet new conditions and it becomes more complex as new participants enter the dispute.

1998

The process of developing a Monument Management Plan (MMP) for the new Monument, including a Transportation Plan, set the stage for the next developments in the unfolding R.S. 2477 dispute on GSENM (Figure 1 shows the Transportation Plan in the final MMP). Federal law requires public input in the land use planning process, a requirement that reflects the idea that democratic decision-making should include the input of all affected and interested parties. Proponents of participatory democracy also argue that participation in government is a transformative process that produces the kind of civic-minded citizens necessary to make democracy strong (Barber 1984).

When the Monument released a draft MMP in November 1998 it held a series of "open houses" to gather public comment on the draft. Locally, the open houses were poorly attended. According to Garfield County Commissioner Maloy Dodds, "The attitude here is we have been beat down [by the federal government] so many times, what's the use of getting involved" (SLT, 8 January 1999: B3). Kane County Commissioner Norm Carroll offered a similar explanation. "People here still don't agree with the way it all happened, and some of them still feel very strongly about that. But they feel the management plan is a done deal, and any input at this point isn't going to do a lot of good" (SLT, 8 January 1999: B3). It appeared that long-term residents of the region, as a result of previous experience with the federal government, were apathetic. However, as a result of the demographic shift occurring in the rural West, residents who had moved in more recently did not share this experience and this attitude.

In addition to the public meetings, BLM also solicited written comments on the draft MMP. One local citizen who submitted comments was Mark Habbeshaw, who had recently moved to Kanab after retiring from a career with the Las Vegas Metro Police Department. He was an avid off-road motorcyclist and had joined the local Jeep club, and he volunteered to look into the roads issue for the newly formed Kanab branch of People for the USA. "I don't know why I did it," he recalled later. "But I felt like it was something I should do" (Havnes 2005).

Mr. Habbeshaw was a thorough researcher who started with a road he was familiar with that was slated for closure, called some key people, documented their conversation, and included this information in his comments. When the final MMP was released, the road remained open. Looking back, he identified this as a pivotal experience that propelled him into local politics. It gave him insight and confidence and showed him that, "if you validly participate, you can make a difference." Mr. Habbeshaw went on to become a leading figure in the dispute over roads on the Monument. His story illustrates the transformative power of public participation and the difference an individual can make.

While the process of preparing a MMP was underway, then-Monument Manager Jerry Meredith was also holding discussions with the Garfield and Kane Commissions about which roads on the new Monument the counties would maintain[13]. Counties take responsibility for maintaining the roads in their transportation systems and receive

[13] The BLM was aware that the transportation plan in the MMP might conflict with existing rights of way. A footnote in the Transportation and Access section of the final MMP states:

> It is unknown whether any R.S. 2477 claims would be asserted in the Monument which are inconsistent with the transportation decisions made in the Approved Plan or whether any of those R.S. 2477 claims would be determined to be valid. To the extent inconsistent claims are made, the validity of those claims would have to be determined. Id claims are determined to be valid R.S. 2477 highways, the Approved Plan will respect those as valid existing rights. Otherwise, the transportation system described in the Approved Plan will be the one administered in the Monument (BLM 1999: 46).

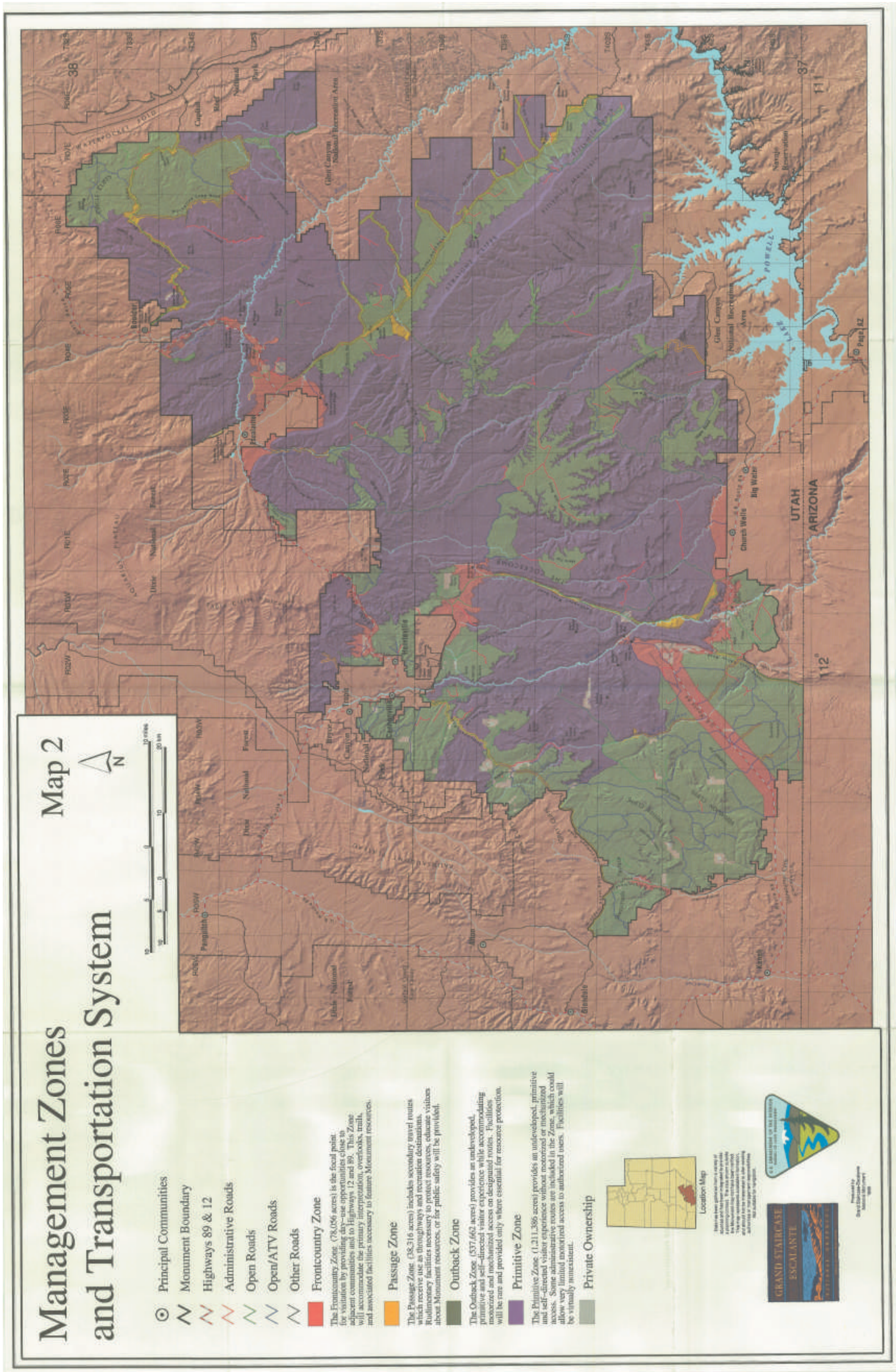

Figure 1. Transportation Plan in final Monument Management Plan

money from the federal government to help them. It is to the benefit of GSENM that they continue to do so. However, the Monument Manager could foresee problems if the MMP recommended closing some of the roads.

In December, Jerry Meredith reached a tentative agreement with the Kane County Commission. Garfield County did not participate. He was pleased that the County seemed to have changed its position and was working with the Monument: "Everybody is really trying. Both sides would like to find an agreement that doesn't mean years in court and millions of dollars in attorney fees" (Woolf 1998). Kane County Commissioner, Joe Judd, who had been fiercely opposed to the Monument when it was created, said county officials were trying to work in partnership with monument managers to resolve conflicts in a friendly way. Although, "it was arrogant as hell for the president to use the law to his advantage as he did," he said, "we're not going to sit around with our head in our hands" (Larmer 1997). SUWA had also changed its attitude toward the County. A spokesperson for SUWA acknowledged, "Kane County deserves a lot of credit" (Woolf 1998). The groups who had been in opposition over the road grading, now seemed to be working together. Everyone was optimistic because democracy seemed to be working the way it was supposed to – toward consensus. But a group of Kane County citizens, who had not been part of the discussions between the County and the Monument Manager, voiced strong opposition to the agreement because it would require that the county give up R.S. 2477 rights of way on the Monument. As a result, the agreement eventually fell through (Woolf 2000).

2000

In February 2000, the final Monument Management Plan went into effect. Kate Cannon was the Monument Manger at that time. She had been with the National Park Service before becoming Associate Manager in 1997 and Monument Manager in 1999. The NPS approaches land management with a preservation mandate, rather than the multiple-use mandate of the BLM. Her appointment raised the concern of those who already feared that GSENM would be managed in a very restrictive manner.

Like her predecessor, Cannon wanted to negotiate a road agreement with Kane and Garfield Counties in order to prevent conflict from developing when roads in the Monument were closed to implement the MMP. She was able to reach an agreement with the Kane County Commission when she conceded that the counties would not have to give up their R.S. 2477 rights of way. Garfield County again declined to participate in any agreement. New Monument Manager Cannon had just finalized the agreement when I first met her in August 2000 and she was ecstatic. Commissioner Joe Judd, on the other hand, sounded weary of the debate: "Roads have been a pain in the hips ever since I became commissioner. It would be nice to put these things aside" (Woolf 2000).

In March, Utah Governor Leavitt had brought the State of Utah into the R.S. 2477 road issue. Frustrated by the piecemeal creation of R.S. 2477 policy from court cases resulting from individual federal-county disputes, he proposed a more comprehensive approach: a massive lawsuit involving the thousands of R.S. 2477 roads claims made by Utah counties. The Governor's reasoning invoked the economic uncertainty rural counties were facing: "We have to resolve this," he explained. "The issue is too fundamental to the future of rural Utah to leave it alone" (SLT, 17 March 2000: A1).

When the State of Utah decided to enter the R.S. 2477 debate, a new dynamic developed and possibilities for alliances and oppositions and for negotiating the balance of power increased. The same group of Kane County citizens who had opposed the first roads agreement opposed the County Commission's new agreement with Kate Cannon. This time their reason was because they felt it could undermine the State's proposed lawsuit. They brought the agreement before a State district court, which put it on hold. The proposed lawsuit never materialized, however, because, later that year, George W. Bush was elected President. The State of Utah changed its strategy and began negotiating with the Interior Department (Rasband 2005).

In December, the Kane County Commission approved a road numbering system for GSENM proposed by Kate Cannon. Minutes from the Commission meeting indicate that three types of signs were approved: road numbering, points of interest, and stay on the road. However, when the road signs were installed, restrictions prohibiting motorcycles and ATVs (all-terrain vehicle, also referred to as OHV [off-highway vehicle]) were attached. The commissioners expressed their disapproval of the restrictions to Monument Manager Cannon, who explained they were a "mistake" and would be removed (Gubler 2003). According to the commissioners, they were removed.

The incident could have been a real mistake or an attempt to implement the transportation plan in the MMP as an accomplished fact. It is not clear what happened or why. This incident illustrates again that we cannot think of the state as an entity that always operates rationally or according to a system of law or policy. Attempts by state officials to interpret and follow laws and policies are shaped by personal backgrounds, bureaucratic procedures, extenuating circumstances, and interactions with other agencies, and they can have unintended consequences. In the complicated system of bureaucracies that is the state, there are many zones of indeterminacy and opportunities for plans to go wrong. At the same time, the personal motivations of bureaucrats often cannot be distinguished from official reasons. In this case, this seemingly small "mistake" became an important determinant of how events in the dispute over roads on GSENM later played out.

2001-2003

In June 2001, U.S. District Court Judge Tena Campbell ruled against the R.S. 2477 highway claims asserted by Garfield and Kane Counties in the 1996 case. A representative for SUWA stated, "This ruling will finally bring some reason to the debate" (Warchol 2001). It was looking like a victory for the environmentalists. Judge Campbell reaffirmed her ruling in 2004. The Counties appealed the decision and the case then went to the Tenth Circuit Court of Appeals.

Also in 2001, Kate Cannon accepted a position as Deputy Superintendent of Grand Canyon National Park. USA Today reported that she was the victim of a "personnel purge," taking place since the advent of the Bush administration, of BLM land managers whose approach to public land management favored environmental interests too much (Kenworthy 2002). Dave Hunsaker, a career BLM employee, became the new Monument Manager in January 2002.

Meanwhile, the State of Utah's negotiations with the Interior Department resulted in a Memorandum of Understanding, signed in April 2003, which established an "Acknowledgement Process" for determining R.S. 2477 rights of way in Utah. Governor Leavitt and Interior Secretary Gale Norton extolled the cooperation between the federal government and the State of Utah as a breakthrough in the R.S. 2477 dispute. "For more then 25 years, road-ownership disputes have strained relationships between Western states and the federal government," said Norton. "It's time to find solutions and we're doing that in Utah with this agreement" (Smith 2003). Garfield County Commissioner Maloy Dodds seemed less enthusiastic about R.S. 2477 agreements that did not include the County's input. He simply commented that the R.S. 2477 litigation that the County was engaged in "is not a very productive way to do business" (Smith 2003). SUWA saw the MOU, and a new "Disclaimer Rule" published earlier that year by BLM, as the result of "secret, closed-door negotiations[14]," and "part of an overall strategy to attack wilderness lands in Utah and to make sure any lands designated for wilderness are held to the barest minimum" (Smith 2003). Local government and concerned citizens both felt left out and mistrustful of the negotiations between the State of Utah and the Department of the Interior. Their feelings reflect the idea that democracy means decision-making should not only be inclusive but also transparent at every level.

After his input on the draft MMP, Mr. Habbeshaw had gone on to join the Kane County Resources Committee, which gives advice to the Kane County Commission on resource issues. In that capacity, he became very knowledgeable about the legal frameworks governing roads and grazing on the public lands. Based on his accomplishments, he was encouraged to run for County Commissioner. In November 2002, Mark Habbeshaw ran for Kane County Commissioner and was elected.

In retrospect, Commissioner Habbeshaw said he felt that he was elected because a void existed for people whose interests were not being represented. He is a member of the Mormon Church, but learned that, in southern Utah members of the

[14] http://www.suwa.org/page.php?page_name=Camp_2477_Home, accessed 01/03/2007.

Mormon Church are not comfortable with conflict and will go to great extent to avoid it. They needed someone to speak up for them and he is a person who likes to get the issues out on the table. This reflects an understanding of democracy as the idea that the people should have a voice and that elected officials should represent their voice. In addition, Commissioner Habbeshaw saw political office as an extension of his career in law enforcement and as a way of being able to pay back the community for being able to live there: "What it goes back to: being a cop, you want to help people."

Commissioner Habbeshaw expressed great respect for the law. He said that during his career in law enforcement his job was to make sure that citizens obeyed the law. Now, as County Commissioner, he is making sure the federal government obeys the law. As he saw it, "The law is our friend. When we get into trouble is when agencies deviate from the law. A federal agency needs to have authority for everything they do; they need to be able to show where it derives from. Where we have had success in protecting our rights is by using the law." Both Commissioner Habbeshaw's words and actions indicate that, in his view, democracy works through the rule of law and citizens who participate can use the system to address their concerns and create change. Nevertheless, one of his first actions in office, intended to further discussion of the roads issue on GSENM, was condemned by many as illegal.

August 2003

On August 13, 2003, Commissioner Habbeshaw and Kane County Sheriff Lamont Smith drove through the portion of GSENM lying in Kane County and removed thirty-one road signs with restrictions on motorcycle and ATV use that had been placed by the BLM. They deposited the signs at Monument Headquarters in Kanab along with a letter citing a state law that allows removal of unauthorized signs on state and county rights of way and requesting the Monument Manager to remove remaining signs on county roads.

The incident sent the town of Kanab into an uproar, made state and national news, and provoked Monument management to take action. In Kanab, some residents praised the county officials for protecting local rights and challenging federal "tyranny;" others condemned them for exacerbating local divisions and tarnishing Kanab's image. The Garfield County commissioners expressed their support for the action. The Kanab City Council split evenly in its appraisal of the incident. Letters to the Editor supporting one side or the other shot back and forth in the local newspaper, the Southern Utah News (SUN). The following example, from a resident of Montana, illustrates the predominant perception of the events from someone outside of southern Utah. "In planning future vacation travel, my wife and I came across your website, but after reading about the actions of the Kane County Commissioners we consider travel to your area right up there with war-torn third world countries in Africa" (SUN, 8 October 2003). A group of friends met over coffee to discuss how they could express their support for the Monument and formed a group called "Friends of the Monument." The group eventually developed into Grand Staircase-Escalante Partners, whose mission is "to assist Grand Staircase-Escalante National Monument in its mission by raising public awareness, support and funding[15]."

It is not clear how the restrictions on motorcycle and ATV use came to be there. Kate Cannon had supposedly had them removed. Had these been overlooked at that time? Or had they been placed subsequently? When asked about the signs, the new Monument Manager, Dave Hunsaker, invoked a zone of indeterminacy created by the discontinuity of government service and the bureaucracy's insistence on documentation. "I have heard various stories," he stated. "But I have nothing in writing" (Spangler 2003). Commissioner Habbeshaw's statement indicated that he understood that the signs signified more than restrictions the county had not agreed to: "A federal road number connotes federal ownership." Their effect would be real, no matter how they got there.

Soon after he had taken office that year, Commissioner Habbeshaw had written to Monument Manager Dave Hunsaker and requested that the signs be removed. When the request was not fulfilled by August, the Commissioner decided that what was needed was "a definite action that would create change." He explained later, "Had we not removed the signs there would be no impetus to consider this. We had to force the issue some-

[15] http://www.gsenm.org/, accessed 01/03/2007.

how" (Spangler 2003). Sheriff Smith, invoking the experience and feelings of many long-term residents, maintained, "As usual, we have been totally ignored. We felt this was the only way to let them know we are serious" (Israelsen 2003a). The officials' actions share the same impulse with the kinds of direct action that radical environmentalists, on the opposite end of the political spectrum, sometimes use to attract attention to their cause and obtain their demands: a need for action when words have failed. The BLM does not officially recognize any Kane County roads in GSENM and removing federal signs from federal lands is a crime. But Commissioner Habbeshaw insisted that his actions were lawful and he was only trying to keep the federal government from asserting a power it did not legitimately posses: "I'm not a criminal. I'm protecting the rights of the county with as much good faith as I can do it" (Spangler 2003).

The county officials' definitive action succeeded in arousing all the participants in the R.S. 2477 dispute and mobilizing even more. Monument Manager Dave Hunsaker said the county's action "completely took us by surprise. At no time was there an indication that we were at an impasse" (Gubler 2003). The State of Utah reacted with dismay. Referring to the recently signed MOU, an aide to Governor Leavitt stated, "It's very unfortunate. We have a cooperative process going on here to identify roads. I just think it's not good timing to be doing things outside that effort" (Israelsen 2003a). Commissioner Habbeshaw was confident that the County had the law on its side: "County officials have acted responsibly and believe their actions will not only receive public support but, mostly importantly, will prevail in judicial review, whether in state or federal court" (SLT, 27 August 2003: A12). He became more convinced as time went by.

SUWA used the incident as an opportunity to claim common ground with area residents, whom they perceive to be typical "conservatives:" anti-environmental, anti-tax, and pro-property rights. The organization sent a letter to Kane and Garfield county residents warning them that their private property rights were threatened by their county commissioners' interpretation of R.S. 2477 and that their tax dollars were being wasted in legal battles to claim R.S. 2477 rights of way (letter from SUWA to Kane County Residents, October 2, 2003).

On August 25th, the Kane County Commissioners, joined by the Garfield County Commissioners, the mayor of Kanab, the local State Representative and State Senator, followed up on the county officials' action with a letter to BLM State Director Sally Wisely in which they expressed their dissatisfaction with the way the Monument was being managed. They suggested that the Monument staff should be reduced and that the Monument manager should be reduced in grade (letter to Sally Wisely, 25 August 2003). The letter stirred up the controversy even more.

The county officials had explained their actions in terms that reflected the idea that in a democracy, their voices should be heard and their concerns addressed by the federal government. Whether they would be successful in getting the federal government to take action or not, the immediate effect of these actions was to broaden awareness of the R.S. 2477 issue, heighten its emotional impact, and get more people to participate in some way. Commissioner Habbeshaw disagreed with those who said the controversy was tearing the community of Kanab apart. He felt, "We should embrace honest debate."

The Salt Lake Tribune had been covering disputes on GSENM since it had been created. But with the latest developments in the roads dispute, its coverage became more sensational. After August 2003, headlines introducing developments in the dispute consistently used catchy language with references to "road war," "road rage," and conflict (see Table 2). A Salt Lake Tribune editorial referred to the county officials as "road warriors" and to their actions as "road rage," "vandalism," and "the tactics of a scofflaw" (SLT 24 August 2003: A12). The paper published an interview with a former BLM employee who referred to the county officials and signatories of the letter as "the village idiot choir" and "local criminals" who were "taking the law into their own hands and proclaiming their own glory" (Israelsen 2003b). The Tribune also consistently referred to the 1866 Mining Act as "a Civil War-era law", which seemed to imply that it was outdated and that those who used it to legitimate their claims were, therefore, backward, ignorant, and behind the times. The Salt

Lake Tribune continued to use this type of rhetoric in reporting subsequent events in the dispute.

In an article in its quarterly member newsletter titled "Kane Kounty Kapers," SUWA reported the events this way:

> It had all the makings of a Wild West showdown: a sheriff, a county official, a pair of vigilantes, a federal government office, a dispute over who owns property, and dramatic scenery as a backdrop. But in this case, there was a peculiar twist to the facts – the sheriff and county official were the vigilantes (SUWA August 2003).

This portrayal was typical of the way the organization represented rural Utah in its newsletter. What purpose might this type of reporting and representation serve?

The representation of rural residents as backward, irrational, lawless, and disorderly reinforces the image of the federal government as enlightened, rational, lawful and orderly, and validates the claim that the public lands should be under the control of federal and not local government. This technique of representation illustrates the influence of liberalism in democratic thought. Because liberalism validates private interests and preferences over values and social relations, it creates a dichotomy between reason and emotion, and therefore "between a rational elite and social categories that are ruled by their passions" (Touraine 1997: 46). "Demonizing" the other is also a typical strategy in resource conflicts where the state or an environmental organization is trying to gain control over resources so it can "protect" them from local inhabitants who use them, but could be considered to have a prior right.

In September Monument Manager Dave Hunsaker turned the incident over to BLM law enforcement officials. In November, the two officials received subpoenas to appear before a Federal Grand Jury. However, by February 2005, neither the case against the two officials, nor the question of jurisdiction over roads on the Monument, had proceeded any further. It was time for Kane County to adopt a new strategy.

Meanwhile, in 2004, the General Accounting Office found the State of Utah-Interior Department MOU to be illegal because it violated the moratorium on federal regulations that had been passed by the 1997 Republican Congress.

2005

In 2005, Kane County began installing its own signs on roads on BLM-administered land within the County, including GSENM. County crews worked west to east, beginning by installing signs on land, including Wilderness Study Areas, administered by the Kanab Field Office, then reaching roads in GSENM. The signs used a road numbering system devised by the county and different from the one BLM was using on the Monument. In some cases, the county placed signs allowing ATV access right next to existing BLM signs that prohibited it (see Figure 2). Commissioner Habbeshaw explained the County's new tactic: "We decided we needed to start managing our roads instead of being afraid to act like they are our roads" (Havnes 2005). "We're signing what we believe to be our county transportation system. If we're wrong, we'll remove them, but we think we're on pretty solid ground" (Baird and Havnes 2005). "It is clear that BLM planning will attempt to close and restrict county roads while failing to properly recognize existing county rights on those same roads." "The counties ask only that the BLM operate within its granted authority" (Habbeshaw 2005).

An official in the Utah State BLM office characterized the county's new strategy this way: "It's disappointing. We've had a standing request, expressing our desire to help them with a map identifying trails. For them to act unilaterally seems more confrontational than collaborative" (Havnes 2005). "Kane County is acting as if the federal planning process has no standing as to how federal lands will be managed" (Baird and Havnes 2005).

With the State of Utah-Interior Department MOU no longer in effect, the State's stance on the County's actions began to shift. The State of Utah Rural Lands Coordinator stated, "We could say 'cease and desist,' but it wouldn't do any good. County officials are elected by their people. What we need to do is find out why they're doing it and see if there's a way to help resolve the issue" (Baird and Havnes 2005).

The Salt Lake Tribune continued to portray the County's signing project and subsequent events as a "road war" (see Table 2).

What the Kane County Commissioners did not realize at the time was that their new tactic

1996	Feds Sue to Halt Road Work in Wild Utah Areas (SLT, 19 October)
1998	Monument Roads Issue Resolved (SLT, 11 December)
2000	Leavitt Takes on Dirt-road Ownership (SLT, 17 March) Kane Considers Roads Deal with Feds (SLT, 16 August) Burr Case Crucial to Road War (SLT, 30 Ocotober)
2001	Conservationists Smell Victory in Road Ruling (SLT, 28 June)
2003	Deal Struck on Control of Roads on Public Land (SLT, 10 April) Removal of Signs Reignites Road War (SLT, 20 August) Monument Fray Heats Up (SLT, 9 September)
2005	County is Again Raising Kane over Roads (SLT, 16 February) Kane County Ups Ante in Road Feud with Feds (SLT, 19, March) Rural Road-sign Rage Erupting Again (SLT, 16 July) Feud over Monument Signs Just Keep Heating Up (SLT, 15 November) Rebellion in Kane County (SLT, 21 November) In Utah, Trying to Undo a Federal Claim Bit by Bit (*New York Times*, 24 November)
2006	Garfield May Join Kane County Road War (SLT, 11 January)

Table 2. Headlines describing road dispute in GSENM before and after August 2003.

had changed the terms of the dispute. By adding ATV-open stickers to the signs, they were claiming that their right of way also gave them authority to manage the roads. One reason the Commissioners would like to ensure the roads remained open to ATVs was that, in the context of the County's economic uncertainty, they felt ATV recreation could be a source of income for the County. However, their idea of tourism was not what supporters of the Monument had envisioned. They felt ATVs would inevitably damage Monument lands.

In March, the Utah State Legislature demonstrated its solidarity with rural Utah counties on public lands issues by passing H.B. 264, State Land Use Plans Amendments. The Bill was intended to unify and clarify the State's position on a number of public land issues. Regarding roads, the bill stated: "Transportation and access provisions for all other existing routes, roads, and trails across federal, state, and school trust lands within the state should be determined and identified, and agreements should be executed and implemented, as necessary to fully authorize and determine responsibility for maintenance of all routes, roads, and trails."

BLM State Director Sally Wisely had met with Commissioner Habbeshaw in February to discuss the county's signing project. In April, she sent a letter giving the County two weeks to take down the signs it has posted or face legal action. By that time, she felt compelled to act because the conflicting signs constituted a public safety issue. She explained in the letter: "These signs have been placed without proper authorization and most are in conflict with current management plans and direction. I am very concerned that such actions, which result in conflicting management directives, may likely present serious safety issues to members of the public, possibly subject them to legal exposure, and cause resource damage" (letter from Sally Wisely, received 26 April 2005). Sally Wisely felt that, as public servants, BLM and the County should be able to resolve the roads issue without endangering their constituents and without litigation.

With the State beginning to side with the County, the dynamics shifted again. A group of Kane County citizens who did not agree with their Commission's actions saw a need to make their views known and sent a letter to Interior Secretary Gale Norton asking her to take action in the

Figure 2: Conflicting road signs: BLM foreground, Kane County background. Photograph by the author.

dispute. The letter stated, "As local citizens, we believe that the scenic and natural resources of public lands in Kane County are being put at risk of irreparable damage by the intemperate actions of the Kane County Commission." Appealing to Secretary Norton's known support of free-market solutions to public land conflicts, they added, "The economy of Kane County is largely dependent upon the scenic beauty of the nearby public lands, and we want to protect the goose that lays the golden egg for our economy" (Gehrke 2005).

The deadline came and went with Kane County still resolutely refusing to remove the signs. Commissioner Habbeshaw affirmed the County was preparing to meet the BLM in court. Meanwhile, an unknown person or persons removed some of the signs and covered the ATV-permitted symbols on others with stickers that prohibited ATVs. In May the County voluntarily removed some of the signs.

Later in May the State of Utah took on the role of mediator. At the request of Utah Lieutenant Governor Gary Herbert, Kane and Garfield County Commissioners began meeting with BLM officials and the State Attorney General's staff over the issue. Lieutenant Governor Herbert explained why the State got involved: "Our hope is to lower the rhetoric and get something done, as opposed to all this saber rattling. This meeting was a start in that direction" (Baird 2005a). After the meeting Sally Wisely commented, "I don't know if at this point anything has really changed, but we did have a good dialog, and I hope that can continue" (Baird 2005a). And although Commissioner Habbeshaw still insisted that Kane County wanted its day in court, he also acknowledged that, "there was some movement toward common ground" (Baird 2005a). A member of the U.S. Congress decided to get involved at this point. Senator Dick Durbin of Illinois urged the Interior Department to take action against Kane County, which was openly defying federal authority. To strengthen his request he reminded the Department that he could block the appointment of Lynn Scarlett to Deputy Secretary if necessary.

Fuel was added to the fire when speakers at the Farm Bureau's annual conference in July compared Kane County's actions to a "fight against tyranny," "the shot heard 'round the world," "a man standing against a line of tanks," and "Tiananmen Square" (House and Baird 2005). These comments received a jeering comeback in a Salt Lake Tribune editorial titled "Incendiary Inanities" (SLT 19 July 2005). While the speakers' comments were hyperbole, they reflected the idea that when the state is not acting in the capacity it should in a democracy, citizens should resist, and by resisting are saving democracy.

Finally, on September 8, the Tenth Circuit Court of Appeals issued its decision in the case against Garfield and Kane Counties, which had been in litigation since 1996. It overruled the District Court's decision, based on BLM's determination of the R.S. 2477 rights of way in question, and ruled that state law should apply. In Utah this means roads must have been in continuous use for ten years prior to 1976. The decision strengthened Kane County's position. Commissioner Habbeshaw found it "particularly supportive of the validity of our claims" (Baird 2005b). Later that month the Kane County Commission felt sufficiently confident to pass an ordinance that opened all Kane County roads to ATVs unless closed by the County. The State of Utah shared the County's approval of the decision. The Utah Assistant

Attorney General stated, "We think this is a big step forward in fixing what the rules are" (Baird 2005b). However, the Interior Department said it would be forced to reassess its policies on roads, and to delay taking action against Kane County for its placement of signs.

SUWA was least satisfied with the decision. Their first reaction was, "It's a mixed bag. There's still a lot of confusion" (Baird 2005b). Soon afterwards they adopted a new strategy. In October, together with Earthjustice and The Wilderness Society, SUWA filed a suit against Kane County for the ATV ordinance it had passed. According to a SUWA spokesperson, "We filed the suit because the Justice Department is dragging its feet" (Baird et al. 2005). A spokesperson for the Wilderness Society explained, "The stakes are unbelievably high for public lands West-wide, not just in Utah. And what we have in an Interior Department that's essentially motionless" (Baird et al. 2005).

Both environmental groups and Kane County have been trying to prod or provoke the federal government to take some action that would bring the R.S. 2477 issue to court and resolve it once and for all. But the federal government has remained immobile. What would explain the immobility of the federal government? Commissioner Habbeshaw believes the reason is the courts will find the County's claims to be valid. The more the federal government avoids bringing the issue into court – nothing materialized after a Grand Jury was convened to look into the sign removal; nothing materialized after the County ignored Sally Wisely's ultimatum – the more Habbeshaw becomes convinced of that. At the time the rights of way were granted, the federal government's policy was to turn the public domain lands into private property in the hands of citizens. That policy changed and now the federal government does not want to give up the rights of way. But the current presidential administration does not want to antagonize the rural citizens who are making the claims because, for the most part, they support the administration and the current majority in Congress. For that reason, it is to the federal government's advantage to stall. If Commissioner Habbeshaw is right, the federal government either has to give up the rights of way, rescind rights it granted before the grant was officially repealed, or continue to generate confusion and uncertainty in order to avoid making either decision. It is also to the federal government's economic advantage to stall because, meanwhile, the counties keep maintaining these roads. BLM does not have the budget to do so should county claims be disallowed and the counties stop maintaining them. Illustrating another inconsistency in the way "the state" operates, money to help the counties maintain roads comes from another branch of the federal government. If the counties lose claim to the roads, their budgets will be reduced and what are seen, under the current "background conditions," as badly-needed jobs will be lost.

In November, to strengthen its position, Kane County also adopted a new strategy. Instead of direct action action, this time the County used litigation, the approach most often taken by SUWA, to expand its options for judicial review. Just before the stature of limitations for challenging the Monument Management Plan expired, Kane County filed a suit against the Interior Department contesting the transportation and water planning in the MMP. In response, SUWA appealed to local residents' conservative sentiments with an advertisement in the Southern Utah News that read: "Latest Lawsuit is Un-American" (SUN, 23 November 2005: 18).

At this point in the dispute over roads, Robert Keiter, Director of the Wallace Stegner Center for Land, Resources, and the Environment at the University of Utah, offered his analysis of the dispute and Kane County's actions. "It certainly has overtones of the Sagebrush Rebellion. The Sagebrush Rebellion was based in large part on legal claims some Western states asserted on public lands, claims which were ultimately rejected." But such actions are, he added, "as much a political statement as a legal matter. It reflects federal-local tensions that have been part of the system from the beginning in the parts of the West where there is a heavy federal presence" (Baird et al 2005). The problem with this type of analysis is that by seeing only continuity with the Sagebrush Rebellion of the 1970s and 1980s, it is not possible to see what is specific to the current dispute on GSENM.

A group of Kane County residents continued to make it known that the commissioners' stance on roads did not represent the views of everyone in Kane County by publishing a guest editorial in the Southern Utah News. A spokesperson for the group said they wanted to make their views known publicly because the Commission "has had no feedback from the public." He added, "There are a lot of locals – even some who ride [all-terrain vehicles] – who are not pleased with the county's road [position]. They're holding their cards close to their chests because they don't want to be bullied" (Havnes 2005c). Commissioner Habbeshaw insisted that, "the Commission is open and listens to everyone." He added, "We've been seeking a judicial solution for years because that's the proper solution, not a petition initiated by a small segment of county residents" (Havnes 2005c).

These comments illustrate another aspect of democracy that participants in the dispute do not bring up directly: the problem of how to attend to minority views in a democracy. Many residents of Kane County feel that their views are not represented by their county government. It would seem that Commissioner Habbeshaw, as commissioner of a small, rural county and himself a representative of the views of a minority in the State of Utah and the nation as a whole, would be more sensitive to this problem. Several of the people I interviewed reminded me that we don't live in a democracy; we live in a republic. But they had different understandings of what that meant. For Commissioner Habbeshaw, a republic "uses a representative form of government with elected officials that represent people and do their very best job to represent the public's best interest. But the public gets a chance to confirm that representation affirmatively by reelection, or to vote that representative out of office if they're not properly representing their constituents." For another civil servant in Kanab, "A democracy is majority rule. A republic protects the rights of the weakest citizens. By protecting the rights of the innocent and weak, we substantiate the community. Majority rule allows popularity to outweigh science and common sense."

Throughout these developments Kane County and the Interior Department continued to meet over the road signs the County had placed. In December, The Salt Lake Tribune reported that they were close to agreement. Both sides offered encouraging comments, but no details, about the meetings. A SUWA representative again objected to the lack of transparency in the process, and asked, "Why is it that the Department of Interior and Kane County are comfortable only operating behind closed doors" (Baird 2005c)? No agreement had been announced as of this writing.

2006

Although my fieldwork did not extend into 2006, it is important to record several significant developments that took place during the year.

Kane County signs along the Hole-in-the-Rock Road in GSENM continued to disappear and, in February, Kane County offered a reward for information leading to the arrest and conviction of the "thief or thieves" (Havnes 2006). The situation is ironic in light of the fact that Kane County officials were themselves accused of a criminal act for removing BLM signs in 2003.

Interior Secretary Gale Norton announced she would be stepping down. Before leaving in March, she signed new department guidelines for resolving R.S. 2477 road claims which she said largely reflect the Tenth Circuit Decision. Interior officials and the State of Utah hailed the new policy, but SUWA and The Salt Lake Tribune opposed it because it defines a highway more broadly than the court ruling (SLT 27 April 2006).

In October, a member of Congress initiated an attempt to solve the dispute through legislation. Representative Steve Pearce from New Mexico introduced H.R. 6298, a bill that proposed a process for state and local governments to claim rights of way that bypasses the federal land management agencies. Environmentalists claimed the process lowers the current standard for road claims and would open national parks and wilderness to such claims. Now they found Congress irrational. A spokesperson for the Wilderness Society called the bill, "the mother of all public land giveaways. I've never seen anything like it. It's absolutely 100% horrible. It defies all logic" (Gehrke 2006). A spokesperson for the Congressman said that the purpose of the bill is to start discussion of what needs to be done to resolve the protracted roads dispute.

In November, Mark Habbeshaw was reelected for a second term as County Commissioner, which would seem to indicate that most county residents supported his actions. In December, Kane County was among the first counties in Utah to submit requests to BLM for "non-binding determinations" of road claims under the new guidelines signed by

Gale Norton. In December also, the Kane County Commission rescinded the ATV ordinance it had passed and announced its intent to remove ATV-open decals from county road signs. The decision was based on advice received from the legal counsel representing Kane County in the lawsuit challenging the ordinance that environmental groups had filed. Commissioner Habbeshaw explained the reason: "It's essentially too big a bite of the apple to defend our property rights and the management of OHVs at the same time. We're trying to secure our rights of way under R.S. 2477, and that is being overshadowed by the issue of OHV damage on federal lands, whether it's a real problem or not" (Baird 2006). His comments at the Commission meeting indicated that his understanding of the County's rights of way had shifted, and along with it his stance on managing the roads: "It is not a right, it is permitted use. We are rescinding it to fix it with the state and federal government. The county does not have carte-blanche authority over the roads. The state and federal government are involved. This action will result in long range protection of our rights and roads (SUN, 20 December 2006). Commissioner Habbeshaw had come to understand a county right of way did not necessarily include the right to manage a road however the county wanted[16]. And he expressed a willingness to work together with the state and federal government to manage the County's roads.

Recap

This section of the paper has described the complicated events in the road dispute on GSENM from the point of view of the participants. It shows how they invoke and attempt to actualize different aspects of an imagined democracy in their words and actions. But their efforts take place in a context of interrelated processes of change at the national level in the role of the federal government and perceptions of the Western landscape and of economic and demographic shifts in the American West. They are experiencing the effects of these changes on their lives at the same time they are thinking and acting what democracy should mean. For local residents this includes considering how the federal government might be contributing to or could alleviate their economic uncertainty. For environmentalists it includes considering how the federal government might be contributing to or could alleviate environmental degradation. The ideas and actions of participants, informed in addition by a changing history of democracy in the United States, are also changing and sometimes contradictory.

Participants' efforts to imagine and actualize democracy are also taking place in juxtaposition with other participants in the road dispute who have different backgrounds and different concerns and are being affected by change in different ways, and who are also working out what democracy means. What participants can accomplish and imagine is also affected by other participants. To shed light on this process, this section has also described the shifting strategies and dynamics of alliance and opposition of participants in the dispute and illustrated the process by which the relationship between citizens and government and between different levels and branches of government is worked out.

This ethnographic approach to the analysis of the dispute over roads on GSENM reveals that it is informed by democratic aspirations and addresses more profound concerns about the ambiguous powers and weaknesses of the federal government and the nature of democratic government. At the same time, it is also informed by attachment to place and addresses concerns about the future of the American West.

Conclusions

On the surface it may appear that the dispute over roads on GSENM has made little progress in the last ten years. Roads were graded. Were they county roads? We still don't know. Signs went up. Signs came down. The complex events, negotiations, judicial deliberations, actions and reactions, fiery rhetoric, changing strategies and tactics, alliances and oppositions seem to have brought us no closer to a resolution of the dispute. However, by drawing on contemporary democratic theory, we can interpret the events in a different light.

I begin with three quotes that point the way:

> "In my conception, a communicative model of democratic inclusion theorizes differenti-

[16] Property rights are more accurately conceived as a "bundles of rights" and the owner does not receive them all (Rose 1994).

ated social segments struggling and engaging with one another across their differences rather than putting those differences aside to invoke a common good" (Young 2000: 18).

"If it is to be democratic, a political system must recognize the existence of insurmountable conflicts over values" (Touraine 1997: 119).

"To believe that a final resolution of conflicts is eventually possible … far from providing the necessary horizon of the democratic project, is something that puts it at risk" (Mouffe 2000: 32).

Democratic theorists Iris Marion Young and Chantal Mouffe and sociologist Alain Touraine do not conceive of democracy as something that brings about a resolution of conflict, produces consensus, or succeeds in discovering the common good. They each approach a theory of democracy by first recognizing that pluralism is constitutive of the idea of democracy at the conceptual level and of actually existing modern democracies at the empirical level. The idea of democracy combines two irreconcilable principles – liberty and equality. Actually existing democracies are composed of citizens who differ in ethnicity, culture, values, and social and economic status. Pluralism means that the variety of viewpoints, values, and ways of communicating is so diverse that "the common good," consensus, or an end to conflict could only be achieved if some groups had been excluded or overpowered. In order for alternatives to dominant power relations to continue to exist, democracy has to be "a process of struggle" (Young 2000: 50), a "constant process of negotiation and renegotiation" (Mouffe 2000: 45), and "a form of work" (Touraine 1997: 127).

The United States, a nation of immigrants, is the most diverse of the modern democracies. With continuing immigration, it is becoming increasingly diverse. Places like the remote, rural communities of southern Utah have traditionally been more homogeneous. But diversity is increasing there too with the arrival of amenity migrants who may have different economic status, political views, values, or lifestyles, and Hispanic immigrants who have a different cultural background.

Participants in the dispute over roads on GSENM reflect the diversity of the nation as a whole. The dispute involves citizens from different geographical, ideological, and social locations and representatives of all levels and branches of government. Even local participants may differ according to whether they come from rural or urban backgrounds, whether they are "newcomers" or "locals," Mormon or non-Mormon. These democratic theorists are suggesting, because of this diversity, there should be no final resolution to the dispute.

Each of these theorists proposes a model of democracy to meet the challenge of pluralism. Their models are similar in that they insist on the central importance of producing "democratic citizens" (Mouffe 2000: 95) who engage and struggle with difference. Here we will focus on Chantal Mouffe's model of "agonistic democracy."

Mouffe stresses that allegiance to democratic institutions cannot be secured solely by rational justifications, such as a shared conception of justice as proposed by Rawls, or legitimacy achieved through public deliberation as proposed by Habermas. To make possible the creation of democratic citizens, there must be a wide variety of practices, institutions, discourses, and forms of life "that foster identification with democratic values" (Mouffe 20000: 96) and promote the development of "democratic forms of individuality and subjectivity" (Mouffe 2000: 95). "Practices" means activities people can engage in: not just practices we usually associate with democracy, like voting, but additionally, things like forming associations, expressing opinions, and engaging in disputes, such as the one over roads on GSENM. In addition, Mouffe emphasizes the role of "the passions" in this process. In contrast to deliberative models of democracy, which seek to eliminate passions from the public sphere in order to make a rational consensus possible, Mouffe argues that democratic practices should seek to "mobilize those passions toward democratic designs" (2000: 103).

Mouffe calls her model "agonistic democracy" because it acknowledges that pluralism inevitably entails a dimension of antagonism and it aims to transform antagonism, a struggle between enemies, into agonism, a struggle between adversaries. An adversary is a "friendly enemy:" "one with whom we have some common ground because we have a shared adhesion to the ethico-political principles of liberal democracy: liberty and equality. But we disagree concerning the meaning and implementation of those principles"(Mouffe 2000:102). The practices that Chantal Mouffe sees as most effective at transforming antagonism into agonism are those that allow "collective passions [to] be given ways to express themselves over issues which, while allowing enough possibility of identification, will not construct the opponent as an enemy, but as an adversary" (Mouffe 2000: 103). Put more simply, what will produce democratic citizens is engagement with difference that permits the discovery of common ground and the development of empathy, and admits the possibility of transformation.

This understanding of democracy does not exclude the possibility of agreement or compromise, but sees them as "pragmatic, precarious, and necessarily unstable forms of negotia[tion]" and "temporary respites in ongoing confrontation" (Mouffe 2000: 11 & 102).

The dispute over roads on GSENM is an example of this kind of practice. First, because the roads are on public land, participants must frame their understanding of the issue, their arguments, and their actions in ways that draw on ideas of democracy. In the dispute, they struggle with diverse others to raise issues (for example, the different ways the Counties tried to get the federal government to make a decision on R.S. 2477 rights of way), and once raised, they must struggle with others over the terms in which they will engage the issue (for example, the Salt Lake Tribune calling the sign removal "vandalism"), they must struggle to get their views heard (for example, the Kane County citizens who don't agree with their commissioners' stance on roads), must struggle to persuade others (for example, SUWA's advertisements in the Southern Utah News)" (Young 2000: 50)[17]. And at the same time that they are struggling over the management of roads on GSENM, they are also struggling over social problems arising from economic and demographic changes in the West.

Second, participants in the dispute share a conviction and hope in democracy, but may conceive of it differently. But an attachment to democracy is not the only common ground participants in the dispute over roads on GSENM share. They also share an attachment to a particular landscape, whether by virtue of a long history of residence in the area or a more recent recognition of its beauty and value. They may have different perceptions of the landscape – as "home" or as "wilderness" – but their connection to the landscape adds to their commitment to the struggle. From the point of view of Chantal Mouffe, the dispute over roads on GSENM can neither be finally resolved, nor should it be. As long as it continues, participants continue to have the opportunity to come to regard each other as adversaries rather than enemies and to become more democratic citizens.

In the past ten years, GSENM has been a particularly significant site for creating democratic citizens. In addition to the dispute over roads, another path-blazing dispute has taken place over the purchase of grazing permits for allotments on the Monument by a conservation organization whose goal was to "retire" the permits and eliminate livestock grazing on the allotments. Garfield and Kane County officials and some local citizens felt that the Grand Canyon Trust's "Grazing Retirement Program" threatened the economy and culture of their region, while GCT felt that eliminating grazing on some allotments was necessary to improve their ecological health. Whatever one's position on these issues and whatever the outcome of these disputes, they provide evidence that democracy, as these contemporary theorists conceive of it, is alive and kicking in southern Utah.

Public land decision-making processes do not always result in dispute, but they do provide an opportunity for public comment and public engagement. When they do result in dispute, participants engage passionately with each other, not just because they are inspired by something called democracy, but because they are also inspired by the beauty of the landscape. For these reasons, public land is an important site for the production of contemporary American democracy.

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[17] Young adds, "Disorderly, disruptive, annoying or distracting means of communication are often necessary or effective elements in such efforts to engage others in debate over issues and outcomes (2000: 50). Think the sign removal again.

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Using Agency Permit Data to Describe Community/Resource Linkages in Utah's Grand Staircase-Escalante National Monument

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ABSTRACT

Rural communities in the West are often highly dependent upon surrounding public lands for a wide range of natural resource-based goods, services, and activities. When it comes to planning and management, public land management agencies are mandated to consider the welfare of these communities, but oftentimes are limited in their ability to fully describe and understand the socioeconomic impacts of community/resource linkages at the local or sub-county level. This paper demonstrates how readily available agency permit data collected by the Bureau of Land Management can be used to help describe how communities surrounding Grand Staircase-Escalante National Monument depend upon and use Monument resources. We also offer guidelines for improving the quality and usefulness of agency permit data.

Keywords: economics, grazing, land use, public lands, resource dependence, social impact assessment, spatial data, sustainability

Introduction

Resource Dependence in Rural Communities

Many rural communities are dependent upon nearby public lands for a variety of natural resource-based goods and services. These range from market-based resources like forest products, minerals, and livestock forage, to recreational opportunities and a host of environmental services (Flora and Flora 2004). Community/resource linkages are particularly important in many areas of the rural West, where local economic dependence on public lands is particularly acute due to the limited availability of private lands, an arid and marginally-productive resource base, limited economic diversification, and high levels of social and economic isolation (Gray et al. 2001).

Since their establishment in the first half of the 20th Century, federal land management agencies have considered the effects of management on the long-term health and sustainability of the natural resources under their charge. More recently, agencies like the USDI Bureau of Land Management

(BLM) and USDA Forest Service operate under a number of mandates to also consider the effects of management on the socioeconomic well-being of nearby communities. Examples include the National Environmental Policy Act (1969), the Resources Planning Act (1974), the National Forest Management Act (1976), and the Federal Land Policy and Management Act (1976). These laws require socioeconomic assessments of nearby communities, as well as an analysis of the social effects of agency decisions (Dana and Fairfax 1980).

Despite these mandates, there is little agency guidance as to the types of data and analytic processes that should be used to generate managerially useful social information. Also absent are guidelines describing the types of data that can serve a useful role in the on-going monitoring needed to support adaptive management practices (Geisler 1993, Endter-Wada et al. 1998, Stankey et al. 2003, Keough and Blahna 2006). As a result, while public land management agencies have historically done a thorough job of considering the biological and physical impacts of alternative management scenarios, most agencies lag far behind in their analysis and use of social science data. This is particularly true when it comes to understanding the impacts of resource planning decisions on local communities. For example, most socioeconomic analyses of community impacts rely on county-level data and economic input-output models like IMPLAN that, due to data aggregation and disclosure requirements, may fail to accurately describe community/resource linkages at the local or sub-county level (Sullivan 1997, Minnesota IMPLAN Group Inc. 2004).

Grand Staircase-Escalante National Monument

Utah's 1.9-million-acre Grand Staircase-Escalante National Monument (GSENM or Monument) was established in 1996 by an Executive Order issued by President Bill Clinton (Bureau of Land Management 1999). The Monument lies within Garfield and Kane Counties and is surrounded by 13 small, resource-dependent communities (Table 1). These communities have relied on extracting natural resources from surrounding lands for nearly 150 years. Historically, these communities have been heavily dependent upon livestock grazing (currently cattle but in past years sheep as well), and the cutting of woodland trees for firewood, posts, and poles (Sullivan 1997). Private lands with access to irrigation water provided an agricultural base for local communities, as well as winter feed for livestock.

In addition to these traditional land uses, tourism has been a long-standing yet oftentimes overlooked economic driver for local communities (Sullivan 1997). Indeed, the Grand Canyon was first protected in 1908 as a national monument, followed by Zion (1909), Bryce Canyon (1923), and Capitol Reef (1937). In the 1920s and 1930s, a popular trip by motor coach took tourists through many of these landscapes and provided jobs and income for local residents and businesses.

When GSENM was created in 1996, local opposition was intense, and animosities have lingered due to concerns over the potential loss of traditional livelihoods like cattle grazing, as well as diminished prospects for future economic development through oil and gas leasing and coal mining on the Monument's Kaiparowits Plateau. These concerns are particularly acute given that less than 5% of the region's land base is privately owned, and limited forage production requires extensive areas to provide even a modest economic return from livestock grazing.

Today, recreation and tourism have become the major economic drivers in the region, although traditional extractive uses continue to dominate the psyche of most locals. Indeed, over the last 25 years, job growth in Garfield and Kane Counties' service sector has far outpaced growth in other sectors, especially traditional resource sectors like mining, agriculture, and forest products (Figure 1). At the same time, inflation-adjusted wages have been falling since at least the early 1980s, and incomes expressed as a percent of the overall state average have steadily declined to the point that resident income is now one-third lower than the state's average. Moreover, unemployment is twice Utah's average of about 4%, and can rise to nearly 25% in tourism's off-season.

Given local attitudes and the dependence of nearby communities on public lands, any change in land ownership, agency oversight, or management policy has the potential to impact the welfare of local communities. For example, policy changes in the late 1980s led to large declines in timber

Community	Date Settled	2005 Population (estimate)	Economy
Bigwater, UT	1950s	415	Originally named Glen Canyon City, this small community with limited services began as a construction camp for workers building Glen Canyon Dam. Bigwater recently attracted the attention of a large, international resort developer due to its location near GSENM and Lake Powell. The town also hosts one of GSENM's five visitor centers.
Boulder, UT	1889	179	Small, isolated community dependent upon natural resources. Limited retail and lodging services. Boulder is attracting retirees and amenity seekers due to its scenic beauty and location near GSENM.
Cannonville, UT	1870s	135	Small, isolated community dependent upon natural resources. Very limited retail services. Home to one of GSENM's visitor centers.
Escalante, UT	1875	744	Mid-level retail services based on tourism and natural resources. Escalante has begun to attract amenity-based businesses and residents due to its scenic beauty and location near GSENM. The town is also home to GSENM's main visitor center.
Fredonia, AZ	1885	1,051	Some tourism potential due to Fredonia's location on the highway to the North Rim of the Grand Canyon. The closure of Kaibab Forest Products' sawmill in the mid-1990s resulted in significant job losses and socioeconomic distress.
Glendale, UT	1871	342	Small, isolated community dependent upon natural resources. No retail services.
Henrieville, UT	1877	144	Small, isolated community dependent upon natural resources. No retail services.
Kanab, UT	1870	3,516	Kane County seat. Relatively well developed economic base due to tourism, travel along US Highway 89, and its role as a local service center. Kanab hosts GSENM's Headquarters, as well as one of its visitor centers.
Mount Carmel, UT (Originally Winsor)	1864	116	Small rural community dependent upon natural resources and tourism from nearby Zion National Park.
Orderville, UT	1870	586	Small, isolated community dependent upon natural resources and tourism. Limited retail services.
Page, AZ	1950s	6,794	Located in Arizona's Coconino County, Page's relatively large and well-diversified economy is based on transportation services, recreation and tourism, and nearby Lake Powell and Glen Canyon Dam.
Panguitch, UT	1864	1,477	Garfield County seat. Government offices, mid-sized economic base serving transportation, tourism, and natural resource-based industries.
Tropic, UT	1892	463	Gateway to Bryce Canyon National Park. Most developed economy in Bryce Valley, but still small even by regional standards. Mostly tourism based, with several motels, restaurants, and bed and breakfasts.

Table 1. Socioeconomic profiles of communities located near GSENM (U.S. Census).

harvest levels on national forests across the West – with severe social and economic consequences for many timber-dependent communities (Kusel 2001, Baker and Kusel 2003). Current efforts by the BLM to address concerns over rangeland health and the sustainability of grazing practices stoke fears of a similar fate in many ranching communities. Indeed, the widespread local resistance to environmental protection efforts in the rural West is largely driven by concerns over the potential loss of access to natural resources. And while the Monument's establishment in 1996 retained

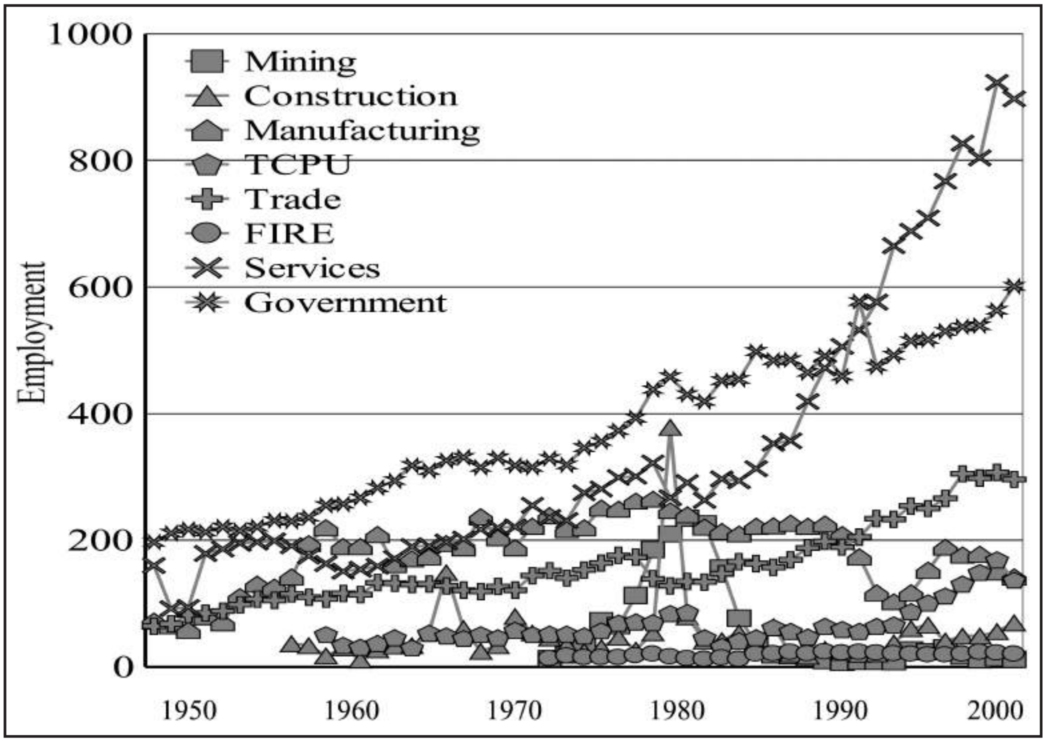

Figure 1. Employment by sector for Garfield County, 1950-2000 (FIRE includes Finance, Insurance, and Real Estate; TCPU includes Transportation, Communications, and Public Utilities) (U.S. Census 2000).

lands under BLM's multiple use oversight, it also expanded the region's primary focus from grazing and mining, to the protection of unique scientific and historical resources to be managed for current and future generations.

Given the high levels of interdependence between public lands and surrounding communities, it is important that public land management agencies understand local community/resource linkages. Such an understanding can help agencies: (1) solicit public input in the design of management alternatives; (2) assess the impacts of proposed management or policy changes; (3) design mitigation practices in the event that proposed changes are likely to present challenges for nearby communities; and (4) provide baseline data and a rationale for the design of socioeconomic monitoring efforts.

In this paper we demonstrate how existing secondary data like agency-issued permit information can be used to spatially describe community/resource linkages in the GSENM region – here defined as Kane and Garfield Counties, the Monument, and the dozen or so small rural communities that share this landscape. The approach reveals a host of advantages. Foremost is the general availability and low cost of permit data. Also important is the community-level detail – a level of resolution often lacking in state and federal socioeconomic data. We conclude with some observations on the limitations of permit data, and on how agency data collection efforts might be enhanced to further the goal of improving the identification, understanding, and measurement of community/resource linkages.

Methodology

Community/resource linkages and dependencies are many and complex (see Kruger 2003), and several descriptive typologies have been proposed in the literature. Building on the work of Beckley (2003), McCool (2003) developed a model of how communities are "embedded" within broader social and biophysical environments. Identifying specific links between a community and the broader environment is important for understanding how natural, social, or institutional changes may influence a community. At this broad level, McCool (2003) hypothesized three general types of community/environment links: (1) instrumental, (2) cultural-spiritual, and (3) ecological. Instrumental links are the more direct or tangible "products" we obtain from the environment for economic, subsistence, or recreational value (McCool 2003). Cultural-spiritual links are the symbolic values provided by the environment, such as Native American sacred sites and other special places where symbolically important activities or connections to a place occur. Ecological linkages result from the ability of the natural environment to produce resources essential for survival, such as clean air and water.

Endter-Wada and Blahna (2004) presented a different type of community/resource linkage framework. Working from the perspective that federal land management agencies are mandated to provide the public with many types of community/resource linkage opportunities, they identified five categories of community "linkages to public lands" based on agency legal and policy requirements: (1) tribal linkages, (2) resource use linkages, (3) interest linkages, (4) neighboring land linkages, and (5) decision-making linkages.

Of special relevance here are resource use linkages, which are essentially a subset of McCool's instrumental links. They are based on laws providing for public access rights to the land and using or collecting resources for personal or commercial benefit, such as grazing, camping, hunting and guiding, and collecting firewood and special forest products. While Endter-Wada and Blahna's resource use linkage category also includes "open use" linkages that do not require permits (e.g., enjoying scenery, picnicking, and hiking) and illegal uses (e.g., poaching), the data for this study represent only legal and permitted resource use linkages.

In this paper, we focus on instrumental or resource use linkages as reflected by permits issued to the public by agency district offices. Federal land management agencies issue permits for a variety of uses. These permits – for which the user is typically charged a nominal fee – ensure that the permit-holder is aware of regulations. Permits also enable the agency to monitor the location of activity, and method and intensity of use. Agency permit data have the potential to supplement traditional socioeconomic data sources used to describe community/resource linkages. For example, traditional data sources like the Economic Research Service, The U.S. Census Bureau, and other data gathered and reported by various state, county, and federal agencies generally present data at the county level, and may thus miss important sub-county community characteristics due to aggregation (Sullivan 1997, Blahna et al. 2003). Agency permit data, on the other hand, are typically community-specific with respect to the permittee or user, and oftentimes location-specific with respect to the use or activity.

In GSENM, permits are required for a wide range of uses (e.g., grazing, certain recreational activities, and the cutting of trees for firewood, poles, and fence posts). These permits are readily available for analysis and mapping on a regular basis, and can be used to evaluate the social impacts of agency plans and management decisions. Permit data collected by Monument staff are housed at the various visitor centers, as well as GSENM Headquarters in Kanab, Utah. Some data are available on the GSENM website. The permit activities included in this study are described below. In this exploratory paper, we spatially express these data based on the permit holder's community of residence in order to depict simple and readily available measures of the relationship between communities, resources, and the Monument.

Results

Grazing

Livestock grazing has been a dominant use on the lands within today's GSENM for nearly 150 years. While the number of animal unit months (AUMs) and livestock have varied over the years, the Monument currently has authorized 76,000 AUMs. The 75 geographically contiguous grazing allotments cover virtually all of the Monument's 1.9 million acres. Figure 2 shows the number of permittees in communities surrounding the Monument (note that permits held by permittees residing beyond the immediate region were assigned to the GSENM community that serves as the base of ranching operations as determined by BLM personnel). Kanab and Cannonville have the largest number of permittees (38 and 37, respectively), followed by Escalante and Boulder.

When these data are adjusted by a community's population, however, they convey a different impression. For example, Figure 3 shows that on a per-1,000 resident basis, Cannonville is by far the most dependent on grazing permits, followed by Boulder and Escalante. In fact, Kanab – with the

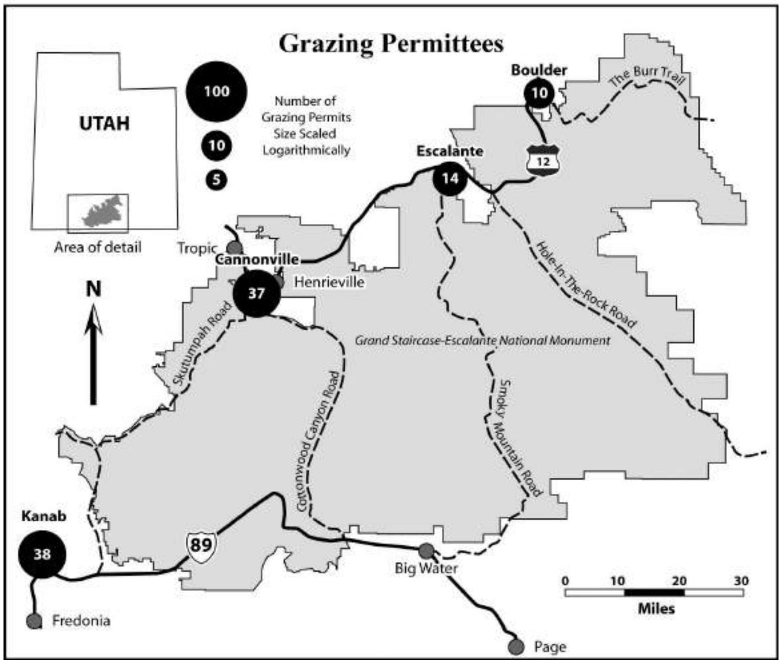

Figure 2. Distribution of GSENM grazing permittees, 2006.

most permittees – has the lowest level of dependence when adjusted by the community's larger population. Figures 4 and 5 show the number of allotments and authorized AUMs, respectively, for each community. Note that while most permittees reside in Kanab and Cannonville (Figure 2), the majority of AUMs (and hence cattle) are associated with ranching operations based in Escalante (Figure 5). As described below, these different metrics can be used to provide a range of useful information about community/grazing linkages on the Monument.

Special Recreation Permits

Recreational visitation to the Monument and surrounding areas has increased over the years. Figure 6 shows visitation to southern Utah's national parks between 1981 and 2005. Visitation at the Monument's five visitors' centers is shown in Figure 7. GSENM issues Special Recreation Permits (SRP) to local businesses engaged in recreation-related commercial use on Monument lands. Examples include guiding services, educational programs, hunting, and photography. On the Monument, the number of SRPs has steadily increased over time, suggesting that the recreational services economy associated with the Monument is gaining in strength, size, and diversity. Figure 8 shows the spatial location of these SRPs. As shown in the Figure, businesses serving recreational needs are concentrated in Kanab. Also, SRPs in smaller communities suggest that even though fewer businesses operate from these locations, their contribution to local economic activity is likely to be disproportional due to these communities' smaller, less-diverse economies.

Forest Products

Forest products-related activities on GSENM that require a permit include the cutting of firewood, poles, and fenceposts. Given the Monument's aridity, most of these activities take place in the western Grand Staircase region of GSENM, where pinion pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) woodlands occupy the more mesic, higher elevation sites. And while these woodlands have supplied forest products to local residents for generations, Figures 9 and 10 reveal the relatively low level of use based on issued permits. Given this low use level, a better representation of this community linkage might be portrayed by aggregating several years' data, although this might mask any trends in use due to changes in local demand, resource availability, or BLM policy. Alternatively, these data could be displayed each year through time to reveal temporal trends in this community/resource linkage.

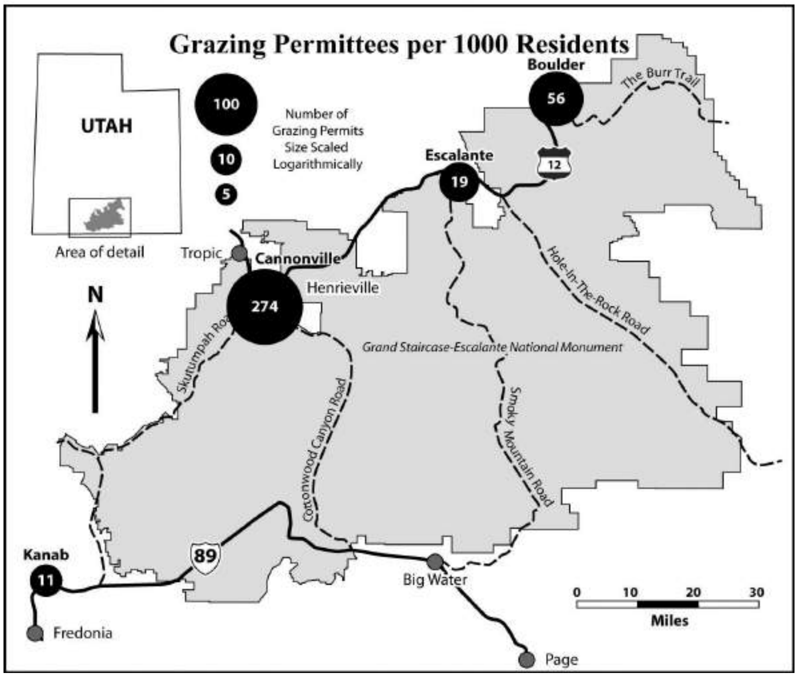

Figure 3. Distribution of GSENM grazing permittees, 2006 (permits per 1,000 residents).

Discussion

The spatial depiction of agency permit data presented here provides a unique view of community/resource use that may not be readily apparent through commonly used agency practices. And as demonstrated above, accessing, summarizing, and depicting permit data is relatively simple, while the spatial depictions that emerge are a useful tool in understanding how local community/resource linkages and dependence may vary across time, communities, and geographic location.

The utility of spatially depicting permit data can be illustrated through a number of examples. For instance, consider the case where changes to grazing practices are being evaluated. The grazing permit data described above are rich in detail, with the numbers of permittees, allotments, and AUMs varying greatly by community. Prospective changes may affect these attributes differently, and hence lead to varying impacts on different communities. For example, efforts to reach permittees would have the greatest impact in Kanab and Cannonville, where the bulk of local permittees reside (Figure 2). However, if the geographic area impacted by grazing was of interest to the Agency, then efforts would focus on the town of Escalante, where a relatively small number of permittees control a majority of GSENM's AUMs (Figure 5).

Agency permit data can supplement more commonly used socioeconomic data to better anticipate local impacts. For example, changes that adversely affect the profitability of ranching operations are more likely to have greater effect in small, isolated communities like Boulder and Cannonville, instead of Kanab – the county seat with a larger and more diversified economic base.

It is also important to recognize that the permit data described here represents a subset of the data that may be available for a particular area. For example, we did not consider hunting and fishing permits, back country use permits issued to individual campers, water rights, easements and right-of-ways, or permits to collect geological, biological, or paleontological specimens. Spatially depicting each of these uses would create additional sets of community/resource linkages that might have relevance to various aspects of Monument management. These linkages would also likely reveal a much larger sphere of influence by spatially locating permittees from distant counties, communities, and states.

Agency employment, while not considered here, is another important linkage between public lands and the economic health of nearby rural communities. For example, federal jobs associated with public lands may be seasonal or year-round,

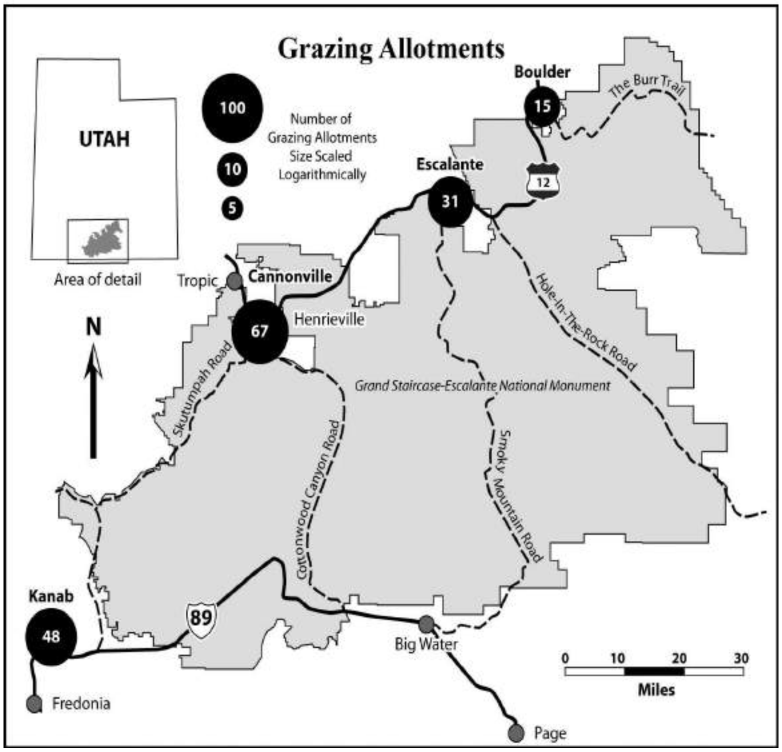

Figure 4. Distribution of GSENM grazing allotments, 2006.

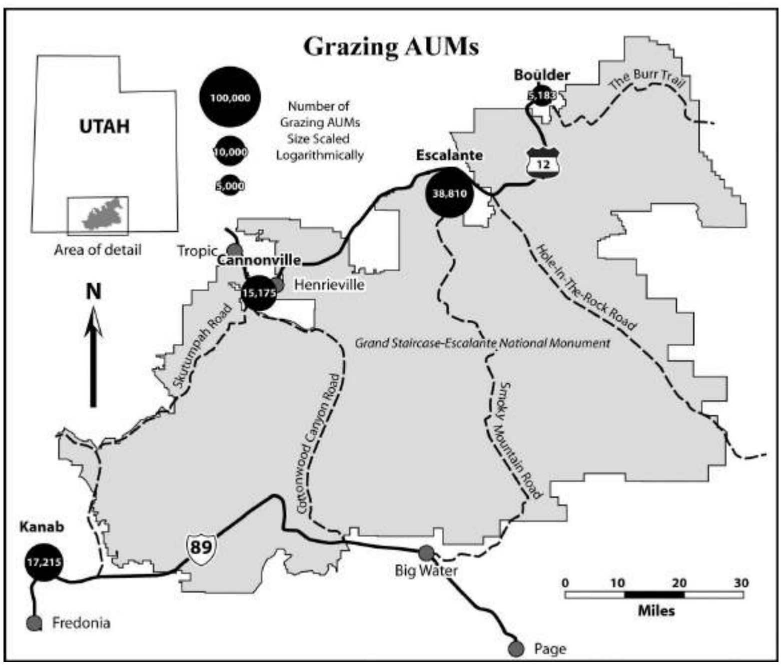

Figure 5. Distribution of GSENM authorized AUMs, 2006.

and often require advanced levels of education that attract highly skilled individuals and their families to rural areas. Year-round jobs provide steady income, relatively high pay, and health and retirement benefits – highly desirable features increasingly missing from private sector jobs and oftentimes altogether absent from rural labor markets. Such benefits are increasingly important in Garfield and Kane Counties, where average local wages have steadily fallen as compared to state averages over the last 25 years.

Unfortunately, the widespread lack of recognition by agency personnel of the potential value of permit data for conducting community social

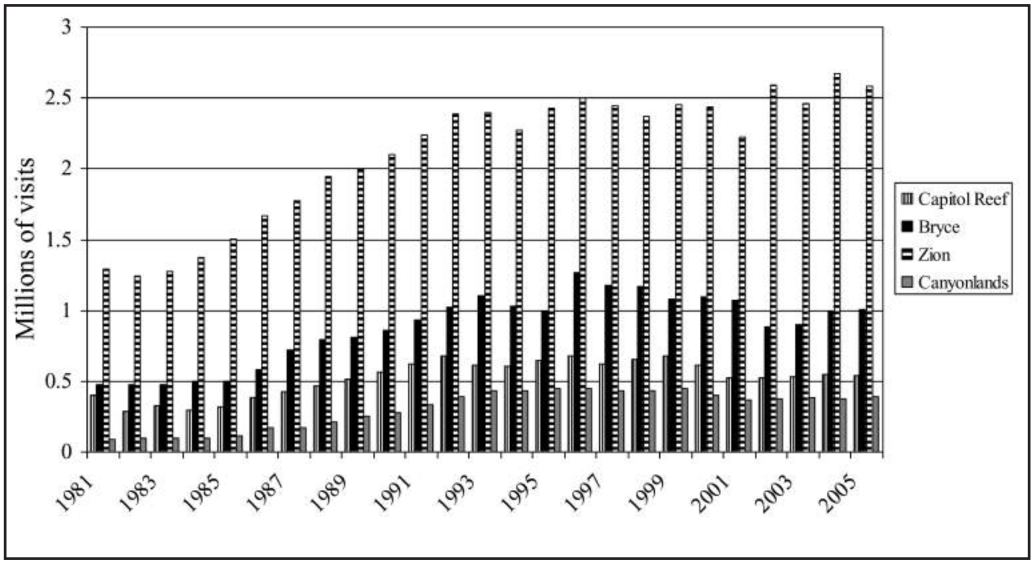

Figure 6. Visitation to Utah national parks, 1981-2005.

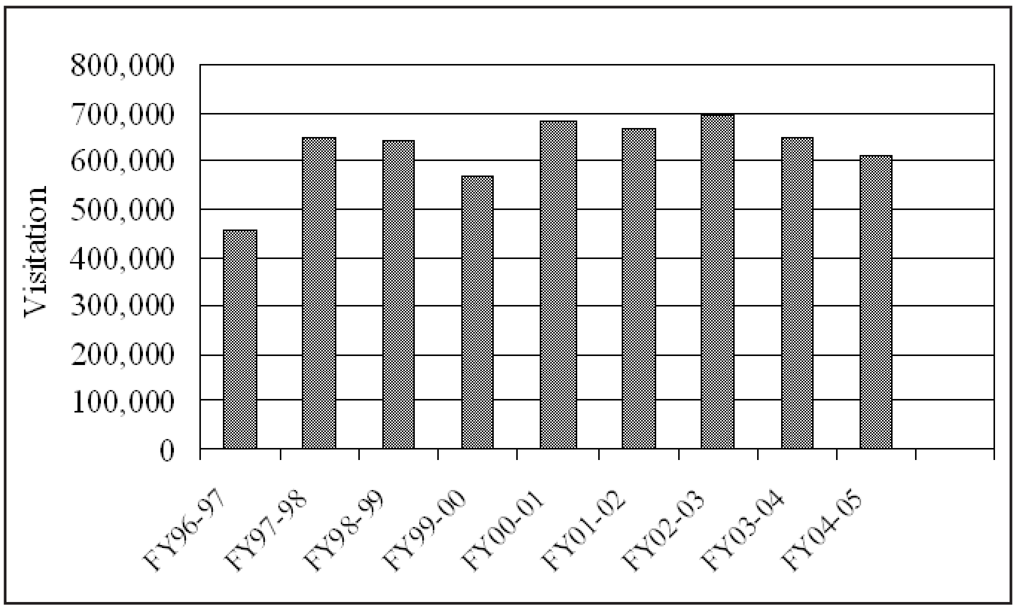

Figure 7. Visitation to GSENM visitor centers, 1996-2006.

assessments may inadvertently lead to incomplete recording of forms, poor record-keeping, and a lack of standardization that might limit subsequent use and application. Recent efforts to standardize permit data through the USDA Forest Service's INFRA database, Timber Information Manager (TIM), and Special Uses Database System (SUDS) are important first-steps in this direction. In addition, ensuring that permits include information about location of permitted use, amount of resources used, and economic values would greatly enhance the usefulness of the data collected. For example, some agency permits for firewood cutting include the number of cords and economic value of the wood being cut, but many others do not.

We also suggest coordination between land management agencies to standardize both the types of information collected, as well as the databases where this information is housed. This would allow for a more complete identification of community linkages to public lands. For example, in our study region some residents of Boulder cut firewood on the Dixie National Forest, some on the Monument, and some on both. Moreover, the Dixie National Forest includes permits for campground use and Christmas tree cutting, while the Monument does not. Ecosystem-based manage-

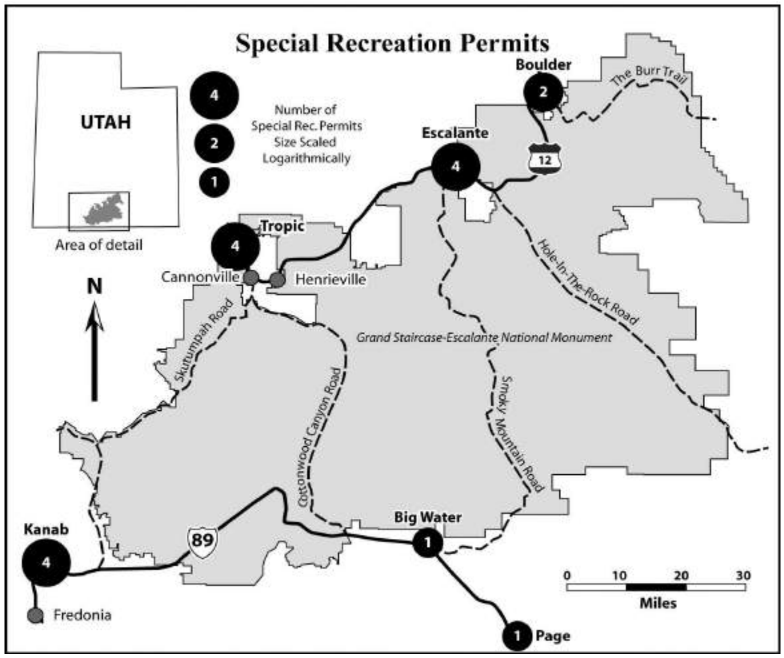

Figure 8. Distribution of GSENM Special Recreation Permits, FY96-97 through FY04-05.

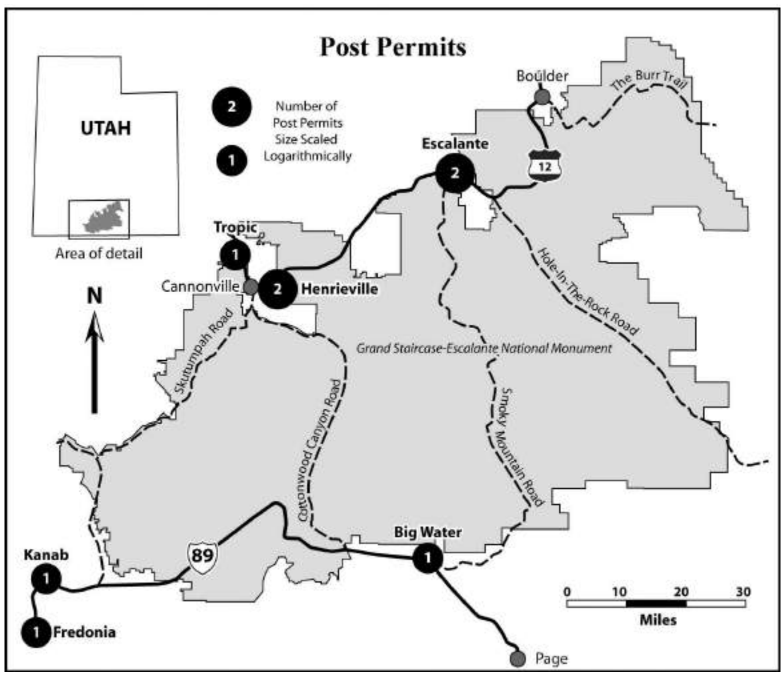

Figure 9. Distribution of GSENM post and pole permits, 2006.

ment necessitates interagency coordination, and the standardization of permit requirements across agencies would be a simple and useful step toward realizing this goal.

As recognition of the value of permit data grows, we are hopeful that the INFRA, TIM and SUDS systems might be expanded to include other agencies. Also needed are increased efforts to ensure data integrity and availability, including the mapping of temporal data for determining trends in use. Better staff training concerning the value and use of such data is also an important prerequisite in elevating permit data to the same level of importance as biophysical data for land management planning and decision making.

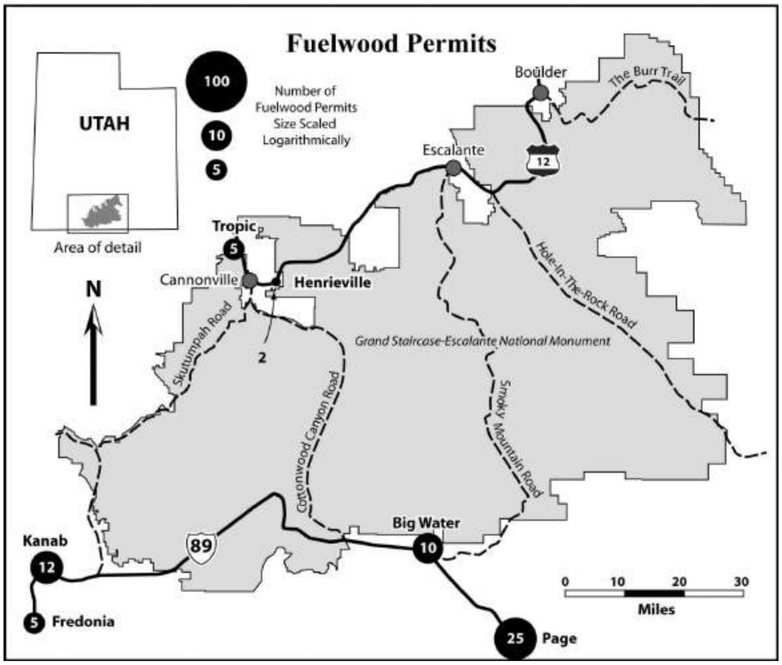

Figure 10. Distribution of GSENM fuelwood permits, 2006.

Conclusions

Permit data collected by public land management agencies contain a wealth of information regarding local community/resource linkages. These data are oftentimes unused in agency planning efforts, yet represent a readily available, low-cost method of describing and understanding how rural communities use and interact with nearby public lands. The growing list of challenges and competing uses facing our public lands suggest the need for a better understanding of community/resource uses and linkages. Meeting these challenges in an environment of diminished agency resources requires that public land managers fully utilize existing data, staff, and resources. The exploratory approach described here using agency permit data represents an important step toward reaching that goal. We hope that in time, these data will begin to realize their full potential in meeting public land management policy objectives by serving a more active role in describing, analyzing, and assessing the social and economic impacts of alternative land use policies.

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GSENM's Recreational Impact Monitoring Program: Trends in Recreation Impacts in the Backcountry and Dispersed Areas

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ABSTRACT

In 1999 an inventory of backcountry recreation sites was completed in Grand Staircase-Escalante National Monument. A total of 229 sites were documented using a Rapid Site Inventory (RSI) process. An RSI is a "quick snap-shot" of a site without quantitative analysis of impacts. The objective of the RSI was to obtain as many sites as possible (in the 90-95% range of site capture). Following the inventory, backcountry monitoring was established and implemented on a yearly basis.

The recreation monitoring program was then initiated in 2001 with a 7-year monitoring schedule for canyons/areas to be monitored. The monitoring data provides for quantitative assessment of impacts and the opportunity to assess longitudinal trends in recreational impacts. The monitoring program is currently in year 6; approximately 10-12 areas have been monitored each year. In 2005, site attribute standards were established for both backcountry and dispersed sites. These standards may be used to identify backcountry sites in need of resource mitigation.

In 2001 an inventory of dispersed campsites was completed for the Monument. The purpose of this project was to determine, through the use of an RSI approach, the current status of recreational impacts, either visible or known, along nearly 800 miles of roads. The project included Frontcountry, Passage, Outback, and Administrative roads. A total of 773 sites were documented in the inventory.

The dispersed monitoring program began in 2002. Quantitative data was collected for the northeast regions of the Monument in 2002 and 2005; data collection for the southwest regions of the Monument was completed in 2003 and 2006; 2004 was a "rest year" for data collection. The results of the dispersed monitoring program have enabled the Monument to analyze recreational needs for dispersed users and plan for site numbers and locations. As noted above, in 2005, site attribute standards were established for both backcountry and dispersed sites. These standards may be used to identify backcountry sites in need of resource mitigation.

Keywords: recreation, monitoring, impacts

Biology & Wildlife

"Actually, it's a bacteria-run planet, but mammals are better at public relations."

– Dave Unwin –

Ecology of Small Mammals Within Spotted Owl Nest Areas in Grand Staircase-Escalante National Monument

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ABSTRACT

The research presented in this report was conducted to better understand prey dynamics of threatened Mexican spotted owls in Grand Staircase-Escalante National Monument. The monument is located in the heart of Mexican spotted owl breeding habitat represented by the Colorado Plateau Recovery Unit. The monument preserves classic examples of many unique geologic and biologic resources of the canyonlands region and maintains a multiple use tradition supporting a rich variety of activities, including: climbing, photography, nature and geologic exploration, wilderness exploration, mineral development and livestock grazing. Understanding dynamics of small mammalian prey within Mexican spotted owl nesting habitat is germane to the owl's conservation in the Monument.

Successful management of spotted owls in the Monument will require stakeholder and manager collaboration, as well as detailed science-based information about population status and trends. A variety of factors may affect owl viability, including climate change, habitat integrity, demographic vital rates, and land-use practices. A first step toward understanding population dynamics of owls and their prey is examination of trends in prey community structure and prey abundance. During this study, mark-recapture techniques were used to estimate prey population sizes and capture rates using live-trapping grids established within spotted owl activity centers in the Paria watershed. The populations of small mammals present on each grid were marked and released and then recaptured during consecutive trapping sessions during July through October each year from 2001-2006. In addition, occupancy and breeding status of spotted owls was monitored each summer at nine different territories.

Pooling results of data collection across the three primary study sites (i.e., Snake, Hogeye, and Starlight Canyons), we observed 12 distinct rodent species using the study grids. Brush mice (*Peromyscus boylei*) were the most common species encountered on all three grids, followed by Deer Mice (*Peromyscus maniculatus*). A variety of other *Peromyscus* species were detected: the Pinyon Mouse (*Peromyscus trueii*), Canyon Mouse (*Peromyscus crinatus*), the Long-tailed pocket Mouse (*Perognathus formosus*), and the Cactus Mouse (*Peromyscus* erimidus). The Western Harvest Mouse (*Reithrodontomys megalotis*), Least Chipmunk (*Eutamias minimus*), Desert Woodrat (*Neotoma lepida*), White-throated Woodrat (*Neotoma albigula*), and a shrew (*Sorex* spps) were also trapped on the study grids. Individually, grid

species richness varied from as few as 4 species in Snake Canyon during 2004, to a high of 10 species on the Hogeye grid in 2006. Starlight Canyon showed the greatest number of unique rodent individuals captured (289) during the 2006 field season. This is a rather large number of rodents for a single hectare of canyon space.

Capture probabilities for small mammals were similar among rodents encountered on all three grids. For woodrats, the "behavior model" ranked highest (i.e., using AIC scores) and indicated woodrat capture and recapture rates were not equal. The inequality supported a "behavioral response" to the traps, i.e., woodrats were not shy about the traps. After accounting for variation in capture rates, estimated capture probability was 46% for mice and 40% for woodrats. In addition to grid trapping, we established line-transects to estimate the effects of grazing on small mammals in the riparian corridors in Hogeye and Snake Canyons during 2003 to 2006. Seven different rodent species were detected during transects, with Brush mice again the most abundance prey species caught, followed distantly by Deer Mice and White-throated Woodrats. The ungrazed transects in both Hogeye and Snake Canyon showed significantly greater rodent species richness, however, during wetter years (i.e., 2005-2006), species richness on the Snake Canyon transects showed no difference between grazed and ungrazed traps. In Hogeye Canyon, increased precipitation did not appear to increase species richness in the grazed riparian habitat, where richness in ungrazed habitat was consistently higher than grazed habitat. Furthermore, overall woodrat abundance was much lower in grazed vs. ungrazed riparian habitat. These results suggest that livestock grazing may have negative affects on spotted owl prey in riparian corridor habitats that provide key food resources for the owl in southern Utah. Grazing seemed to lower overall prey abundance and most importantly, grazing appears to be associated with diminished woodrat numbers, the primary prey for Mexican spotted owls in Utah.

Surveys for spotted owls were conducted throughout the Monument during 2000-2006. At the onset of our survey activities (in 2000), spotted owls were detected at eight sites, including four sites with owl pairs and four sites with single males. By 2004, nine potential owl territories were identified and monitored for occupancy and reproductive status for the duration of our study. Owl site occupancy and productivity dropped dramatically during the drought years 2001-2004, including several owl sites that were abandoned. The spotted owl subpopulation in the Monument was close to elimination during the 2003 and 2004 field seasons. During the 2005-2006 field seasons, rainfall increased significantly and both owl occupancy and reproduction increased. Spotted owl females that colonized the Snake and Starlight Canyon sites in 2005 were both subadults (3 yrs old). These subadults produced offspring during the 2005 field seasons. The results of spotted owl monitoring indicated relatively high persistence by males compared to the female, low fertility and occupancy rates during drought years, but a propensity to recover in response to returning rains in the desert canyonlands.

Introduction

Grand Staircase-Escalante National Monument, located in southern Utah, was created to preserve the region's unique scientific resources (Clinton 1996). Encompassing 1.9 million acres, the monument provides a premier setting for ecological field research (Fig. 1). The spotted owl (*Strix occidentalis*) has been the focus of agency concern in the west due to loss of nesting habitats throughout its range (Forsman et al. 1984, Willey 1998). The Mexican spotted owl (*Strix occidentalis lucida*) was placed on the ***threatened*** species list in 1993 (Cully and Austin 1993). Research indicates varying owl population trends, with several populations in Arizona and New Mexico showing significant declines (Seamans et al. 1998).

Although classically associated with late seral forests, Willey (1995, 1998) showed that Mexican spotted owls are also widespread in arid desert-scrub habitats throughout much of southern Utah and Northern Arizona. In the monument, Mexican spotted owls have been reported in visitor accounts and formal surveys since the early 1980's (McDonald et al. 1990, Willey 1997). The owl is strongly associated with steep and complex sandstone "canyonlands" dominated by arid vegetation communities rather than mesic old growth forest (Brown 1982, Thornbury 1965). Previous studies of spotted owls around the monument focused on understanding distribution and habitat (Rinkevich 1991, Willey 1995, Willey 1997), juvenile dispersal (Willey and Van Riper 2000), or impacts of recreation (Swarthout 2001). Aspects of prey ecology for Spotted owls occupying canyonlands habitat have not been addressed (e.g., population abundance, survival rates, trends in abundance over time), and only two reports have identified prey used by spotted owls in Utah (Wagner et al. 1982, Rinkevich and Gutierrez 1996), both showing woodrats (*Neotoma*) as a primary prey component.

Research Objectives

Specific knowledge of spotted owl prey will generate greater understanding of the prey's ecology, and thus help biologists manage spotted owls by targeting primary prey and associated habitats (USDI 1995, Willey 1998, Rinkevich and Gutierrez 1996). The objective of this study was to develop baseline information concerning trends in prey abundance and factors that influence population dynamics to lay groundwork for future management and research activities. Of special interest for the Colorado Plateau region are the long term impacts of climate change, and human activities on spotted owls and their prey (USDI 1995, Sakai and Noon 1997). Thus a second objective was to assess the effects of climate changes on both spotted owls and their primary prey. Given our objectives and the absence of current knowledge about spotted owl prey, the following guiding research questions were developed:

(1) What small mammal species occurred within Spotted Owl nesting habitats in the Monument?
(2) What was the species diversity of the small mammal community present with Spotted Owl nesting habitats?
(3) Were the numbers of prey species, and numbers of individual animals (unique captures) relatively constant, or variable, among trapping years and sites?
(4) What was the estimated capture and recapture probabilities of key prey species on trapping grids in Spotted Owl nest areas?
(5) Utilizing grazed and ungrazed transects within Spotted Owl nest areas, what were the patterns of small mammal abundance and species richness along transects sampled during the summer breeding season when cattle were present?

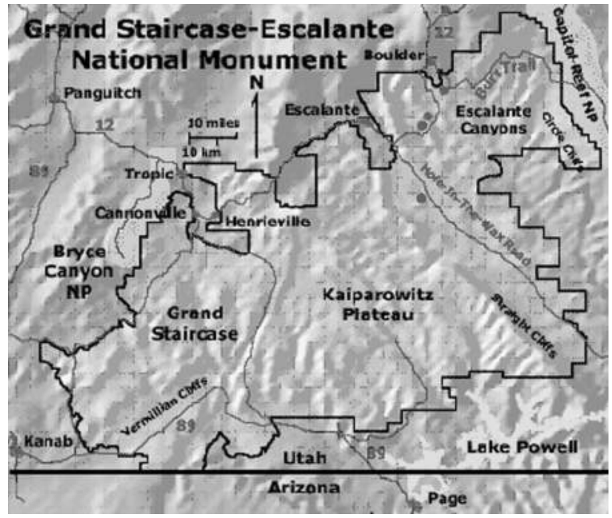


Figure 1. Location of GSENM in southern Utah

(6) What was the occupancy level and nesting status of the Spotted Owl territories where small mammal grids were established?

Research Methods

Study Areas

Grand Staircase-Escalante National Monument is located within the Colorado Plateau physiographic province of the western United States (Brown 1982). The Monument is located approximately 15-km northeast of Kanab in south-central Utah (Fig. 1). Landscapes in the monument are dominated by deeply entrenched sandstone canyons dissected by numerous tributaries rimmed by high cliffs and stair-step benchlands (Willey 1998). Canyon rim habitats give way to relatively flat forested plateaus often including Ponderosa pine (*Pinus ponderosa*) or Pinyon-juniper (PJ) (*Junniperus utahensis*) forests. Vegetation below the canyon rims includes riparian and upland vegetation stretching along canyon bottoms, with desert scrub vegetation present along the slopes above the riparian zones, and often present on mesa tops. Pinyon-juniper habitats are scattered among mid-elevation slopes, and mixed conifer vegetation scattered among north-facing alcoves or on Mesa tops. Elevation ranges from 1,109 to 3,960 m.

Monitoring Spotted Owls

Survey methods for spotted owls at each site followed the standard survey protocol established by Forsman (1983). The protocol includes guidance and recommendations for owl surveyors to: (1) make inferences regarding the presence or absence of owls in a defined area; (2) assess occupancy and nesting status, and locate nests, in areas where habitat alterations or disturbances to owls are likely to occur; and (3) provide information to allow designation of Protected Activity Centers (USDI 1995).

It has long been recognized that the best way to detect the presence of spotted owls within potential habitat is to mimic their calls and listen for a response (USDI 1995). Following the standard protocol, we established calling points every 0.5 miles along survey routes stratified along canyon bottoms in the four principal prey study areas. The number of calling routes and calling stations depended on the size of the area, topography, and vegetation, but typically 6 calling stations were placed within each prey study area each year to monitor for owl occupancy and breeding status (Willey 1998).

The vocal repertoire of spotted owls consists of a variety of hooting, barking, and whistling calls (Willey 1995). Three call types accounted for 86 percent of calling bouts heard in Arizona: four-note location call, contact call, and bark series. The four-note call appears to be used the most frequently by owls defending a territory. Therefore, surveyors used all three of these calls during surveys, with the four-note call as the primary call. We conducted visits to all nine historic spotted owl territories during May-October 2000 to 2006. Surveyors spent at least 15 minutes at each calling station: 10 minutes devoted to calling and listening in an alternating fashion, and the last 5 minutes listening. Each calling point was called four times during the field season, or until spotted owls were detected. Once owls were detected we conducted follow-up visits to identify nesting status and monitor occupancy. We recorded observations of single owls, owl pairs, and number of young; locations of nest areas and locations of roost sites. We selected three territories as primary study sites to initiate long-term study of spotted owl prey ecology. The sites included: Hogeye Canyon, Starlight Canyon, and Snake Canyon within the Paria watershed (Fig. 2).

Small Mammal Surveys

We established square capture grids for small mammals at each of our focal study areas (Hogeye, Snake, and Starlight Canyons). The trapping grids for small mammals were placed within 300-m of the known nest sites (Willey 1998). Each trapping grid consisted of a 100 X 100 meter square trap grid, with 10-m spacing between traps, and thus 100 live traps placed on a matrix at each study site. Each trap grid was run for 5 consecutive nights and we repeated each grid up to four times during the summer field season to examine within-season and between-year variation in population size (Wilson and Obrien 1994, Rexstad 1994, Sakai and Noon 1997). Grids were trapped each year during July through October 2000 to 2006. Once captured, rodents were marked with Monel type ear tags, identified to species, and

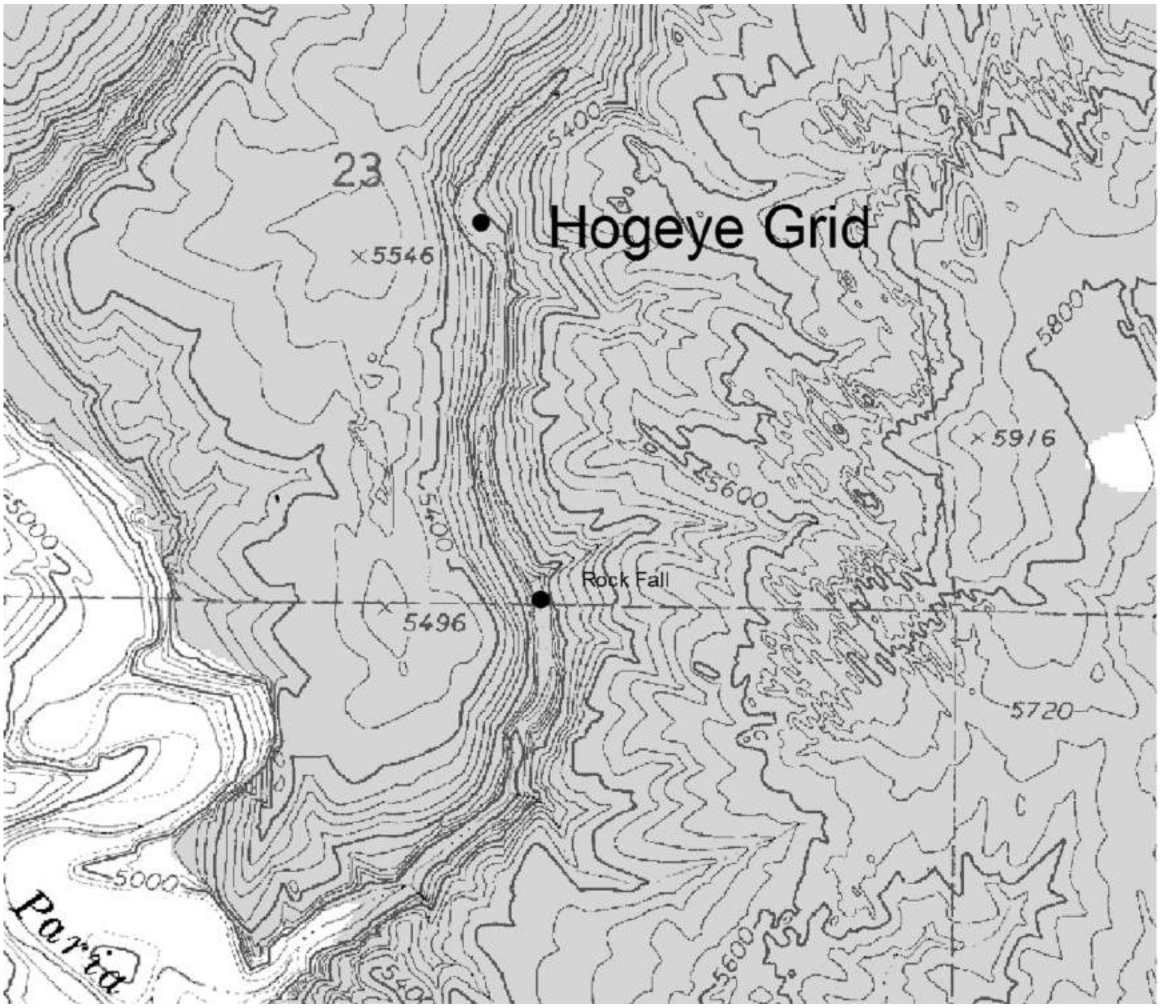


Figure 2. Map of the Hogeye Canyon study site in Grand Staircase-Escalante National Monument, Utah.

weighed with a Pesola scale (grams) or measured for body and tail length (cm). We also recorded sex, reproductive condition, and estimated age class (Linsdale and Tevis 1951).

For the analysis of small mammal trapping data, rodent abundance was estimated for all *Peromyscus* species and woodrats. Abundance was estimated on the grids using the methods of Otis et al. (1978) and Anderson et al. (1983), including closed population modeling and the simple metric total unique captures per grid. Patterns of species presence were estimated using live recaptures within, and among, the study grids (Wilson and O'Brien 1994). We used Programs MARK (White and Burnham 1999) to estimate the capture rate, recapture rate, and population size for each grid. We used closed population models (Otis et al. 1978) and additional estimators derived by Chao (1988), Chao et al. (1992), and Burnham (1990) to derive summary statistics.

Grazing Effects Transects

We established two grazing "experiments" using line-transects for small mammals at Hogeye and Snake Canyons during the 2003-2006 field seasons (Fig. 2). In each canyon, we set up line transects within riparian habitats running up and down canyon above and below rugged rock falls that prevented cattle from accessing the upper 25 "control" traps at each site. Thus, 25 live traps were monitored in ungrazed riparian habitat, and 25 traps were monitored in grazed riparian habitat. Transects were run for 5-nights during 3 separate trap periods during June-October 2003-2006. We set up each "treatment" trapline in areas of high cattle use in contrast to "control" traps located above rockfalls in riparian habitat free of cattle grazing. We compared rodent abundance and species richness between the experimental groups at both sites.

Habitat Measurements

We measured the following habitat characteristics at each grid and line-transect rodent trap location (n=100 per grid, n = 50 per grazing transect): (1) Using line intercept a 5-m cable was stretched from each trap center point north and all vegetation, rock, bare ground, and debris that intersected the line were tallied by cover class (generates coverage among habitat cover types); (2) recorded maximum shrub height along the line; (3) slope; (4) aspect; (5) recorded all trees present within 5-m of trap including tree height, and DBH; (6) canopy cover was recorded using a spherical densiometer; (7) Community type was recorded (e.g., PJ, desert shrub, grassland, slickrock); (8) and all vegetation species were recorded.

Results

Spotted Owl Inventory and Monitoring

Surveys for spotted owls were conducted throughout the Monument during 2001-2006. At the onset of owl surveys during summer 2001 spotted owls were detected at eight sites, including four occupied by spotted owl pairs and four with only males. By 2006, nine potential owl territories had been identified and monitored for occupancy and reproductive status.

During six consecutive summers monitoring the 9 territories, we observed that the number of sites occupied by spotted owls, number of pairs versus single males, and number of young produced greatly varied (Table 1). For example, the number of sites occupied by spotted owl pairs dropped quickly and we observed complete cessation of breeding during 2002-2004. Two sites "winked out," and the local owl population appeared on the brink of elimination in 2004 (Fig.3).

However, during the 2005 and 2006 field seasons, both occupancy and reproduction showed strong increases (Table 1).

Spotted owl females that recolonized the Snake and Starlight sites during spring 2005 were both subadults (i.e., 2-yrs. old). Both females produced owlets during 2005, showing plasticity in age-first-reproduction, often linked to low density (Seamans et al. 1999, Franklin et al. 2000). We observed higher site persistence by males than females during the 2001-04 drought, and saw low fertility in the Monument during the drought (Table 1, Fig. 3&5). Similar trends were observed in Capitol Reef (Fig. 3) and on the Kaibab plateau

Territory	2001	2002	2003	2004	2005	2006
Bull Valley	♂	♂	♂	♂	♂	♀♂
Sheep Creek*	⓿	⓿	⓿	⓿	♂	♂
Snake Canyon	♀♂❶	♂	♂	♂	♀♂❸	♀♂❸
Hogeye Canyon	♀♂❶	♀♂	♂	♂	♀♂❷	♀♂❸
Starlight	♀♂	♀♂	♀♂	♀♂	♀♂❶	♀♂❸
Wahweap	♂	♂	♀♂	♂	⓿	♀♂
Four Mile	♂	♂	⓿	⓿	⓿	♂
Sara Allen	♂	⓿	⓿	⓿	♂	⓿
Hackberry (Sam)	♀♂❷	♂	♂	♂	⓿	⓿

*Alternatively, the Bull Valley male could be using Sheep Creek

Symbols:
♂ = Male spotted owl
♀♂ = Pair of spotted owls observed
❶❷❸ = Number of juveniles observed
⓿ = No owls observed

Table 1. Results from surveys within Spotted Owl territories during 2001-2006 in Grand Staircase-Escalante National Monument, southern Utah.

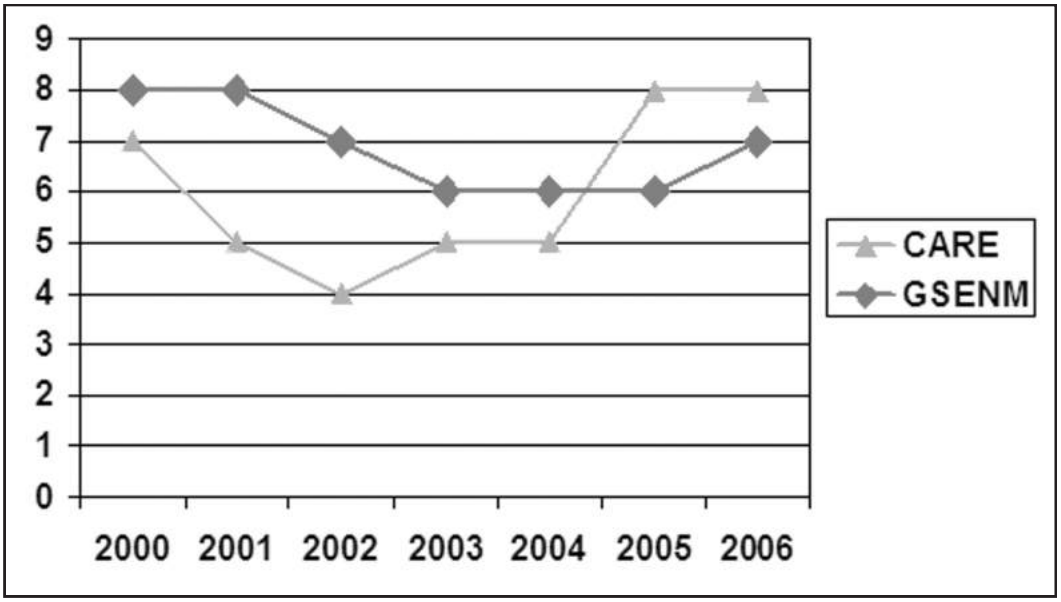


Figure 3. Trends in owl territories observed (y-axis) in the Canyonlands region during 2000-2006. Number show owl territories occupied in two study areas: GSENM and CARE = Capitol Reef.

for spotted owls, and northern Goshawks, respectively.

Small Mammal Surveys in Spotted Owl Nest Habitat

Rodent populations present on trapping grids were captured, marked, and released at the point of capture. Pooled across the three study sites, 13 different species were distributed among the grids (Tables 2, 3, and 4). Brush mice (*Peromyscus boylei*) were the most common species encountered on all three grids, followed by deer mice (*Peromyscus maniculatus*). A variety of other *Peromyscus* species were detected, although at relatively low numbers (indicating rarity), including: Pinyon Mouse (*Peromyscus trueii*), Canyon Mouse (*Peromyscus crinatus*), Long-tailed pocket Mouse (*Perognathus formosus*), and Cactus Mouse (*Peromyscus* erimidus). White-throated woodrats (*Neotoma albigula* – henceforth NEAL) were quite common in the later years of study, especially at Starlight and Hogeye Canyons (Tables 2, 3, and 4). Eighty-two unique individual NEAL were observed on the Starlight grid in 2006 - a remarkable number of woodrats for a one hectare grid.

In addition to the NEAL and *Peromyscus*, the Western Harvest Mouse (*Reithrodontomys megalotis*), Least Chipmunk (*Eutamias minimus*), Desert Woodrat (*Neotoma lepida*), a single Ord's Kangaroo Rat (*Dipodomys ordii*) and a shrew (*Sorex* spps) were also trapped on the study grids, although mostly in low numbers (Table 2). Species richness varied from as few as 4 species in Snake Canyon during 2004 (Table 3) to a high of 10 species on the Hogeye grid in 2006 (Table 2). Starlight Canyon had the highest total abundance of all rodents pooled (290) during the 2006 field season (Table 4).

Capture probabilities derived from Program MARK were similar for woodrats and mice (pooled) across all grids. For woodrats, the "behavior model" (Otis et al. 1978) was ranked highest (AIC scores) as the best approximating model for estimating abundance (Table 5), and indicated woodrat and mouse capture and recapture rates were not equal. The inequality supported the observation by field biologists that rodents on our grids were easily caught and quite "trap happy." After accounting for variation in capture rates, final estimated capture probability was 46% for mice and 40% for woodrats. Further, the percent of new versus recaptures dramatically dropped during each grid trapping session, for example, at Hogeye the percent of new captures during a trap session started as high as 78% new captures, and dropped to 0% during final days which suggests a large proportion, if not all, of the local population was captured and marked (Tables 5 through 8).

Species[1]	2001	2002	2003	2004	2005	2006
PEBO	9	17	21	62	70	153
PETR	7	2	6	0	11	7
PEMA	21	8	1	34	6	7
PECR	0	1	14	1	2	36
PEER	0	0	0	0	0	4
PEFO	0	9	8	11	0	8
REME	0	0	0	0	3	15
EUDO	11	17	11	2	0	3
NEAL	5	1	3	17	37	43
NELE	1	0	0	3	0	0
NECI	0	0	1	0	0	0
SOREX	0	0	0	0	0	1
Total	**54**	**55**	**65**	**130**	**129**	**277**
# Species	**6**	**7**	**8**	**7**	**6**	**10**

[1] Species acronyms:
PEBO = Brush Mouse (*Peromyscus boylei);* PETR = *Pinyon Mouse (Peromyscus truei)*; PEMA = Deer Mouse *(Peromyscus maniculatus)*; PECR = Canyon Mouse *(Peromyscus crinitus)*; PEER = Cactus Mouse *(Peromyscus erimicus)*; PEFO = Longtail Pocket Mouse *(Perognathus formosus)*; REME = Western Harvest Mouse *(Reithrodontomys megalotis)*; EUDO = Cliff Chipmunk *(Eutamias dorsalis)*; NEAL = White-throated woodrat *(Neotoma albigula)*; NELE = Desert Woodrat *(Neotoma lepida)*; NECI = Bushy-tailed Woodrat *(Neotoma cinereus)*; Sorex = unknown shrew.

Table 2. Number of unique individual animals captured, tagged, and released during 2001 to 2006 on the Hogeye Canyon capture grid using Sherman live traps in Grand Staircase-Escalante National Monument, Utah.

Species[1]	2002	2003	2004	2005	2006
PEBO	23	42	40	93	134
PETR	1	0	0	2	0
PEMA	12	20	18	13	8
PECR	1	4	1	3	2
REME	0	0	0	4	8
EUDO	22	2	0	0	8
NEAL	2	4	5	7	7
NECI	0	1	0	3	1
Total	**61**	**73**	**64**	**125**	**168**
#Species	**6**	**6**	**4**	**7**	**7**

[1]Species acronyms: PEBO = Brush Mouse (*Peromyscus boylei);* PETR = *Pinyon Mouse (Peromyscus truei)*; PEMA = Deer Mouse *(Peromyscus maniculatus)*; PECR = Canyon Mouse *(Peromyscus crinitus)*; REME = Western Harvest Mouse *(Reithrodontomys megalotis)*; EUDO = Cliff Chipmunk *(Eutamias dorsalis)*; NEAL = White-throated woodrat *(Neotoma albigula)*; NECI = Bushy-tailed Woodrat *(Neotoma cinereus).*

Table 3. Number of unique individual animals captured, tagged, and released during 2002 to 2006 on the Snake Canyon capture grid using Sherman live traps in Grand Staircase-Escalante National Monument, Utah.

Species[1]	2002	2003	2004	2005	2006
PEBO	18	25	54	101	150
PETR	5	10	8	9	7
PEMA	4	14	27	17	24
PECR	0	4	2	0	10
PEER	0	2	0	6	0
PEFO	5	4	12	34	16
REME	0	0	0	1	0
EUDO	1	1	0	0	0
NEAL	0	1	0	43	82
NELE	0	0	1	3	0
DIOR	0	0	0	0	1
Total	33	61	104	214	290
# Species	5	8	6	8	7

[1]Species acronyms: PEBO = Brush Mouse (*Peromyscus boylei)*; PETR = *Pinyon Mouse (Peromyscus truei)*; PEMA = Deer Mouse *(Peromyscus maniculatus)*; PECR = Canyon Mouse *(Peromyscus crinitus)*; PEER = Cactus Mouse *(Peromyscus erimicus)*; PEFO = Longtail Pocket Mouse *(Perognathus formosus)*; REME = Western Harvest Mouse *(Reithrodontomys megalotis)*; EUDO = Cliff Chipmunk *(Eutamias dorsalis)*; NEAL = White-throated woodrat *(Neotoma albigula)*; NELE = Desert Woodrat *(Neotoma lepida).*

Table 4. Number or unique individual animals captured, tagged, and released during 2002 to 2006 on the Starlight Canyon grid using Sherman live traps in Grand Staircase-Escalante National Monument, Utah.

A strong temporal trend in overall abundance of *Peromyscus* was detected during the research (Fig. 4). During the initial years mouse abundance showed a steady drop, but during the later years, populations exhibited a steady yearly increase in abundance on all studied grids (Fig. 4). Finally, climate data collected from the University of Nevada, Reno (NOAA, unpublished records), who supplied weather data from the vicinity of the trap study sites were summarized, including mean rainfall, and average temperatures from May-Sep 1996 to 2005 (Fig. 5). The data reflect the increasing drought conditions during the initial years of our study.

Grazing Effects on Spotted Owl Prey

Line-transects for small rodents were run to estimate the effects of grazing on spotted owl prey in riparian corridors adjacent to nesting core areas (Willey 1998). Grazing transects were established in both Hogeye and Snake Canyons during 2003 to 2006. Seven different rodent species were detected during transect runs (Table 9), with Brush mice again the most abundance prey species caught, followed by Deer Mice and White-throated Woodrats (Table 9).

The ungrazed transects showed significantly greater rodent species richness throughout the course of study (Fig. 6), however in the final wet year (i.e., 2006), species richness on the Snake Canyon transects showed no difference between grazed and ungrazed traps (Fig. 6). In Hogeye Canyon, increased precipitation did not appear to increase species richness in the grazed riparian habitat, where richness in ungrazed habitat was consistently higher than grazed habitat. Furthermore, overall woodrat abundance was much lower in grazed vs. ungrazed riparian habitat (Fig. 7). Overall, for both canyon study sites, the ungrazed line-transects showed significantly greater mouse abundance, including differences ranging from 20 to 50 more mice per transect during the study (Fig. 8). Grazed transects did not appear to experience as great a recovery in rodent abundance during wet years compared to ungrazed sites (Fig. 8). Thus the grazed riparian rodent community did not appear to benefit, in terms of population growth, from the increased rainfall seen in the study areas during the final year of study (Table 9, Fig. 8).

Model	AICc	Delta AICc	AICc Weight
{M(b)}	52.490	0.00	0.383
{M(tb)}	53.381	0.89	0.245
{M(o)}	54.102	1.61	0.171
{M(t)}	55.390	2.90	0.089
{M(b)} sites}	56.075	3.59	0.063
{M(.)} sites}	56.707	4.22	0.046

Table 5. Model results from closed population modeling (Program MARK) for woodrats captured during the 2003 field season, Grand Staircase-Escalante National Monument.

Model	AICc	Delta AICc	AICc Weight
{M.}	56.053	0.00	0.699
{Mb}	58.177	2.12	0.239
{Mt}	61.606	5.55	0.043
{Mtb}	62.801	6.75	0.023

Table 6. Model results from closed population modeling for mice species (all species pooled) captured on 100 x 100 meter grid established at the Hogeye Canyon site during summer 2003 in Grand Staircase-Escalante National Monument.

Key to Tables 5 and 6	
M(b)	"behavior model" (capture probablility ≠ recapture probability)
M(tb)	"time and behavior model," where capture probabilities can vary by time, and capture probability ≠ recapture probability
M(.)	"null model" (capture = recapture probability; time not a factor)
Mt	probabilities vary only by time, and capture probability = recapture probability
Mo	all capture probabilites are constant over time

Discussion

Long-term ecological studies provide unique opportunities to study resource-consumer relationships in naturally complex settings (Brown and Ernest 2002). Since 2000, our research monitored a predator-prey desert system based on spotted owls that occupy sites in the Paria River watershed of Grand Staircase-Escalante National Monument. Understanding interactions and relationships between desert resources and consumers, and examining how these linkages might affect community structure and temporal dynamics in southwestern deserts is of particular interest to biologists faced with the daunting task of recovering and sustaining threatened and endangered wildlife and plants (USDI 1995, Rosenstock 1996, Thibault et al. 2004). Furthermore, ecologists have long been interested in assessing "bottom up" versus "top down" patterns of regulation transmitted along food chains and trophic levels in desert system where water is the primary limiting resource (Brown 1989, Brown and Heske 1990, Lima et al. 1999, Grubb et al. 1997, Brown and Ernest 2002, Davidson and Lightfoot 2007).

Previous work in desert systems has shown both chaotic, nonlinear system dynamics (Brown 1989, Brown and Heske 1990, Lima et al. 1999, Ernest et al. 2000), and also strong linear classical "bottom up" behavior (Thibault et al. 2004). For desert systems, the bottom-up model seems intuitive, and recognizes that water is the primary limiting resource for desert plants. Thus, fluctuations in desert rodent communities should be closely tied to variation in plant productivity, and ultimately associated with variation in precipitation (Brown and Ernest 2002). Numerous studies have documented strong linear effects of drought-breaking precipitation on arid ecosystems. Typically these studies observed strong linear increases in abundance by desert rodent communities in response to returning rains after drought (Beatley 1969, Meserve et al. 1999).

Date	All Captures	New Capture	% New Capture
First Session			
6/22	14	4	29%
6/23	10	2	20%
6/24	12	0	0%
6/25	14	3	22%
6/26	7	0	0%
Second Session			
7/12	9	3	33%
7/13	13	1	8%
7/14	11	2	18%
7/15	12	1	8%
7/16	16	0	0%
Final Session			
10/26	10	3	30%
10/27	14	4	29%
10/28	8	1	13%
10/29	6	0	0%
10/30	6	0	0%

Table 7. Total captures, new captures, and the percent of new captures for small mammals encountered on Hogeye Canyon study grid, Grand Staircase-Escalante National Monument, 2002 field season, Utah.

Date	All Captures	New Capture	% New Capture
First Session			
7/22	23	18	78%
7/23	29	7	24%
7/24	31	7	23%
7/25	33	2	6%
7/26	29	3	10%
Second Session			
8/19	13	4	31%
8/20	18	2	11%
8/21	44	7	16%
8/22	30	3	10%
8/23	38	1	3%
Final Session			
10/7	31	11	36%
10/8	40	9	23%
10/9	44	5	11%
10/10	55	7	13%
10/11	61	5	8%

Table 8. Total captures, new captures, and the percent of new captures for small mammals encountered on Hogeye Canyon study grid, Grand Staircase-Escalante National Monument, 2005 field season, Utah.

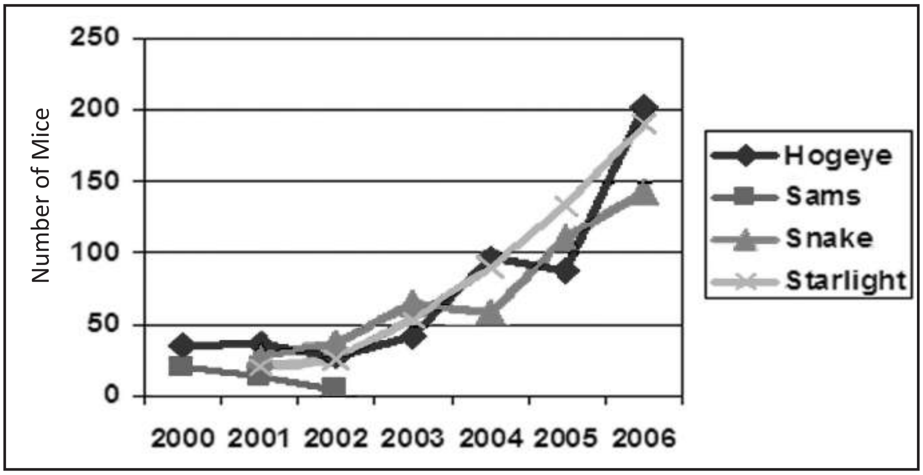


Figure 4. Temporal patterns in mice abundance (y-axis; total number captured presented) at four study areas during 4 years from 2000-2003 in GSENM, Utah.

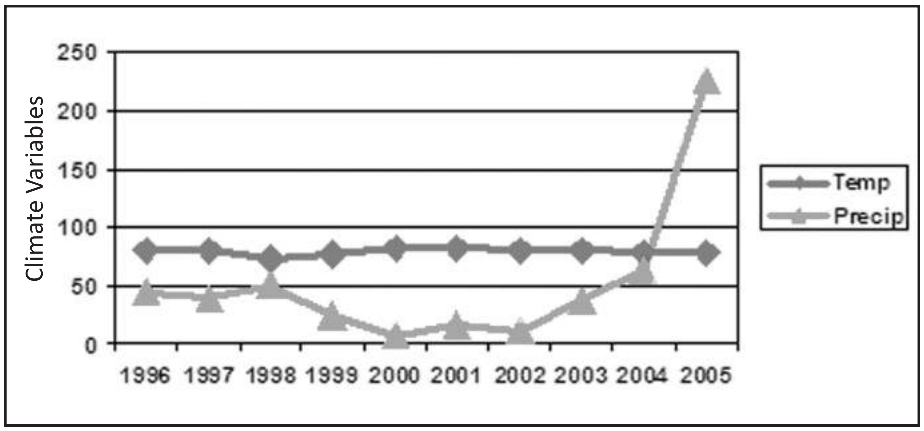


Figure 5. Climate data from University of Nevada, Reno, NOAA atmospheric center (unpublished records, Reno, NV). Data from five stations in the vicinity of small mammal study sites summarized by monthly mean rainfall (100th in.), and mean monthly temperatures (Def. F) from May-Sep 1996-2005.

Within the Paria River watershed in the monument, our research detected strong linear (geometric) increases in rodent species abundance over the course of our investigation (Fig. 4). A severe drought gripped southern Utah during the early decade, thus the 2000-2003 field seasons experienced extremely dry spring and summer seasons (Fig. 5). The drought broke in southern Utah during the 2004 field season, and 2005-2006 showed increasing spring and summer rain events (see http://www.ut.blm.gov/monument/weather-index.php). In what appears to be a classic exponential increase associated with increased spring and summer rainfall, small mammal populations showed increases in both species richness and abundance during increasingly wetter study years (Tables 2, 3 & 4, Figs. 4 & 5).

Recognizing that water is a key resource in deserts, it comes as no surprise that the amount and timing of precipitation were limiting factors for desert rodents. Mechanistically, rainfall events produced plant blooms whose primary productivity resonated up through food webs (Brown and Ernest 2002). The effects of drought, and drought relief, on desert rodents in the Paria were evident in the contrast of total abundance of small mammals captured, and the percentage of new captures versus recaptured rodents contrasted between the 2002 drought year, and the 2005 wet year. During 2002, total captures per night were quite low (6-16 total animals caught), and percent new captures dropped to zero in the final nights, suggesting no new individuals existed (Table 7). In contrast, during the wet 2005 field season, new captures never dropped to zero and total captures per trap night ranged from 13 to 61 rodents (see Fig. 4).

What was the impact of climate changes and rodent dynamics on Mexican spotted owls? It

Transect Type:	**Ungrazed**				**Grazed**			
Study Year:	**03**	**04**	**05**	**06**	**03**	**04**	**05**	**06**
Hogeye Species List								
Brush Mouse	12	19	44	70	7	20	33	45
Deer Mouse	4	17	10	3	1	12	11	1
Canyon Mouse	0	0	0	1	0	0	0	1
Pinyon Mouse	0	0	0	0	1	0	0	0
Pocket Mouse	0	0	1	3	0	0	1	3
Desert Woodrat	0	3	1	0	0	1	0	0
White-throated Woodrat	1	4	19	12	0	0	5	5
Total Captures	**17**	**43**	**75**	**89**	**9**	**33**	**50**	**55**
Snake Canyon Species List								
Brush Mouse	17	17	45	60	7	14	40	47
Deer Mouse	5	5	3	7	1	6	13	3
Canyon Mouse	1	0	2	1	0	0	0	0
Pinyon Mouse	3	0	0	1	1	0	0	0
Pocket Mouse	0	0	3	5	0	0	0	5
Desert Woodrat	0	3	0	0	0	0	0	0
White-throated Woodrat	0	1	3	6	0	2	3	2
Total Captures	**26**	**26**	**56**	**80**	**9**	**22**	**56**	**57**

Table 9. Results from Hogeye and Snake Canyon line transects for small mammals captured within riparian areas exposed to grazing and free from domestic grazing in Grand Staircase-Escalante National Monument, Utah, 2003-2006.

appears that drought had a negative impact on owl occupancy, pair status, and production of young in the Paria region (Table 1, Fig. 3). During the 2000-2003 dry-period, the number of territories occupied by spotted owls dropped, the number of sites with pairs dropped, and reproduction stopped completely, with fertility equal to zero during 2002-2004. We also observed evidence that a lag in the owl's response to the drought breaking exists, e.g., although rainfall increased significantly in 2004, reestablishment of territories and production of young owls were not observed in the Paria watershed until 2005. Perhaps the return of summer rains and a strong monsoon in 2004 came too late to affect owl reproductive rates (owls typically breed in early March). Finally, in both 2005 and 2006 spotted owl territories were reestablished and productivity showed a strong increase (Table 1). I suspect that the increased rainfall led to increases in plant growth, seed production, and increased insect populations, leading in turn to strong increases in rodent abundance translating up the food web to increased owl occupancy rates and fertility (Brown 1989, Brown and Heske 1990, Franklin et al. 2000, Brown and Ernest 2002, Thibault et al. 2004) (Table 1).

The research conducted in the Paria River watershed also provided strong evidence that desert rodent communities were affected by factors other than precipitation. In the Paria, differences in rodent community structure appeared to reflect effects by livestock grazing and/or loitering in riparian habitats (Table 9). In two replicate settings, canyon riparian habitats with nearly identical precipitation patterns, vegetation composition, elevation, and stream flow patterns differed markedly in rodent species abundance and community structure in grazed versus ungrazed experimental units (Table 9, Figs. 6 & 7). Livestock grazing appears to have dramatically reduced both woodrat

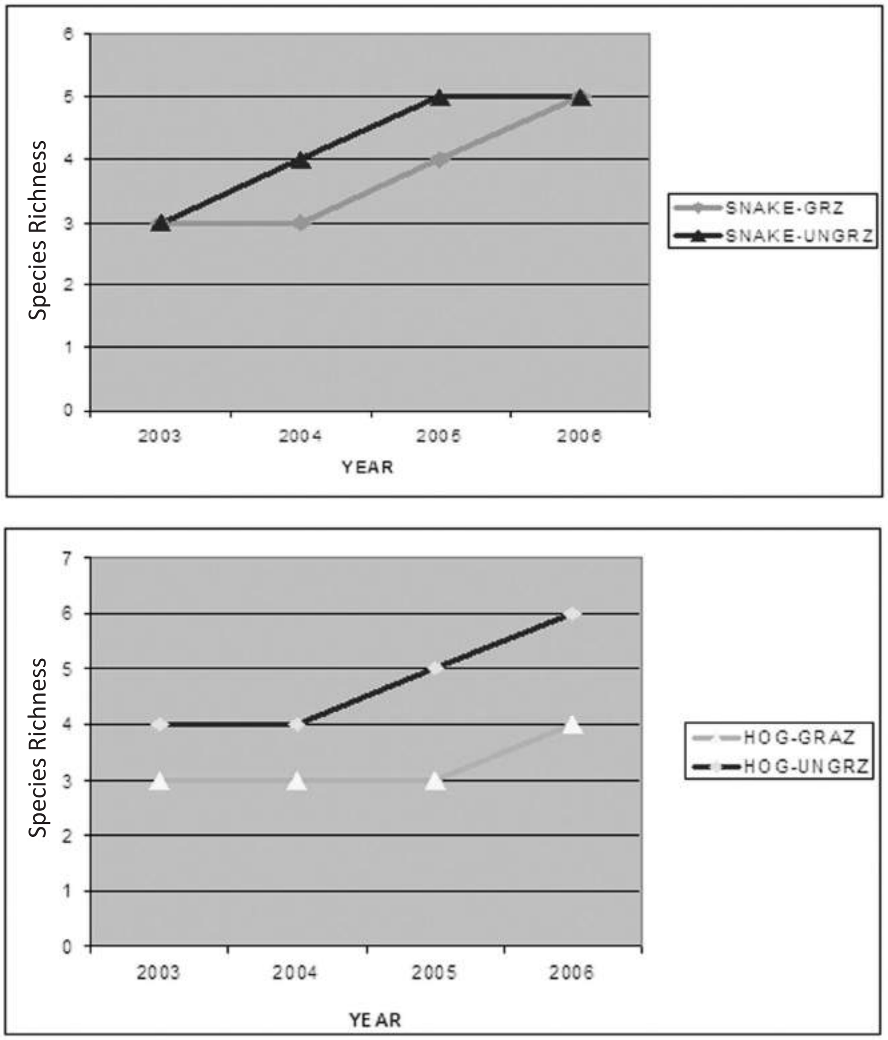
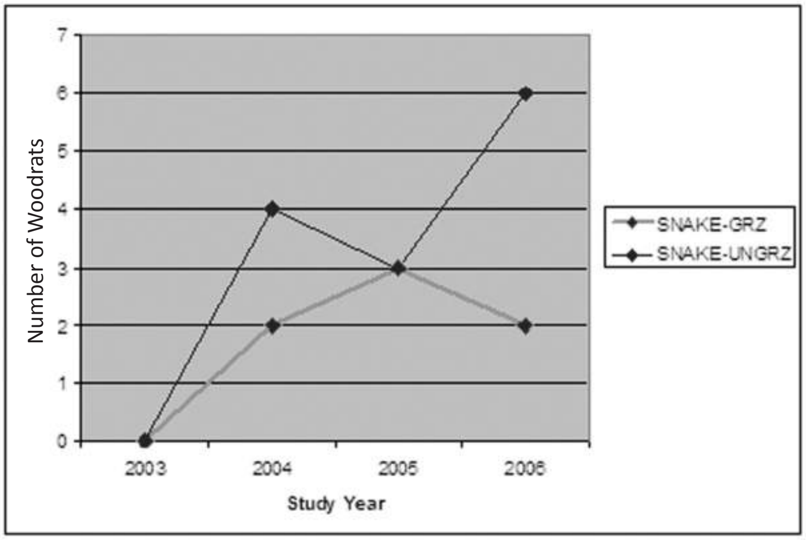


Figure 6. Line graphs showing changes in the species richness of small mammals trapped on Grazed (light lines) versus ungrazed (dark) line transects in riparian habitat within Snake and Hogeye Canyons.

and overall mouse abundance, and grazing may have altered rodent community structure, eliminating some *Peromyscus* species (Table 9). The implications for Mexican spotted owls, whose primary prey are woodrats and mice is obvious and alarming (USDI 1995). Negative influences of grazing by cattle in arid regions have been well documented (e.g., Rosenstock 1996, Jones and Longland 1999, Jones 2000). The Paria study appears to provide more evidence that cattle are keystone species in riparian habitats, thus cattle presence may not enhance conditions suitable for persistence of threatened Mexican spotted owls in certain riparian corridors (Bock and Webb, 1984, USDI 1995).

Management Implications

Although rodent population declines may be related to processes other than climate, including for example, livestock grazing, capture and research, predation pressure, and disease; the results of this research strongly implicate climate as a major process in desert rodent population dynamics. It seems obvious that water supply is the primary limiting factor for productivity in arid ecosystems, and I find it fortuitous that our research began at the start of significant drought in the region and included recovery from drought. Given the predictions of continued climate change in the western U.S., and the virtual lack of other studies on rodent system in the region (e.g. see Alston 2003), I strongly urge continuation of this study to accomplish the following goals: (1) to further document rodent population changes in response to climate change in the Paria region, (2) to monitor the spotted owl and its response to



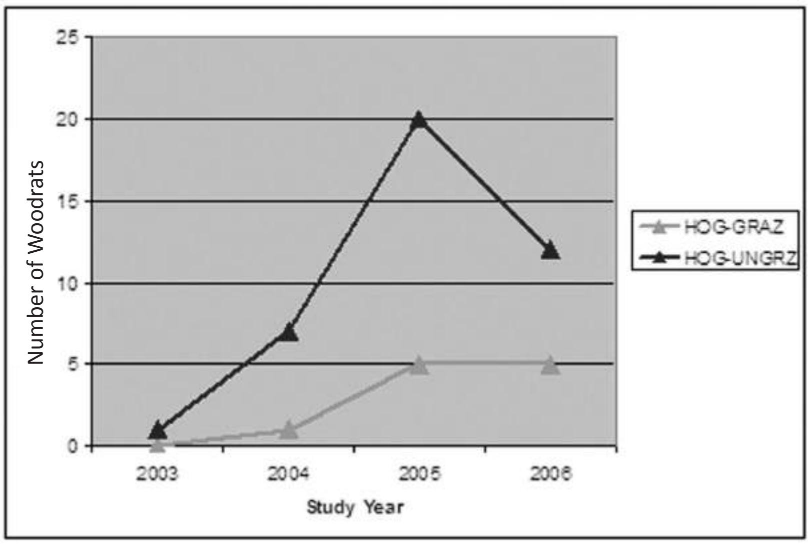


Figure 7. Line graphs showing changes in the woodrats (Neotoma spps.) trapped on grazed (light colored lines) versus ungrazed (dark) line transects in riparian habitat within Snake and Hogeye Canyon study sites.

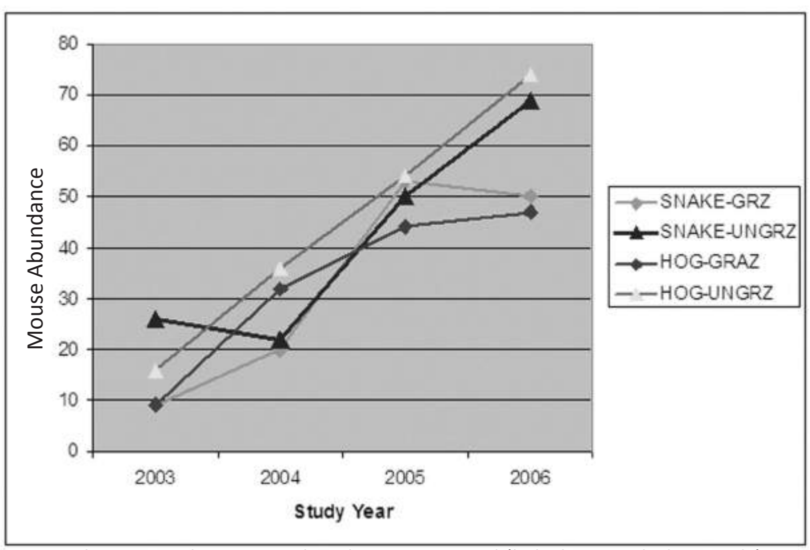


Figure 8. Line graphs showing changes in the mouse abundance on grazed (light lines with diamonds) versus ungrazed (dark lines with triangles) line transects in riparian habitat within Snake and Hogeye Canyon study sites.

climate change and rodent population dynamics, (3) to continue to examine the effects of livestock grazing on small mammals in desert ecosystems, (4) to fill in gaps in knowledge concerning the linkages between climate change, grazing, and vegetation responses that affect small mammals, and (5) to make accurate predictions concerning the responses of desert rodents and spotted owls to temporal and spatial variation in precipitation and livestock effects. A more long-term knowledge of the relationships will be required.

Perhaps also important are eruptions of rodent populations that can be linked to outbreaks of rodent borne diseases, e.g, hantavirus. Long-term monitoring could help alert managers and communities to predict these epidemics. Clearly the conditions are ripe in the Paria region for increased incidence of *Sin Nombre* strain of hantavirus given the huge increases in rodents we observed during this study (see Harper and Meyer 1999).

Finally, there are several implications from this research regarding the effects of livestock grazing on prey species of threatened Mexican spotted owls (USDI 1995). Although limited to two experimental treatment sites, the line-transect data strongly suggested that grazing by cattle, or at least their movements and loitering in the riparian corridors in Snake and Hogeye canyons, was associated with decreasing rodent species diversity and population abundance. The grazing effects results are particularly disturbing for woodrats, who showed strong reductions in the grazed experimental units. Given that woodrats are the primary prey selected by spotted owls in the canyonlands region (USDI 1995), any reduction in woodrat biomass is a red flag for spotted owl managers. In addition, the strong drop in mouse abundance, sometimes as high as 40-less mice per 250-meters of line transect, was also significant for spotted owls. Clearly grazing transects showed reduced prey biomass for spotted owls in the lower reaches of Hogeye and Snake Canyons where cattle are known to occur. I recommend a management experiment, where cattle are excluded from both canyons while long-term monitoring of the line-transects continues. This would provide an experimental framework to assess recovery from grazing in riparian systems.

Aknowledgments

Numerous field assistants and biologists put in long hours conducting this research and I thank them greatly for all their contributions. Dennis Pope and Harry Barber, BLM Wildlife Biologists (real ones that actually get outside and see the resource) deserve special thanks for providing field assistance, motivation, horse packers, consistent funding, and great energy throughout the study. Judy Ousley and Maria Gochis provided critical contract support and coordination from the BLM State Office, they too deserve special thanks.

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Community Structure of Flies in Grand Staircase-Escalante National Monument: Differences in Occurrence and Abundance at Two Sites, Spring 2000 and Spring 2005

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ABSTRACT

Insects perform many important ecosystem functions such as herbivory, decomposition, and pollination. Sustainability of natural systems depends upon the continued performance of these functions. Insect diversity may provide redundancy of functions and thus resilience to perturbations, yet disturbance can affect insect communities and thus ecosystem condition. Few ecological relationships involving insects have been described on the Colorado Plateau. More can be learned about the role of insects in ecosystem functioning by monitoring changes in insect community structure in response to changes in disturbance regimes. Retirement of grazing permits in parts of Grand Staircase-Escalante National Monument provided an opportunity to track changes in arthropods following the removal of livestock, and to compare arthropod communities in grazed and retired systems. The Diptera were consistently one of the numerically dominant groups at sampling sites in the Gulch and Steep Creek over the course of this study (fall 1999-spring 2005). Here we examine differences in composition and abundance of flies at the family levels on alluvial bench environments in Steep Creek (ostensibly retired from grazing in 1999) and The Gulch (still open to grazing), comparing community structure of spring fly faunas at the two sites from 2000 and 2005. Thirty four families are represented in samples, with 22-27 families at a given site in a given year. Some flies showed similar changes at both sites, such as the Sciaridae which increased from a few individuals to well over 100 at each site. Increases at C2 were coupled with decreases at G1 for some families, such as the Anthomyiidae, while the opposite pattern also occurred, e.g., the Sarcophagidae.

Keywords: ecosystem function, sustainability of natural systems, resilience, insect communities

Differences in Ant Community Structure at Two Sites in Grand Staircase-Escalante National Monument: Changes Over Time in Response to Drought or Anthropogenic Disturbances

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ABSTRACT

Ants can be important ecosystem drivers, and community dynamics of ants can play a role in ecosystem response to disturbances and environmental stress. Grazing management has changed in parts of Grand Staircase-Escalante National Monument in southern Utah. At The Gulch (grazed) and Steep Creek (ungrazed since 1999), ant community composition was determined in each year from fall 1999 through spring 2005; data presented here are from fall 1999 through fall 2004. Specimens were identified to genus and assigned to functional groups. Ants belonging to five genera made up over 96% of the total ant abundance found at the two sites with *Pogonomyrmex* having the greatest overall abundance. *Dorymyrmex* and other opportunistic ants were captured more frequently at the ungrazed Steep Creek site while *Camponotus* and other generalists were significantly more abundant at The Gulch (grazed) site. Fluctuations in abundance of functional groups occurred within each site over time, affecting community structure. Opportunists were abundant in the fall and declined in the spring while hot climate specialists were abundant in the spring and declined in the fall. Inherent site differences, drought, interactions between species and recent changes in management of the two sites all may play a role in ant community dynamics at these two sites. The intense drought over the course of this study appears to have exerted an over-riding influence; differences correlated with management regime are not readily apparent at this time.

Keywords: ants, grazing management, community structure and dynamics

Lions on the Plateau: A Research Program for the Colorado Plateau

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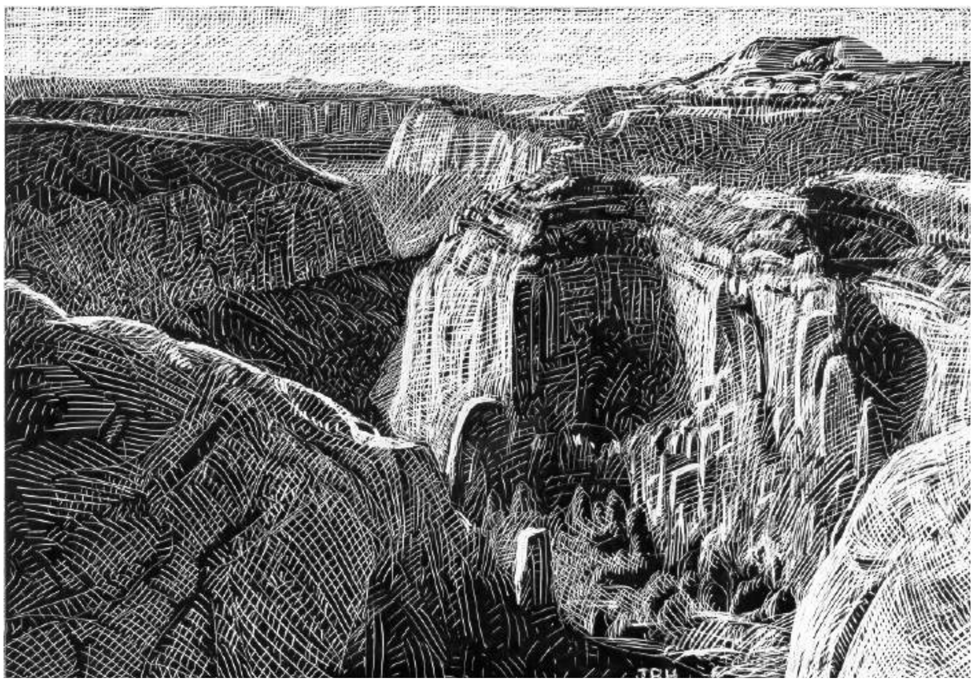
ABSTRACT

Mountain lions are the most widespread large predator on the Colorado Plateau, and are common enough to have both direct and indirect effects on ecosystems. They are intrinsically valued as natives of National Parks (NPs) and Monuments (NMs), yet they pose a potential threat to human safety and are potential depredators of livestock on BLM-administered lands. Managers of protected areas on the Colorado Plateau are challenged by the conflicting goals of conserving ecologically functional mountain lion populations while minimizing livestock losses and ensuring human safety. Under such circumstances, information is necessary for clarifying options that produce win-win solutions. We initiated a 10-yr research program on the Colorado Plateau in 2002 that is providing detailed information on mountain lion movements, habitat selection, and predation, including effects of human facilities on mountain lion behavior. This integrated program, thus far a collaboration between the National Park Service (NPS) and USGS, has deployed GPS/satellite collars on lions in and near the Flagstaff uplands NMs and at Grand Canyon and Zion NPs. We will deploy additional collars this year in Capital Reef NP. So far we have identified dusk as the time of peak predatory activity and produced preliminary models of habitat selection showing areas of concentrated lion activity. This kind of information facilitates management to minimize contact between mountain lions and either livestock or people. We have also detected consistent avoidance of paved highways and preferential use of areas near towns by female lions, estimated seasonal and sex-age specific kill rates and movements, and described other details of mountain lion behavior. We plan to work with additional NPS units, private landowners, and BLM NMs to study lions under a broad range of conditions, thereby ensuring a robust basis for management of lions in diverse areas and jurisdictions.

Keywords: mountain lions, predation, habitat use, national parks, national monuments



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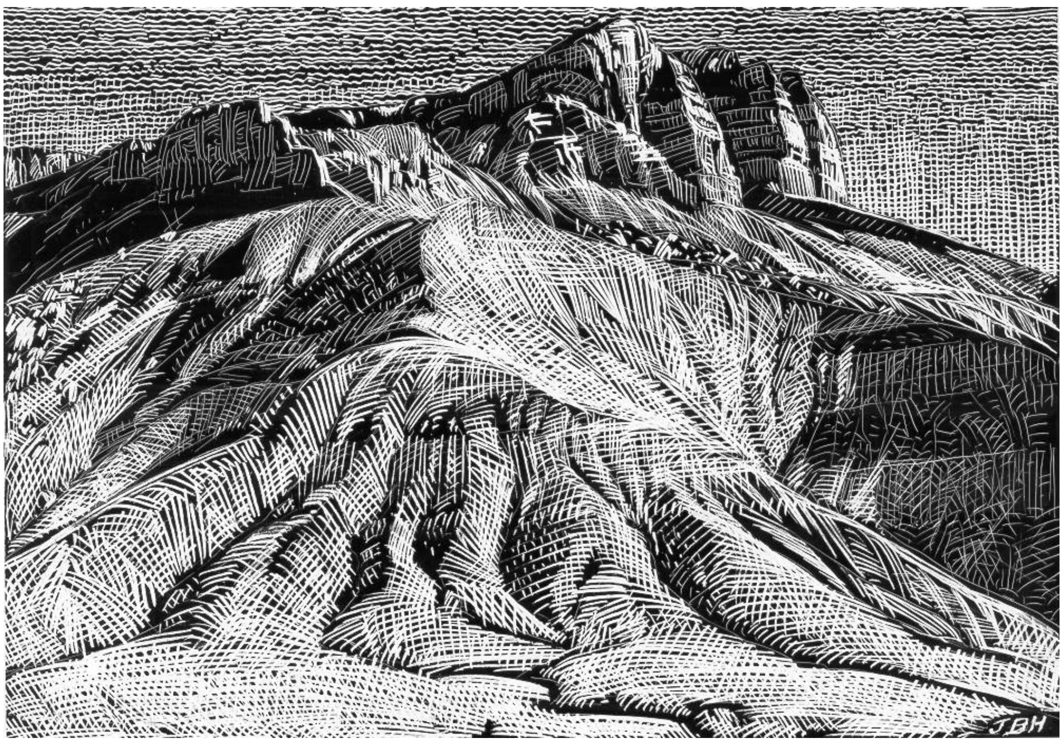
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The Interaction of Aeolian and Fluvial Processes During Deposition of the Upper Cretaceous Capping Sandstone Member, Wahweap Formation, Kaiparowits Basin, Utah, USA

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ABSTRACT

Detailed examination of the Upper Cretaceous capping sandstone member of theWahweap Formation in the Kaiparowits Basin, Utah reveals the presence of aeolian stratification. Deposition by aeolian processes is recognized and distinguished from subaqueous deposition by the presence of centimeter-scale, inversely graded wind-ripple stratification. The aeolian stratification in theWahweap Formation is the first occurrence reported from Upper Cretaceous strata on the Colorado Plateau of the western U.S.A. Aeolian stratification occurs as thin wind-reworked caps of fluvial-bar sandstones deposited within low-sinuosity braided streams and as more extensive deposits of small-scale dunes that developed in geographically restricted dune fields. eolian reworking of bars took place during low-stage flow and was possibly controlled by intermittent (seasonal) discharge variations. Prolonged aridity led to increased sand supply entering the aeolian system, dunes nucleated and grew rapidly between the braided stream systems. These small-scale dunes rarely developed extensive or tall slip faces as evidenced by the rare preservation of grain flow strata and the dominance of wind-ripple stratification. The dune field was characterized by sinuous-crested dunes, probably barchans, amid and linked to the extensive braided stream systems. Based on modern analogs, the resulting change in sand storage/ supply probably is related to a short-term shift to a more semi-arid/ arid climate, possibly seasonally. However, a longer-term climate change to semi-arid/arid may be indicated for the dune complex near the boundary with the overlying Kaiparowits Formation.

Keywords: aeolian deposits, Cretaceous Wahweap Formation, braided rivers, Utah

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Introduction

Systematic study of the generation of small-scale aeolian stratification has led to recognition of unique physical processes that produce inversely graded ripple stratification, the distinctive product of wind-ripple migration (Hunter, 1977, 1981). These inversely graded, wind-ripple strata provide a criterion that allows separation of subaerial from subaqueous depositional processes at a centimeter scale (Hunter, 1977, 1981; Kocurek and Dott, 1981).

Although aeolian stratification is widespread throughout the Pennsylvanian to Jurassic age strata of the Colorado Plateau (Blakey et al., 1988; Marzolf, 1988; Peterson, 1988), this study is the first reported occurrence of aeolian stratification from Upper Cretaceous sediments of the Plateau. The Upper Cretaceous capping sandstone member of the Wahweap Formation in the Kaiparowits Basin, Utah preserves relatively thin units of aeolian stratification within largely fluvial deposits. Two distinct geometries of the aeolian stratification units suggest two scales of aeolian processes: fluvial bar-top reworking and small dune development in geographically restricted dune fields.

This study of the Upper Cretaceous capping sandstone member: 1) describes the preserved inversely graded wind-ripple stratification, including its associations with encompassing fluvial deposits; 2) interprets the depositional processes and geomorphic systems; and 3) examines possible climatic factors that controlled the interaction between aeolian and fluvial systems.

Geologic setting

Within the Kaiparowits Basin, the Upper Cretaceous Wahweap Formation conformably overlies the Straight Cliffs Formation and is in turn overlain by the Kaiparowits Formation (Fig. 1; Peterson, 1969; Eaton, 1991; Lawton et al., 2003). The Wahweap Formation is informally subdivided into, from oldest to youngest, lower, middle, upper and capping sandstone members (Eaton, 1991). In the study area, the upper and capping sandstone members are distinguished. The upper member is a dominantly tan sublithic arenite, whereas the capping sandstone member is characterized by white quartz arenite (Eaton, 1991; Eaton and Nations, 1991; Pollock, 1999; Lawton et al., 2003).

Recent Ar^{40}/Ar^{39} radiometric dating by Roberts et al. (2005) on tuffs distributed throughout the Kaiparowits Formation supports the Late Cretaceous Campanian age for the Wahweap Formation, an age assignment originally based on microvertebrate biostratigraphy (Eaton, 1991, 2002). Preliminary pollen studies reported by Lawton et al. (2003) also support the Campanian age.

Methodology

Stratigraphic sections, measured at a centimeter scale, record grain-size variations, sedimentary structures, paleocurrent directions, and bedding geometries (Figs. 1 and 2). Directions of paleoflow were measured along the axis of trough cross-beds and when tectonic dips exceeded 5°, the tectonic dip was removed by stereonet rotation to restore the original paleocurrent direction. Data from the detailed measured sections were used to identify

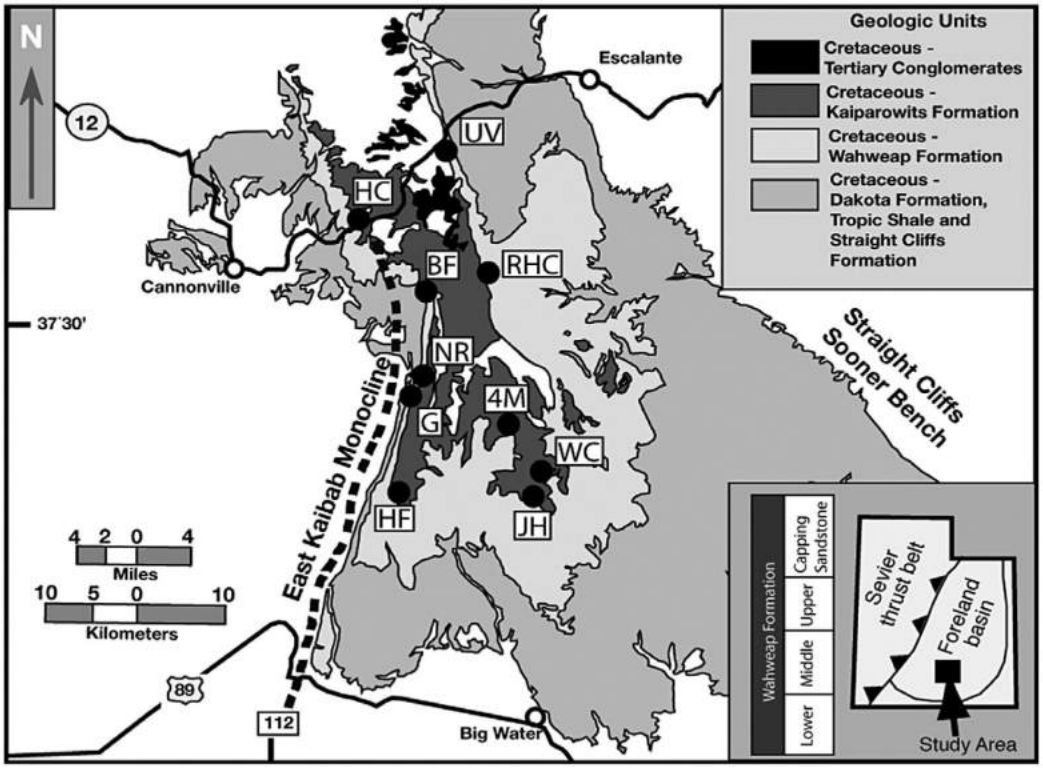

Figure 1. Geologic map, stratigraphy and location of the study area within Grand Staircase-Escalante National Monument. Geology map modified from Sargent and Hansen (1982). UV - Upper Valley, RHC - Right Hand Collet, WC - Wesses Canyon, JH - John Henry Conyon, 4M - Four Mile Wash, HF - Horse Flat, G - The Gut, NR - North of the Road, BF - Bull Flat, and HC - Henrieville Creek.

sedimentary facies, which were interpreted at the process level. Photomosaics were constructed to aid in the delineation of larger-scale bedding and facies geometries.

Fluvial depositional systems of the capping sandstone member

The capping sandstone member fluvial deposits in the Kaiparowits Basin have been studied by Pollock (1999) and Lawton et al. (2003). They depict the capping sandstone as multistoried sheets of amalgamated sandstone and pebbly sandstone channel complexes that contain channel and downstream accretion architectural elements and uncommon overbank fines. Typically, large-, medium-, and small-scale trough cross-beds are the predominant sedimentary structures within the elements.

Our measured sections also indicate that various scales of trough cross-bedding are the predominant sedimentary structures (Fig. 2). The scale of the cross beds characteristically decreases towards the top of the sheet elements with medium- and small-scale trough cross beds confined to the tops of sheets. The bases of the sheets are scoured into the underlying sheet or into rarely preserved overbank deposits (Fig. 3A), and commonly are zones delineated by up to 2 m thick of mudstone rip-up clasts. Overbank deposits are a minor component and of limited extent and can contain isolated channel elements (Fig. 3B). In the upper conglomerate-rich part of the capping sandstone member (Fig. 2), pebble conglomerates and pebbly sandstones characterize the base of the sheet bodies ofwestern sections. To the southeast, however, the presence of coarse sandstone marks these transitions.

Pollock (1999) and Lawton et al. (2003) interpreted the sanddominated (lower) portion of the capping sandstone member to be the product of low-sinuosity braided stream systems based on the South Saskatchwan River studies by Cant and Walker (1978). The upper conglomeratic portion was interpreted to be the product of a perennial gravel-bed river (Pollock,1999). Little (1997)

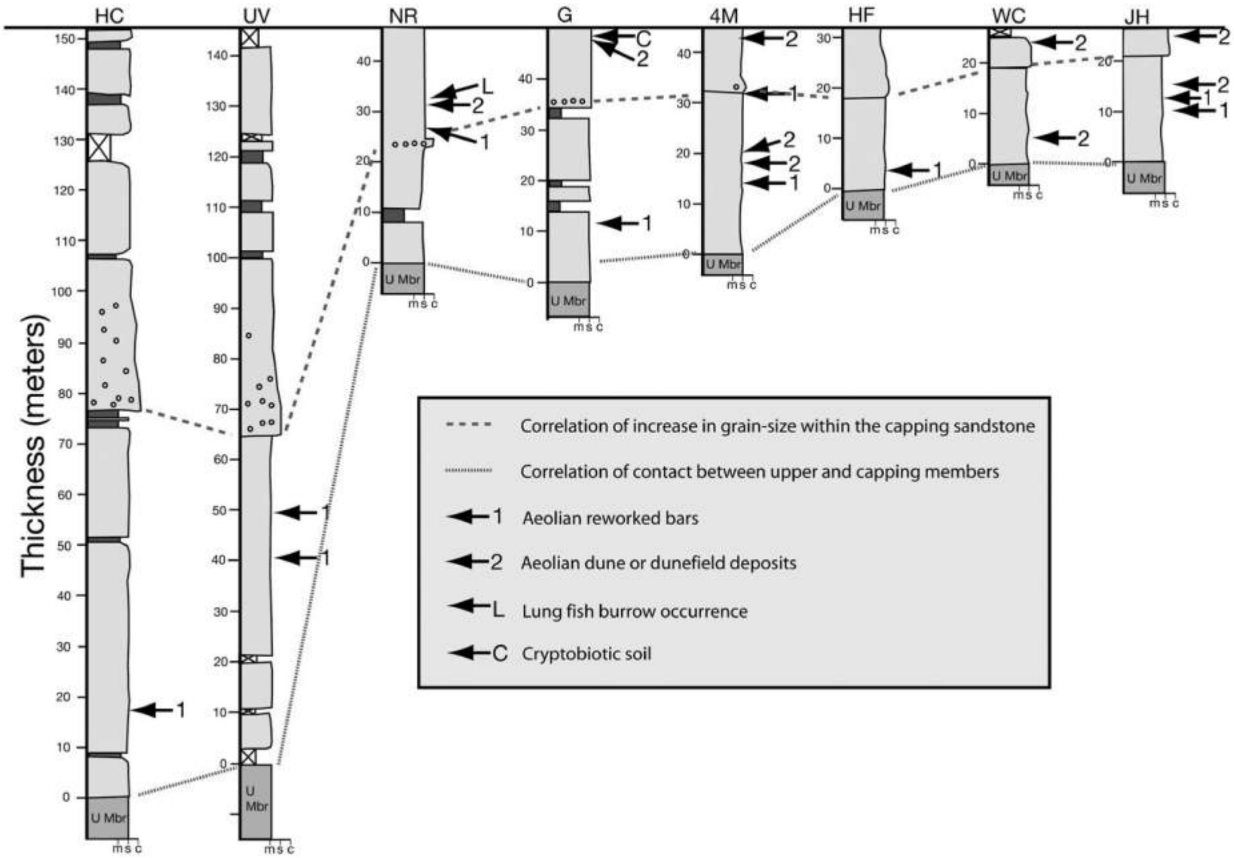

Figure 2. Measured sections through the capping sandstone member of the Wahweap Formation. Section localities are given in Fig. 1. Note the reduction in thickness of the capping sandstone and in the amount of conglomerates from northwest (left) to southeast (right). The stratigraphic positions of aeolian deposits are indicated by arrows. Note that dune deposits are preserved more commonly in the southeast portion of the study area. Bar top deposits are distributed more evenly across all the sections. For localities information see Fig. 1. The Wahweap–Kaiparowits contact is erosive at various localities. No laterally continuous datum is present within the Wahweap Formation. See Fig. 1 for location key.

interpreted the fluvial system as gravelly braided and sandy braided with the sandy braided deposits placed not in the capping sandstone member, but in the upper member of the Wahweap Formation; most workers consider these strata to be part of the capping sandstone member (Eaton, 1991; Eaton and Nations, 1991; Pollock, 1999; Lawton et al., 2003).

The South Saskatchewan River model, proposed by Cant and Walker (1978) has been recently modified by Sambrook Smith et al. (2006) on the basis of Ground Penetrating Radar (GPR) surveys of the river. According to Cant (1978), gravel-based sandy braided rivers migrate laterally, leaving sheet-like or wedge-shaped deposits consisting of channel and bar complexes and composed of a mixture of high-angle cross beds and trough cross beds. Sambrook Smith et al. (2006) demonstrated that high-angle inclined strata are less common than generalized in the Cant and Walker (1978) model, and that trough cross bedding and low angle bedding are the dominant sedimentary structures preserved in the system. The sedimentary facies in the capping sandstone member are similar to those described by Sambrook Smith et al. (2006), and thus a relatively deep, perennial, sandy braided river system like the South Saskatchewan (Miall, 1996) is an analogous depositional system.

Aeolian stratification

Inversely graded stratification has long been recognized as a viable criterion to distinguish aeolian action (Hunter, 1977, 1981). Freyberger and Schenk (1988) report that pin-stripe laminations are produced by the infiltration of fine sands and silts between coarse grains in the troughs of wind ripples sheltering them from further transport hence creating a less well-sorted lamination rela-

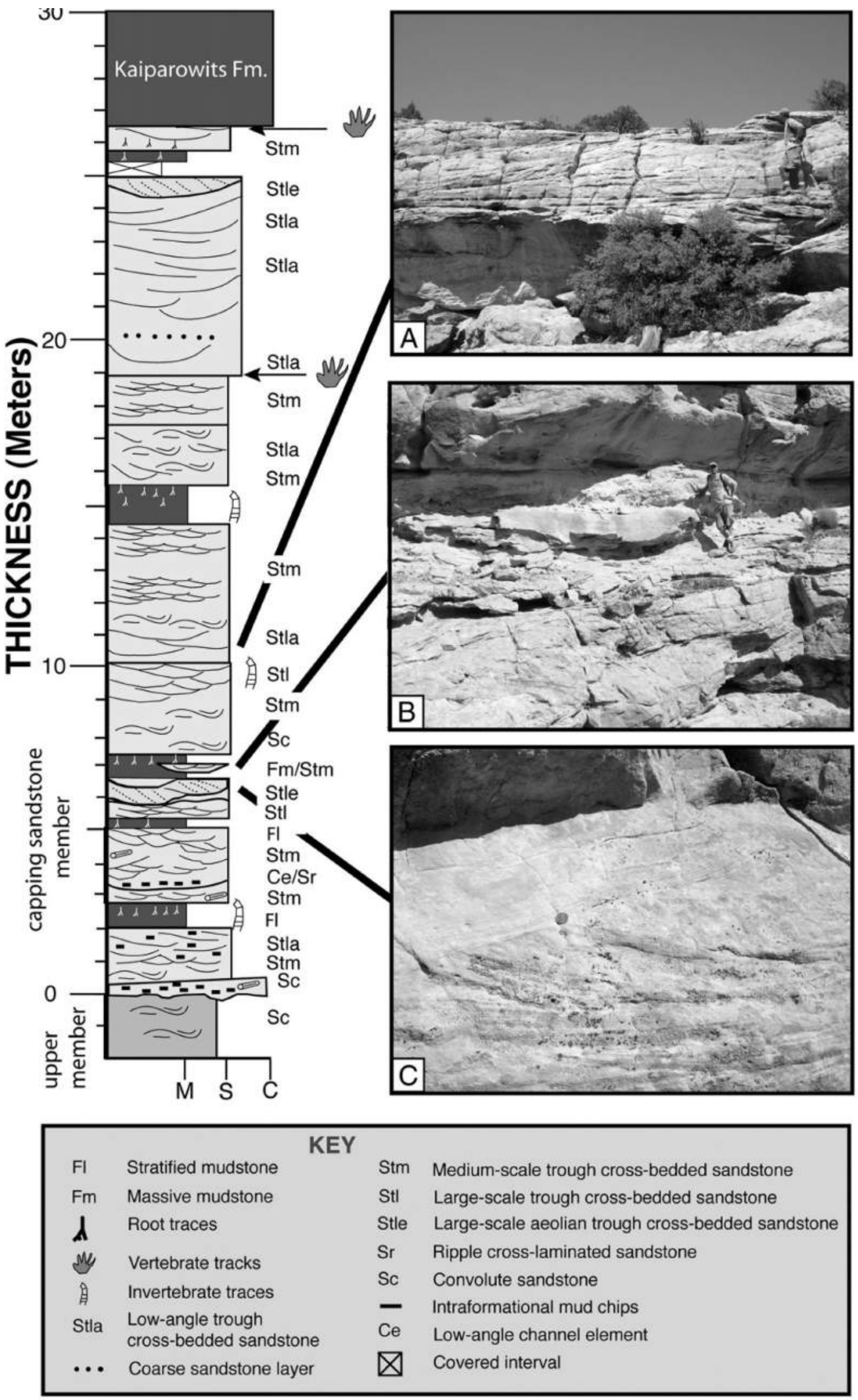

Figure 3. Measured stratigraphic section at Wesses Canyon. A) Low-angle element. Figure in scale is 2m. B) Channel element in mudstones. Figure in scale is 2m. C) Aeolian trough crossbed set. Coin for scale is 1.9 cm.

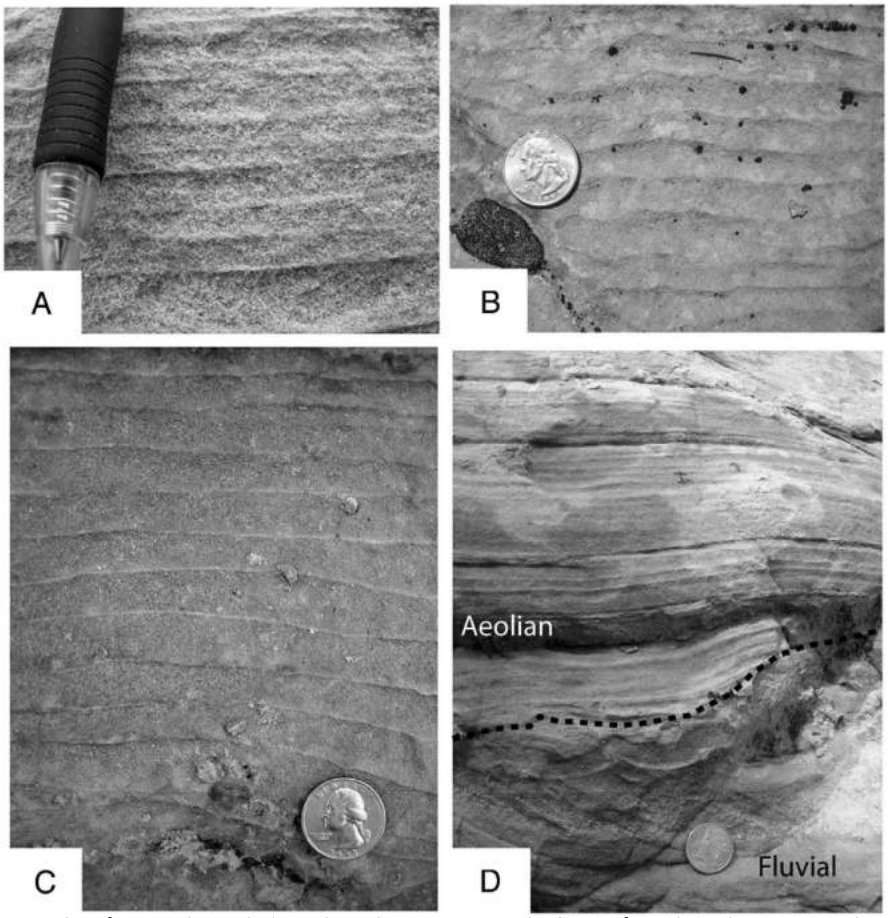

Figure 4. Field photographs of inversely graded wind-ripple strata. Note the base of wind-ripple strataweathers out in relief. Coin is 2.5 cm in diameter. A) Photograph from North of the Road section at 28 m. B) Photograph from Four Mile Wash section at 20 m. C) Photograph from Henrieville Creek section at 17 m. D) Photograph from Henrieville Creek section at 17 m.

tive to the remainder of the overlying wind-ripple deposit (see Figs. 4 and 5). Differences in permeability are created causing later differential diagenesis that establishes minor color variations and enhances resistance to weathering of the silt-rich pin stripes causing them to stand out in relief. The saltation process dominating over avalanching on the leeface of the wind ripples is responsible for the lack of internal laminations.

The recognition of inversely graded stratification and pin-stripe lamination permits rapid delineation of wind-ripple from fluvial stratification. Wind-ripple stratification, composed of inversely graded fine/medium- to medium/coarse-grained sandstone (Fig. 4), is present as both isolated thin beds and as relatively thick trough cross-bed sets. In three-dimensional exposures, the strata are continuous and lack internal cross-laminations (Fig. 4). In thin section, a finer silt fraction is found at the base of the wind-ripple strata defining the pin stripe laminations (Fig. 5).

5.1. Thin units of aeolian stratification: wind-reworked fluvial bar-top deposits

Thin beds of aeolian strata are distributed throughout the sections of the study area (Fig. 2). The aeolian bounding surface is commonly erosive into the underlying sets of fluvial foresets (Figs. 2,3,4D,6). Lenticular-shaped scours, up to 40 cm thick with a maximum lateral extent of 1.5 m, cap cosets of the large- to medium-scale trough cross-bed sets (Fig. 6 A–B). Rarely, wind-ripple strata concordantly drape fluvial cross beds. Where the aeolian sets can be traced laterally, these deposits are of a limited lateral extent.

Thin beds of erosively based aeolianites intercalated with fluvial deposits of the capping sandstone member suggest localized erosion by deflation followed by wind-blown deposition on low-sinuosity braided fluvial bars. Fluvial systems enhance the probability of aeolian transport because sediment is already effectively sorted in channels and bars to the appropriate size for

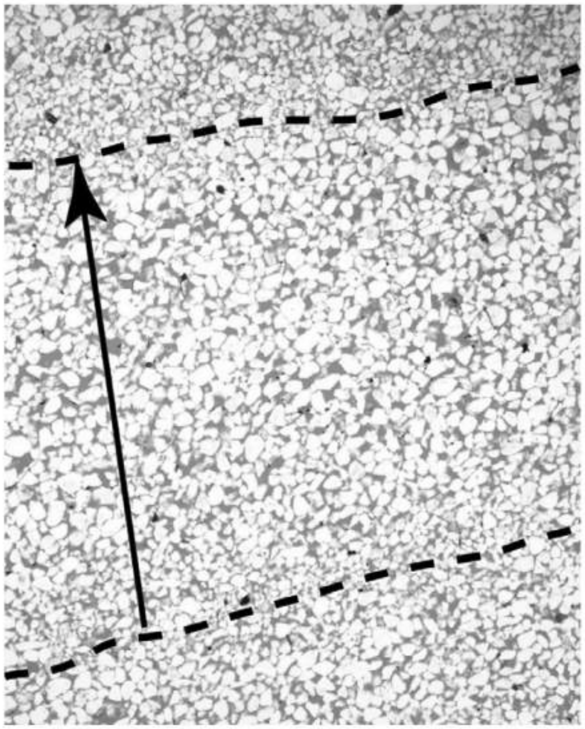

Figure 5. Photomicrograph of wind-ripple strata from John Henry Canyon section. Arrow is 5 mm. Note the presence of sheltered silt-sized grains in pores restricted to the lower portion of the lamination and the inverse grading.

entrainment by wind (Fig. 6C; Glennie, 1987; Pye and Tosar, 1990).

Significant aeolian reworking of channels and bars has been recognized in various Holocene settings and ancient deposits (Glennie, 1970; Good and Bryant, 1985; Clemmenson and Tirsgaard, 1990; Eriksson and Simpson, 1993; Simpson and Eriksson, 1993; Tirsgaard and Øxnevad, 1998; Krapf et al., 2005; Sambrook Smith et al., 2006). These deposits have been interpreted as wind-generated bedforms in fluvial channels (see Fig. 6C), wind-ripple strata associated with fluvial strata, and as deflation and wind-drift surfaces.

During summer low-stage flow after spring snow melt in the South Saskatchewan River, a possible Holocene analog for deposition of the capping sandstone member (Pollock, 1999; Lawton et al., 2003), sand on the tops of bars and exposed channels is remobilized by wind (Sambrook Smith et al., 2006). Additionally, Sambrook Smith et al. (2006) report the development of extensive wind-rippled surfaces and establishment of small barchanoid aeolian dunes on tops of the fluvial bars and compound bars in the South Saskatchewan River.

Significant aeolian reworking of fluvial and alluvial deposits also occurs in the Koigab Fan of Namibia and the Sachs River, Canada. Deflation and generation of lag deposits by aeolian processes has been documented from the Koigab Fan of northwest Namibia (Krapf et al., 2005). In this setting, sand in channels and on the fan surface is mobilized by wind after drying under hyperarid climate following high intensity, rare flood events. Good and Bryant (1985) report that annual, short duration snow-melt spring floods on the Sachs River, Bank Island of the Northwest Territory, Canada distribute sand adjacent to the ephemeral stream system. During the arid summer that follows, wind action reworks the fluvial deposits into windripples, adhesion structures and deflation surfaces. In this setting, aeolian reworking and deflation are limited not by the water table as in most low-latitude aeolian settings but by the permafrost zone (Good and Bryant, 1985).

Tirsgaard and Øxnevad (1998) document "small wedges" of windripple strata distributed along reactivation-related bounding surfaces in braided fluvial deposits interpreted to be developed in a semi-arid to arid setting in the Middle Proterozoic Eriksfjord Formation. These features are similar to the thin units of aeolian stratification found in the capping sandstone member. Tirsgaard and Øxnevad (1998) interpret these features as wind reworking of the lee-face of bars and use modern analogs developed in ephemeral river systems (Glennie, 1970).

Aeolian reworking of bar tops, preserved as thin sets of windripple strata similar to the capping sandstone member, have also been reported preserved within braided stream systems intercalated with flood basalts in the Precambrian Eastern Creek Volcanics (Eriksson and Simpson, 1993). Wind reworked bar tops, similar to those in the capping sandstone, have also been identified in a braided river system from the Mesoproterozoic Whitworth Formation (Simpson and Eriksson, 1993).

5.2. Trough cross-bedded aeolian stratification: deposits of small dune fields

In the capping sandstone member wind-ripple stratification composes trough cross-bed sets that record the presence of small dunes or dune fields between the braided-river channels.

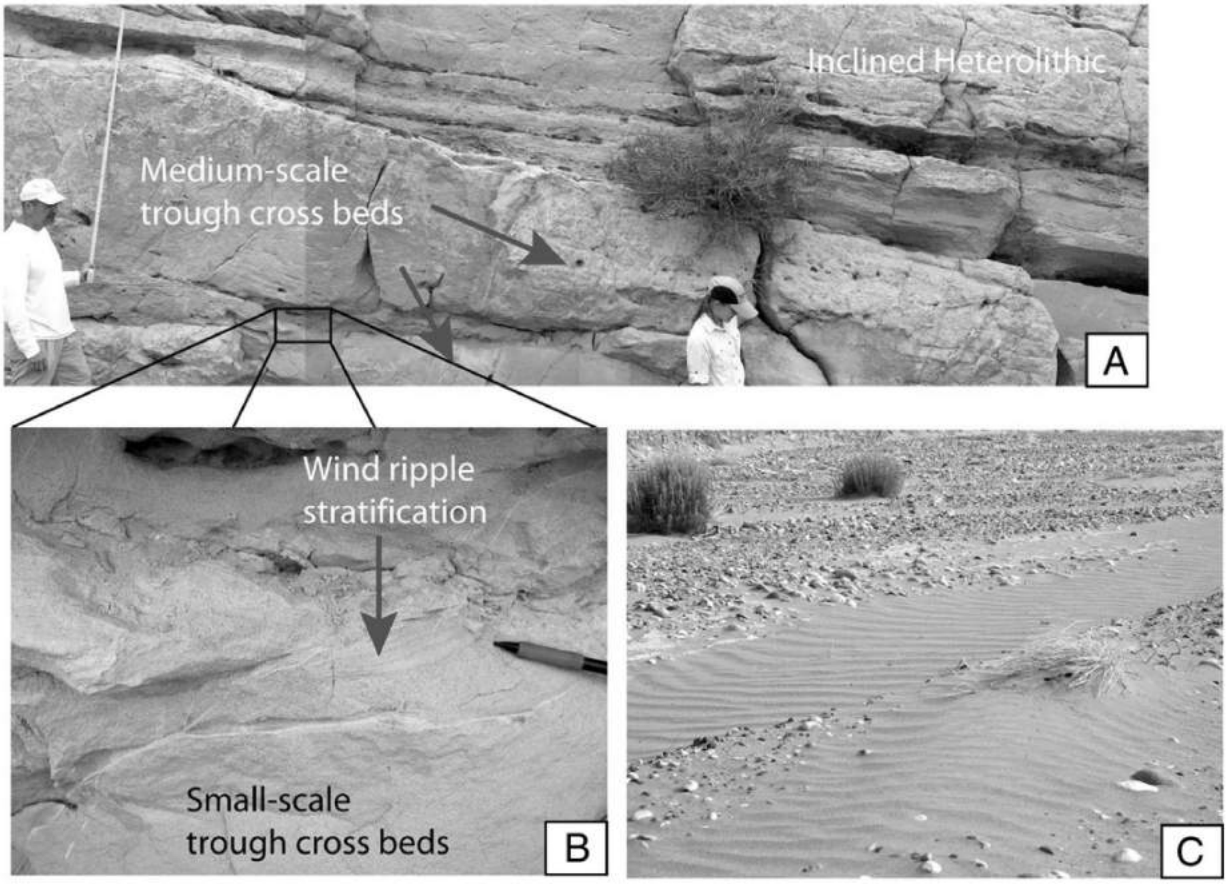

Figure 6. Field photographs of wind-reworked fluvial bar top deposits. A) Field photomosaic of fluvial cross-beds with wind-ripple strata preserved at the top of the medium-scale trough cross-bed sets that are overlain by small-scale trough cross-bed sets. B) Enlargement of lenticular scour filled with wind-ripple stratification. Photographs A and B are from the North of the Road section at 25 m. C) Modern wind reworking of sandy gravel bar in the Wahweap wash, Utah.

The aeolian trough cross beds occur at numerous stratigraphic intervals in the capping sandstone member, but are more abundant in the southeastern sections (Figs. 2 and 3). Aeolian trough cross beds are composed of inversely graded stratification that grades from fine-grained sandstone into medium-grained sandstone. Typically preserved thickness of the trough cross-bed set is 0.3 to 1.2 m (Fig. 7), but cosets may be up to 3.0 m thick. Commonly, where sets can be traced laterally, channelized fluvial deposits erosively truncate the aeolian cosets. In the Wesses Canyon section (Fig. 3) an exceptional three-dimensional exposure demonstrates the trough cross-bed set nature of the deposits and contains wind-ripplemarks with their crestlines parallel to the dip of the foresets in the trough (Fig. 7B). Grain flow strata are rare, having been observed in only a solitary meter-thick trough cross-bedded set at Wesses Canyon (Fig. 2). Limited paleocurrents indicate wind transport varied from the southeast or the west–northwest.

As a consequence of erosion by overlying fluvial units and the lack of stratigraphic marker beds, physical correlation of the aeolian trough cross-bed sets is not possible. The presence of thinly preserved, often less than 1 m sets of simple trough cross beds composed of predominantly wind-ripple strata indicates deposition by small, sinuous-crested aeolian dunes in a geographically limited dune field (Kocurek, 1991). However, the similar stratigraphic position near the top of the capping sandstone member of aeolian trough cross-bed strata in the Wesses Canyon, John Henry, Four-mile and Gut sections (Fig. 2) may indicate a more extensive unit that is potentially correlative over approximately 20 km. Absence of high resolution time constraints and overprinting by structural deformation does not allow, at this time, resolution of this correlation hypothesis.

Kocurek and Ewing (2005) have demonstrated that in dune fields displaying simple dune patterns and a single construction phase, the orientation of

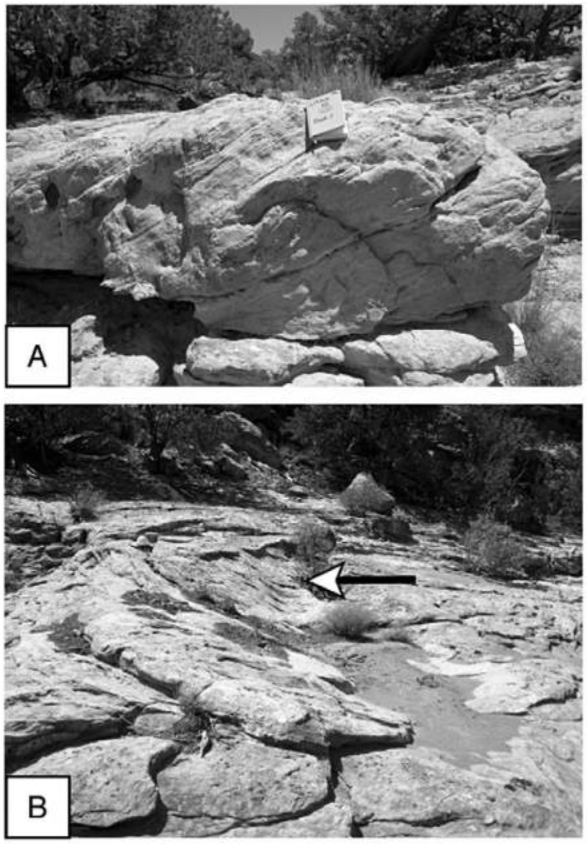

Figure 7. Field photographs of small dune facies. A) 80 cm thick tabular set of wind-ripple strata at the contact of capping sandstone and the Kaiparowits Formation. Notebook is 19 cm. Photo taken at 25 m in the John Henry section. B) Preserved trough cross beds in bedding plane view. Set thickness is 0.25 m, a width of 5.0 m and a length of 15.0 m. Arrow highlights preserved wind-ripple bedforms low in the trough set. Hat for scale is 40 cm in diameter. Photo taken at 6.5 m in the Wesses Canyon section.

the dune field is determined by wind regime. Investigating dune formation at Padre Island, Texas, Kocurek et al. (1992) established that dunes progressed through predictable evolutionary phases. The initial phase is the generation of sand patches, dominated by wind-ripple transport followed by protodunes and the initiation of flow expansion. As dune length and height increase, flow expansion builds to flow separation, with protodunes developing a grainfall-dominated lee face, which is subsequently replaced by dune lee faces characterized by grainflows. The evolution of sand patches to barchan dunes characterized by grain flows took place over several months. Numerical model studies of these types and scales of aeolian interactions have generated similar results as those observed on Padre Island, TX (Werner, 1995; Werner and Kocurek, 1999).

Hence during capping sandstone deposition, winds entrained sediment mobilized from the low-sinuosity braided fluvial systems. Initial sand transport from the associated fluvial system in the capping sandstone member probably developed as sand patches followed by small protodunes. The paucity of preserved grainflows probably indicates that barchan dunes rarely developed flow separation and a steep lee face, but the presence in one set demonstrates flow separation did occur. In small dunes grain flows are most often restricted to the upper reaches of the dune slipface (Kocurek and Dott, 1981). Alternatively, the absence of preserved grainflows may indicate that only the lower portions of the foresets were preserved because of low climb angle of the bedforms. Climb angle is controlled by sediment supply, transport competence, and sediment availability (Kocurek, 2003).

The presence of thinly preserved aeolian sets often is interpreted as indicating the presence of the dune field margin as opposed to an erg or dunefield core (Porter, 1986; Loope and Simpson, 1992). The interaction of aeolian and fluvial systems at erg margins has been studied intensely (Langford, 1989; Langford and Chan, 1989), but does not serve as an appropriate analog. It fails because of the absence of a demonstrable dunefield core and the absence of a dunefield of significant geographic extent. A possible exception occurs at the top of the capping sandstone where aeolian stratification is present in various sections (see Fig. 2).

Discussion

Aeolian sedimentary systems inherently are sensitive indicators of environmental conditions, and are thus potentially useful for interpreting climate change. The examination of the impact of minor climatic change on modern aeolian systems is in its infancy (Lancaster, 1997; Rendell et al., 2003; Al Farraj and Harvey, 2004). The influence of annual monsoonal to decadinal climate change on dune stratification packaging has been interpreted for cyclic cross-strata in the Jurassic Navajo Sandstone (Hunter and Rubin, 1983; Kocurek et al., 1991; Chan and Archer, 1999; Loope et al.,

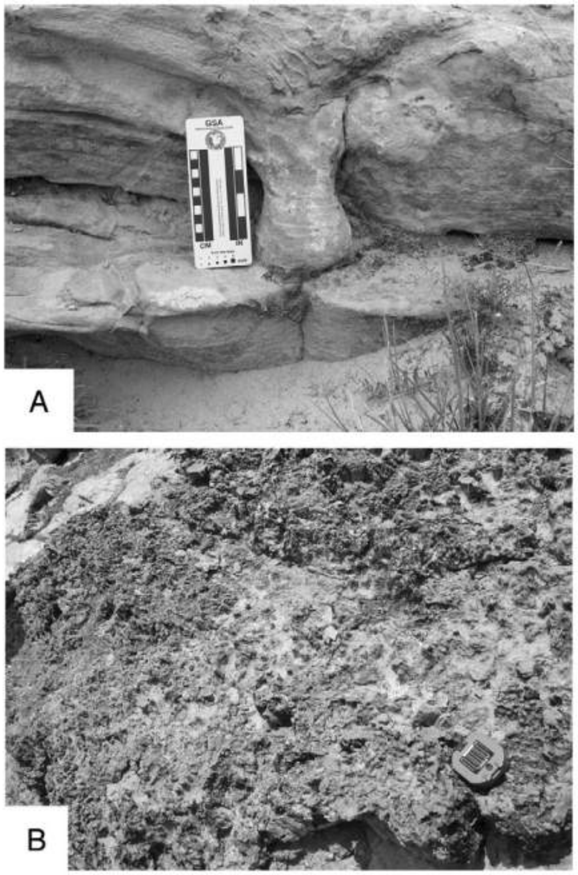

Figure 8. Field photographs. A) Preserved lungfish burrow. Note soft-sediment deformation above the burrow entrance. Smaller side of scale is in cm. B) Possible preserved cryptobiotic soil. Compass is 7 cm in length.

2001) and from recent coastal dunes (Hunter et al., 1983).

Aeolian sedimentation is significant only in areas where vegetation cover is lacking, most notably in arid climates, but is locally important on braided-river plains (both glacial and non-glacial) and sandy coastlines. Aeolian deposition in the capping member was clearly associated with braided rivers (non-glacial); the importance of marine and/or climatic influence will be evaluated below.

Eustatic sea level was falling during the Campanian (Jarvis et al., 2006). The position of the capping sandstone depositional setting with respect to the shoreline of theWestern Interior Seaway is problematic with no evidence of brackish or marine influence recognized in the stratigraphy (Eaton, 1991, 1999). The nearest reported evidence for possible tidal influence is found approximately 100 km to the east in correlatives of the entire Wahweap in the Henry Mountains (Eaton, 1990). Roberts (2007) reports that a short period sea-level rise caused a tidal overprinting in the overlying Kaiparowits Formation fluvial systems. Modern coastal dune fields, such as those along the Oregon coast, developed from a complex set of variables such as coastal morphology, sea-level fluctuations and palaeoclimate (Peterson et al., 2007) and therefore may not serve as an appropriate analog for interpreting the aeolianites of the capping sandstone.

The interaction of, or the change from, fluvial to aeolian processes in response to climate change can take place over a range of temporal scales, which may result in a variety of stratigraphic patterns. Various types of interbedded fluvial and aeolian strata in modern and ancient deposits have been interpreted to reflect different time scales, from seasonal to Milankovich-scale periodicities (Kocurek, 1996, 1999; Lancaster, 1997; Clemmenson et al., 1989; Howell and Mountney, 1997; Swezey, 2001; Bullard and Livingstone, 2002; Veiga et al., 2002; Scherer and Lavina, 2005).

Bullard and Livingstone (2002) argue that fluvial and aeolian systems are not discrete but are linked dynamically via sediment flux. These ties can be important in shaping the geomorphology of the area because change in sediment flux is linked to variations in climatic conditions (Lancaster, 1997). Hence climate changes will influence sediment flux and may potentially initiate local changes in a geomorphic system. During deposition of the capping sandstone, climate changes may have led to discharge fluctuations of the braided stream system that dictated sediment supply to the aeolian geomorphic system, that controlled alternating states of braided-stream dominated to one characterized by sparse to abundant sand dune fields between the braided channels.

Bullard and Livingstone (2002) recognize four "key links" between the aeolian and fluvial system. Three links highlight sediment flux from aeolian to fluvial system: 1) rills and mass wasting of dune slopes (e.g., Wizevich, 1997; Loope et al., 1998; Sweeney and Loope, 2001; Simpson et al., 2002; Hugenholtz et al., 2007), 2) migration of and erosion of dune terminations, and 3) interdune and dune flooding (Langford, 1989; Langford and Chan, 1989). The fourth link highlights sediment transport from the fluvial to aeolian and this is especially relevant to the capping sandstone member.

Aeolianites in the capping sandstone member reflect wind reworking (preserved bar top deposits) and deflation of bar tops and the transfer of sand from a fluvial system to a coeval aeolian system to generate small dune fields (aeolian dune deposits). The examination of the sediment exchange, let alone the rates and controls on sediment flux between the aeolian and fluvial reservoirs, have not received detailed scrutiny from a geomorphic perspective (Bullard and Livingstone, 2002). Rendell et al. (2003) demonstrated the role of short-term climate change in the generation of source sand from the Niger River to local climbing dune structures. The sand is apparently blown from overbank flood deposits, and dune development occurs during humid climates, whereas paleosols form during arid climate periods. On the sedimentary basin scale, Clark and Rendell (1998) and Kocurek and Lancaster (1999) demonstrated the impact of sediment supply from the fluvial system to the development of the associated aeolian systems. Apparently, arid climate periods are times of increased sand supply and the development or expansion of basin-scale aeolian systems.

The Late Cretaceous climate is considered to have been warm and equitable with reduced pole-to-pole gradients compared to the modern climate (Barron, 1983). Numerous lines of evidence, such as plant community structure, have been proposed to support an equitable climate (Spicer and Parrish, 1987). Recent global circulation models have generated coarse reconstructions of precipitation versus evaporation potentials for the Cretaceous world (Sellwood and Valdes, 2006). Their analysis locates the study area during deposition within the negative to slightly positive excess precipitation. The Walter biomere zones for the source area of the capping sandstone sediment is “winterwet” (warm temperate winter, dry) and for the depositional basin is “warm temperate” (humid) (Sellwood and Valdes, 2006; Fig. 6).

Season change as a mechanism that affects the flux of sediment between the fluvial and aeolian systems in the capping sandstone is consistent with the modern analogs such as the South Saskatchewan River (Sambrook Smith et al., 2006), Koigab fan, Namibia (Krapf et al., 2005), and the Sachs River (Good and Bryant, 1985) where sand is mobilized by wind after peak seasonal runoff. Paleontological evidence supporting seasonality is limited; the capping sandstone member has few reported and confirmed occurrences of fossils. The presence of probably seasonal aestivation lungfish burrows found near the top of the capping sandstone indicates a semi-arid to arid climate (Figs. 2 and 8A; Orsulak et al., 2007). These traces are characterized by a vertical burrow with a bulbous termination (see Figs. 2 and 8A; Hasiotis et al., 1993). Additionally, Orsulak et al. (2007) describe the collapse of fill into a burrow after the lungfish escaped during climate amelioration. Additional, proxy evidence for climate are reported vertic type paleosols from the capping sandstone that develop under alternating wetting and drying cycles, often seasonal (see Pollock, 1999).

A longer-term climate change for near the contact of the capping sandstone member and Kaiparowits Formation is supported by preservation of a probable cryptobiotic crust (Figs. 2 and 8B; Simpson et al., 2008). The cryptobiotic crust is interpreted based on preserved morphology, a pedicillated surface morphology with mm- to cm-scale irregular prismatic columnals (Fig. 8B), and is characterized by poorly sorted quartz arenite contrasting with wellsorted quartz arenite elsewhere in the capping sandstone (Fig. 8B). There is no direct evidence of microbial community except for slight color mottling (Fig. 8B). Cryptobiotic crusts develop under semiarid to arid conditions in dryland ecological systems (Friedman and Galun, 1974; Skujins, 1984; West, 1990), The close association of this cryptobiotic crust with aeolianites compellingly suggests a semi-arid to arid climate.

Conclusions

1. The capping sandstone member of theWahweap Formation in the Kaiparowits Basin of Utah contains aeolian strata. This is the first reported occurrence of aeolianites from the Upper Cretaceous strata of the western U.S.A.
2. Aeolian stratification occurs as thin reworked tops of fluvial bar deposits, and as trough cross bedding, deposited by small sinuouscrested dunes in geographically restricted dune fields located amid extensive low-sinuosity braided stream systems.
3. Aeolian reworking of bars took place during low-stage flow, demonstrating mobili-

zation of sand from the fluvial to the aeolian system. With increased sand supply entering the aeolian geomorphic system, dune fields nucleated and grew rapidly between the braided stream systems.

4. The resulting change in sand storage, from fluvial to aeolian probably is related to a short-termshift to a more semi-arid/arid climate over a seasonal time frame with a longer-term climate change indicated for more geographically pervasive aeolianites near the capping sandstone member — Kaiparowits Formation contact.

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Microbial Biofilm Effects on Local Conditions (cm range) in Arid Environments and their Potential Involvement in Iron Chemistry

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ABSTRACT

Microbial biofilms have been found across a wide spectrum of environments, including arid ecosystems. Biofilms actively affect many of these systems through corrosion, weathering, pore clogging, and the formation of anaerobic conditions in otherwise aerobic conditions. In the sandstone and sedimentary systems in southeastern Utah, biofilm systems are involved in hardening of sandstones through the production of EPS and EPS plus filaments (72 kPa and 100 kPa respectively). When associated with ephemeral water systems, biofilms reduce the rate of evaporation slightly and appear to protect cells in dried films from the effect of heat. Beyond having a direct effect on the substratum, these biofilms may provide the conditions necessary for the survival of a group of potential metal-reducing bacteria (MRBs) from the δ-Proteobacteria group–specifically relatives or representatives of the genera *Anaeromyxobacter*, *Desulfuromonas*, and *Cystobacter.* Species diversity of MRBs within these ecosystems is limited to seven or eight representatives, yet they seem widespread throughout the area. Measurements of iron(II) in the sandstones showed iron(II) concentrations ranging from 0-212 μM with the lowest concentrations associated with intermittent stream beds. From these data, we conclude that microbial biofilms have a direct effect on the local habitats through surface hardening, pore clogging and potentially iron reduction.

Abbreviations used: BLM, Bureau of Land Management; GSENM, Grand Staircase-Escalante National Monument; EPS, extracellular polymeric substances; MRB, metal-reducing bacteria; IRB, iron-reducing bacteria; PCR, polymerase chain reaction

Introduction

Microbial biofilms found in arid environments are intriguing yet understudied biological entities (Friedmann 1980; Bell 1993; Souza-Egipsy et al. 2004). In the sandstones, sediments and soils of the Colorado Plateau in southeastern Utah, microbial communities reside on and just within the surface of the substrate (Bell 1993; Kurtz Jr. and Netoff 2001; Kurtz Jr. et al. 2005). The best studied soil systems in this area are those harboring a set of communities known as microbiotic crusts (West 1990; Belnap and Lange 2001; Garcia-Pichel et al. 2001). Microbiotic soil crusts are classified according to the dominant organism found in the ecosystem, ie. lichen, cyanobacteria, or moss, with the cyanobacterial crusts being of the most importance to this study (Belnap and Lange 2001). While these crusts are somewhat diverse in their classification, they share some universal features (West 1990; Belnap and Lange 2001). Due to lack of water, the crusts take years to decades to develop and all act to stabilize the soil. As long as the crust remains intact, it reduces soil erosion through the formation of a hardened layer on the soil surface. Additionally, these crusts act to trap enough water within the soil to maintain metabolic activity beyond what is possible in soils lacking these crusts (West 1990; Belnap and Lange 2001). Less well studied are the microbial films found on sedimentary deposits located in ephemeral streams and other ephemeral water sources and the cryptoendolithic microbial biofilms found in the porous sandstones that dominate the local geology.

Previous work by Kurtz and Netoff (2001) suggested that these biofilms had the potential to stabilize their local environment through surficial hardening of the sandstones. However, no data were available to address the mechanism of this hardening. Stabilization of marine sediments through the production of extracellular polymeric substances (EPS) has been documented (de Brouwer et al. 2005) and EPS were considered part of a potential mechanism for surficial hardening of sandstones (Kurtz Jr. and Netoff 2001; Kurtz Jr. 2002). Other aspects of how these cryptoendolithic biofilms affect the local ecosystem have not been addressed. Little is known about whether these biofilms may have an effect on water retention. Overlaps between the diversity of cyanobacteria found in the cryptoendolithic cyanobacterial populations and those found in microbiotic crusts were found to be present (Bell 1993; Johansen 1993). This suggests that similarities in ecosystem functionality between cryptoendolithic biofilms and microbiotic crusts exist.

Based upon what is known about the physiochemical parameters associated with biofilms in general (Costerton et al. 1994), cryptoendolithic biofilms should have the potential to provide a suitable habitat for organisms with specialized growth requirements. Previously, the presence of a population of potential iron-reducing bacteria (IRBs) was detected in laboratory grown consortia as well as environmental samples (Kurtz Jr. et al. 2005). This suggests that these cryptoendolithic biofilms can support the presence of anaerobic organisms or at least organisms that are microaerophilic or aerotolerant. Due to the potential for reduction of iron(III) by IRBs, it is possible that these cryptoendolithic biofilms participate in larger-scale processes. A phenomenon referred to as iron bleaching was observed in the studied area. Chan and colleagues have shown that the bulk of the bleaching occurred in the past as the sandstones were uplifted and a prehistoric hydrocarbon reservoir was breached and drained (Chan et al. 2000; Beitler et al. 2005). While this explains the observed bleaching of the stone, it does not address the potential that iron bleaching is continuing due to biological activity.

In this paper, direct and indirect evidence is presented that suggests that these microbial biofilms are active in water retention, surface hardening, and potentially modern iron bleaching. The data presented also suggest mechanisms for how water is retained and how surfaces are hardened.

Methods and Materials

Field Sites and Sampling

Samples were acquired from the sites indicated on the map in Figure 1 under permit from the GSENM. Samples were collected during the summer months of the years 2002, 2004, and 2005 and stored in sterile Whirlpak bags in a dry, dark space. General temperature data were collected using a Raytek infrared thermometer (+/- 0.2˚C) and monitored temperature data were collected using Fisher Scientific traceable dual thermometers connected to DAS 4 dataloggers. Micrometeorology data (wind speed, temperature, and relative humidity) were collected at 1.5 m above the surface using a Kestrel 3000 Pocket Weather Station. GPS coordinates were obtained using a Garmin GPS12.

Genetic Analysis

DNA was extracted from approximately 100 mg of each sandstone sample using the MoBio Ultra Clean Soil DNA extraction kit according to manufacturers instructions. Thirty nanograms of DNA from each sample was used as the template for PCR (polymerase chain reaction) amplification of a 350 bp 16S rRNA gene fragment using primers GEO564F-GC and GEO840R, which are specific for *Geobacteriaceae* (Cummings et al. 2003); however, these primers will amplify sequences from closely related genera. The presence of *Shewanella* sp. was tested using the primers specific to this genus (Todorova and Costello 2006). PCR

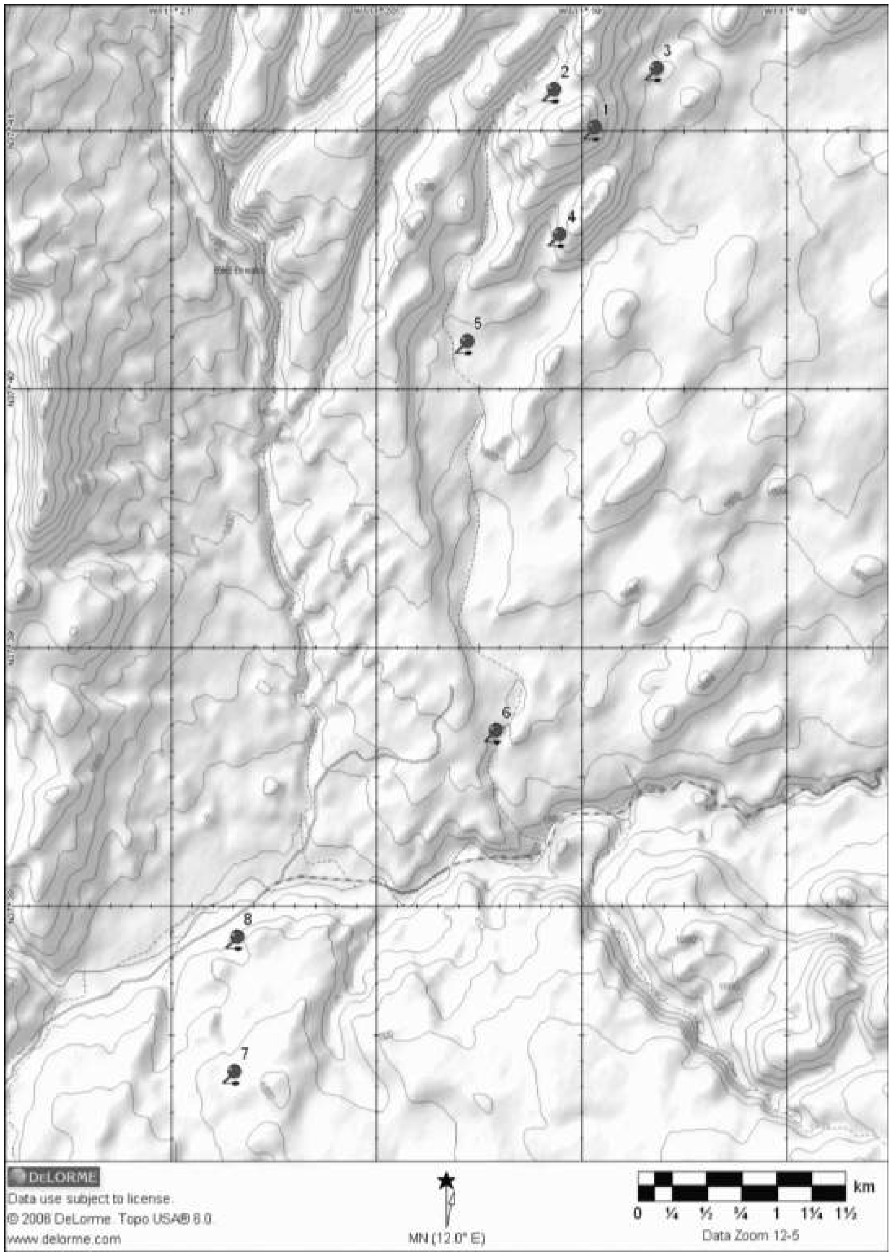

Figure 1. Site map of region under study with sampling sites marked. The region is located in southeastern Utah and can be found on the Red Breaks Quadrangle published by the US Geological Service. Site numbers correspond to entries in Table 1 in which measured iron(II) concentrations are shown. The map was developed using mapping software developed by Delorme (2006 Delorme Topo USA, www.delorme.com).

products were separated by DGGE (Kurtz Jr. et al. 2005) and the resulting bands were subsequently eluted from the gel and sequenced using primer GEO840R. DNA sequences were used to search the GenBank database using BLAST (Altschul et al. 1990; Altschul et al. 1997).

Stress Testing of Biofilms

Microbial biofilms were grown on sand as described previously (Kurtz Jr. et al. 2005). Two sets of cultures (six individual cultures per set) were established for this series of tests, one culture dominated by a group of photosynthetic bacteria and a second set dominated by filamentous cyanobacteria. Film strengths for each type of film were determined using a three-point break test, with the initial estimate of strength being calculated as g cm^{-2}, which was subsequently converted to kPa (Neuman and Maxwell 1999). Cell morphology was confirmed using a Nikon E600 epifluorescent

Site	Description	[Fe^{2+}]µM
1	SE wall of groove	211.85±37.18
1	Floor of groove	53.20±9.23
1	NW wall of groove	43.19±7.02
2	Rock slope	40.00±10.46
3	Rock slope	56.20±7.84
4	Ephemeral stream bed	0
5	Rock slope south of pool (~13 m)*	146.32±66.91
5	Stream bed upstream of pool (~20 m)*	0
6	Light colored abraded cliff face	0
6	Dark colored intact cliff face	0
7	Rock slope	114.69±13.95
8	Cliff face	39.80±2.37
* Approximate distance from spot at which GPS coordinates were taken		

Table 1. Iron(II) concentrations measured at sample sites indicated on map in Figure 1.

microscope with phase-contrast and Nomarski-DIC capabilities. Photosynthetic cells were detected using autofluorescence (Kurtz Jr. et al. 2005).

Iron(II) Assay

Iron(II) was measured using the ferrozine assay (Carter 1971). The mass of acid extractable Fe^{2+} (ng) from 100 mg samples was measured in triplicate or pentuplicate for each sample site. Based upon a saturation capacity of 260 µl/g of stone, the concentration of iron(II) was calculated and presented as µM. Stone saturation capacity was determined by saturating sandstone samples of known weight and adding water until the sample was saturated.

Results

Temperatures and Pore Clogging

Temperature data collected over the course of three years show that morning rock surface temperatures (RSTs) average 20-25 ˚C. Depending on topography, afternoon RSTs range from 40-50 ˚C. Stone coloration did affect RSTs with lighter colors being cooler by approximately 5 ˚C. Surfaces of loess deposits were often found to have temperatures that were 10-15 ˚C hotter than the rock surfaces. Spot measurements of wet sand deposits next to ephemeral or long term pools indicated that these deposits were significantly cooler than the surrounding rock surfaces or loess deposits. Temperatures measured on these wet deposits ranged from 8-15 ˚C in the morning just prior to dawn to 25-32 ˚C in the mid-afternoon with full sunlight. Relative humidity levels ranged from <10% during the mid-afternoon to 30% at dawn.

A continuous monitoring experiment was set up to measure the temperature fluctuations in an ephemeral pool system over a period of 48 hours. The data are presented in Figure 2 which shows that the temperature of the water in the pool is comparatively stable with respect to the temperatures measured in any of the other three points. Temperature fluctuations were most extreme in areas of dried biofilm over sand with temperatures peaking at or near 60 ˚C during the period in which monitoring occurred. Less extreme, but still notable are the data from the two wet sand sites. Two sites were measured to determine any effect microbial growth had on the temperatures measured. As seen in Figure 2, a 3-5 ˚C lower temperature was detected in the area that had been stripped of any microbial growth. Since faster rates of evaporation result in lower temperatures, these results indicate that microbial growth slows the rate of evaporation in these ecosystems.

Biofilm Strength

Field observations noted that microbial growth on the surface of sediment seemed to provide surface stabilization. This was especially notable when sediment deposits were dry and the surface microbial film had hardened and became brittle. It had been noted in a previous study that rock surfaces colonized by microbial growth were hardened slightly, resulting in differential weathering (Kurtz Jr. and Netoff 2001). Culturing of microbes on beds of sand using *ex planta* biofilm samples as an inoculum allowed for a measurement of the amount of pressure required to damage these biofilms. Using these dried biofilm cultures, it was determined that microbial films dominated by filamentous microbes (data not shown) were able to withstand a pressure of 100.6 ± 10.9 kPa (0.99 atm) before structural failure. During these experiments, an unexpected selection occurred in which a set of biofilms from the same inoculum sample (from a wind abraded cliff face) were grown on sieved sand (125-250 µm), resulting in

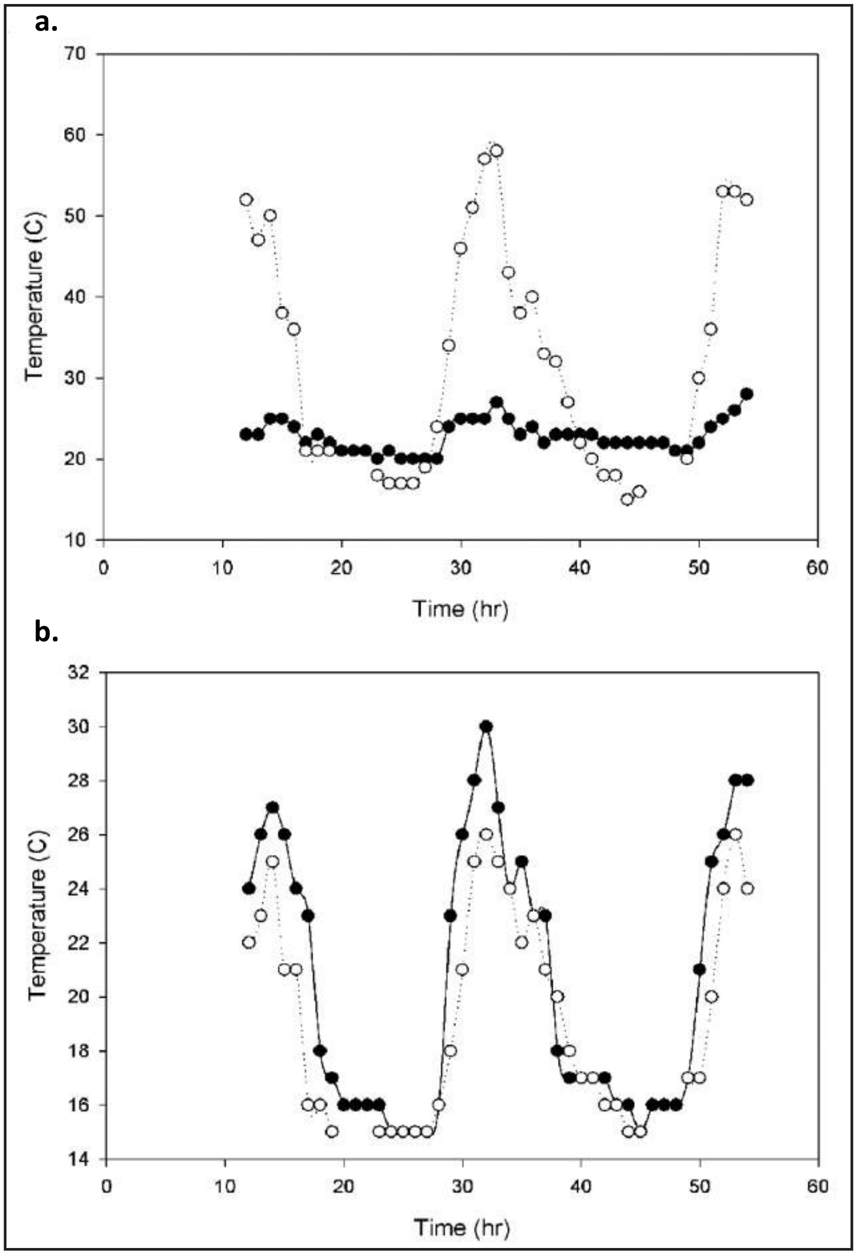

Figure 2. Temperature data from a long term pool found at site 5 in Figure 1. Data were acquired from four locations around the pool. Panel a shows data collected from the water (closed circles) and from the dried microbiotic crust associated with a downstream sediment deposit (open circles). Panel b shows data collected from wet sediments, with (closed circles) and without (open circles) surface biofilms.

the growth of a cyanobacterial biofilm dominated by thalloid cells (data not shown). Transfer of these cells to an unsorted sand bed allowed the development of a second set of biofilms that had no detectable filamentous growth. These films were allowed to dry and were found to resist a pressure of 72.5 ± 8.2 kPa (0.71 atm). While some of the difference in pressure resistance could be attributable to variations in EPS production, the majority of this difference is likely due to the absence or presence of filaments in the biofilm.

Diversity of IRBs

Iron-reducing bacteria (IRBs) were previously detected in these arid biofilm systems (Kurtz Jr. et al. 2005). To better understand the distribution of these bacteria in the region, a molecular survey was conducted. This survey indicated that

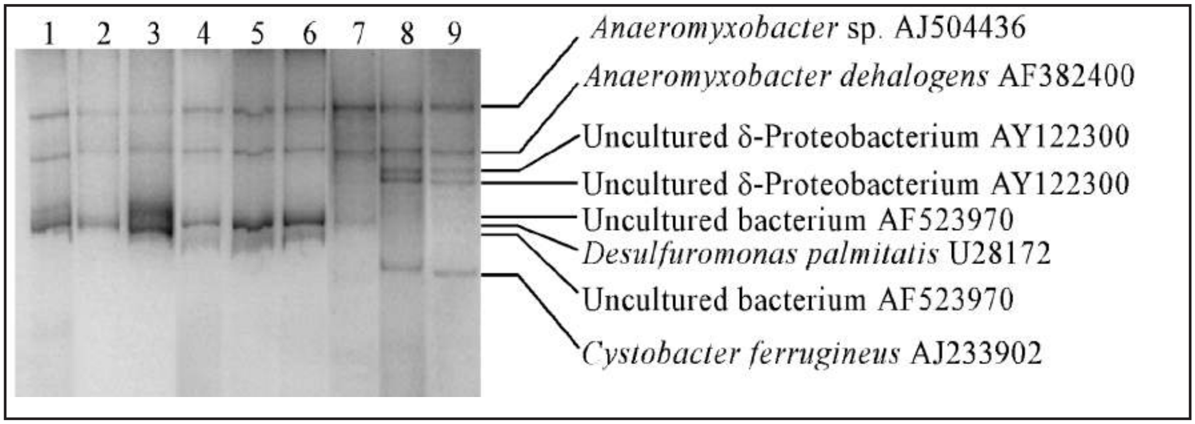

Figure 3. TDGGE data showing the presence of IRBs throughout the study area. Band identifications are based upon DNA sequence data and are shown to the right of the electropherogram. Lanes 1-7 are representative IRB diversity profiles for sample sites 1-7 shown in Figure 1. Lanes 8 and 9 are diversity profiles developed from laboratory grown biofilms used in the strength measurements. GenBank Accession numbers are shown for the closest DNA sequence relative for each band.

IRBs are common in the region, though as seen in Figure 3, this diversity is limited to at most seven microbial species. Sequence data for these specific molecular species indicates that while members of the genus *Geobacter* are not present, the genera *Anaeromyxobacter*, *Desulfuromonas*, and *Cystobacter* are represented, all of which have been shown to have at least one species capable of reducing iron(III) to iron(II) (Treude et al. 2003; He and Sanford 2004; Kuever et al. 2005). *Shewanella* sp. were not detected via PCR. These data led to an assessment of iron(II) concentrations found in the study area which ranged from 0-869 μM with an average concentration of approximately 100 μM. Site data for this study are shown in Table 1. These data show that iron(II) concentrations can be correlated to topography with higher iron(II) concentrations found on slopes rather than stream beds of intermittent water ways. Visual observations of catchments in these stream beds suggest that iron is being deposited in the catchment basin. However, these data do not separate photoreduction of iron from biological reduction.

Discussion

Microbial biofilms have been noted to have many effects on the substratum to which they are attached. Most of these effects have been determined using experimental biofilms on a flat surface (Costerton et al. 1995; Beech et al. 2005; Coetser and Cloete 2005). Studies that examine biofilm communities in natural settings are commonly focused on a specialized function of that community rather than an understanding of how that community affects its local environment (Yallop et al. 2000; de Brouwer et al. 2005). Yet, whatever natural community is studied, the presence of that community stabilizes the substratum at least temporarily. This stabilization effect also seems to be a relevant feature of biofilms in arid environments, including microbiotic soil crusts.

Stabilization of the environment by microbial biofilms is also associated with temperature moderation. The data shown indicate that the presence of these bacterial films reduces the rate of evaporation enough to cause a 2-5 ˚C increase in temperature. Pore-clogging is likely the most probable cause of this reduction in evaporation (Vandevivere and Baveye 1992; Mattison et al. 2002; Thullner et al. 2003). Additionally, pore-clogging is probably greater than measured as the predominate microbe in these biofilms are dark colored cyanobacteria and other photosynthetic microbes which would tend to absorb more heat, thereby increasing the evaporation rate. However, at this time the data to separate these two opposing factors is not available.

As a result of microbial growth and pore-clogging, the microbial community entrains the sediments and hardens the surfaces of the surrounding soft sandstones. Entrainment of sediments has already been demonstrated in other systems (Campbell 1979; de Winder et al. 1989; Dade et al. 1990; Johansen 1993; Neuman and Maxwell 1999, Mattison et al. 2002; de Brouwer et al. 2005) and in arid environments. Trapping of particles by microbial communities in arid environments and the subsequent entrainment results in a number of potential benefits for the community including protection from UV radiation. Single-celled organisms have little protection from the damaging effects of UV radiation, therefore, their ability to grow below the surfaces of porous rocks and sediment deposits would potentially provide some protection from UV light. Entrainment of sediment and hardening of sandstone surfaces prevents the rapid movement of cells from a location conducive to metabolic activity to a location that may not support microbial growth. Finally, the production of EPS and the subsequent clogging of pores by cells and EPS reduces the rate of water loss, an especially important benefit for organisms that reside in an arid environment.

Mechanistically, sediment entrainment and rock surface hardening have two primary components. EPS production provides the bulk of the resistance in our experimental systems. However, the growth of cells with a filamentous morphology acts to strengthen the EPS cement and to increase the resistance of the dry biofilm to fracture by a factor of approximately 1.4 fold. This resistance to breaking is on the order of an atmosphere or less. The resulting hardness differential between the surface and subsurface stone is apparently enough to cause a slight decrease in erosion when compared to the sandstone or sediment lacking this protective microbial film (Kurtz Jr and Netoff 2001).

Microbial biofilms can provide a suitable habitat for microbes that would not be expected to reside in a given ecosystem (Costerton et al. 1994). In this case, biofilms provide an environment low in oxygen allowing the growth of microbes requiring low concentrations of oxygen. While direct measurements of oxygen concentrations within these surface habitats (<1 cm deep) is not possible, the routine detection of IRBs in these communities implies that the redox potential is sufficiently low enough for the survival and growth of these bacteria in these arid sandstones. Combined with the detection of a substantial amount of iron(II) detected in most of the samples analyzed, it is likely that these organisms are metabolizing organic material and reducing iron(III) with the excess electrons. A second source of iron(II), photoreduction, has not been accounted for in these systems and therefore, it is not possible to say that the IRBs are responsible for the detected iron(II) in the system. However, it is entirely probable that the IRBs are forming some of the measured iron(II) and therefore may play a role in the larger phenomenon referred to as iron bleaching. Currently, iron bleaching is best understood as a paleogeochemistry phenomenon in which this portion of the Colorado Plateau is a breached hydrocarbon reservoir (Chan et al. 2000). During the loss of the stored hydrocarbons, iron was chelated and moved from the sandstones yielding the characteristic pattern of lighter and darker stones seen today.

Based upon the evidence provided, the surface microbial communities have a number of impacts on the local conditions found on the Colorado Plateau. These communities are involved in temperature moderation through reductions in the evaporation of available water and are most likely involved in preventing water loss into the porous sandstone through pore clogging and through the deposition of hematite in the basins of ephemeral pools (Chan et al. 2005). Through the production of EPS, hardening of stone surfaces and sediment surfaces does occur. This surficial hardening may result in the formation of small scale features in the sandstone surface due to the modification of erosion rates by wind and water. It is also apparent that iron-bleaching is not necessarily a process that occurred only in the past, but may be an ongoing process mediated by microbial activity.

Acknowlegments

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Using Stable Isotopes and Tritium to Determine Flow Path and Relative Age of Water in the Sheep Creek Watershed, Southern Utah

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ABSTRACT

Preliminary results from oxygen and hydrogen stable isotope analyses (^{18}O, ^{2}H) and tritium (^{3}H) were used to determine the relative age of spring and surface water in the Sheep Creek Watershed in Southern Utah. Sheep Creek is a tributary of the Paria River that carries runoff from Bryce Canyon National Park. Stable isotopes were used to interpret the flow path of water from the rim of Bryce Canyon to the Paria River to determine the influence of water quality from Sheep Creek. The data plot between the Basin and Range and Colorado Plateau Province's local meteoric water lines with evaporative processes seen locally. Tritium data were used to determine the relative age of the groundwater emerging from four different stratigraphic units from the Tertiary through Jurassic periods. Preliminary results identify young and old water in the catchment. The stable isotope and tritium data presented provide a baseline for further studies.

Keywords: stable isotopes, ^{18}O, ^{2}H, tritium, Sheep Creek, Paria River, groundwater age, Grand Staircase-Escalante National Monument, isotope hydrology

The Paria River exceeds the Environmental Protection Agency total maximum daily load (TMDL) limits of salinity and total dissolved solids. Sheep Creek, a tributary to the Paria River, has high salinity levels. This project is examining the flow path of water through Sheep Creek to determine if it is having an influence on the salinity in the Paria River. Currently, the Utah Department of Environmental Quality is reviewing the TMDL on the Paria River and a decision on its removal from the EPA's 303(d) impaired waters list is expected shortly.

The Sheep Creek Watershed is a sub-basin in the Paria River drainage located in southern Utah (Figure 1). The study area is located in the southwest edge of the Colorado Plateau physiographic province bordering the Basin and Range province (Figure 2). The watershed includes parts of Bryce Canyon National Park (BCNP), Dixie National Forest and Grand Staircase-Escalante National Monument (GSENM). The main creek system in the watershed is Sheep Creek. Swamp Canyon Creek, in BCNP, is the headwaters of Sheep Creek, which flows into the Paria River. The objective of this project is to use stable isotopes ^{18}O and ^{2}H and tritium to determine the flow path and relative age of the water in Sheep Creek and compare it to a stable isotope sample from the Paria River, above

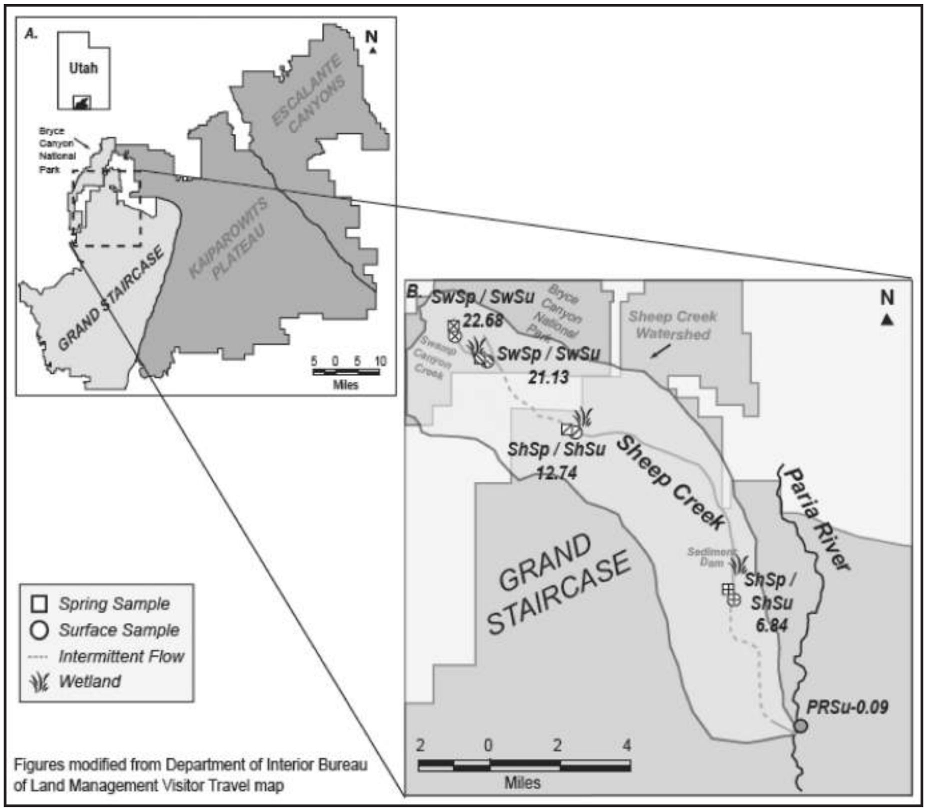

Figure 1. (A) Location map of Grand Staircase-Escalante National Monument (GSENM) and Bryce Canyon National Park (BCNP) in Southern Utah. (B) Enlargement of study area with a rough outline of the Sheep Creek Watershed.

the confluence with Sheep Creek. This information will contribute to determining if water from Sheep Creek has an influence on the Paria River and its water quality.

Five locations were sampled for tritium in 2002 and 2003 and nine locations were sampled for stable isotopes in 2003. The first sampling site in the study area, the furthest upstream in the headwaters of Swamp Canyon Creek, is located in BCNP at an approximate elevation of 2,400 m (7,900 ft). The last sample site, in the Paria River above the confluence with Sheep Creek, is at an approximate elevation of 1,600 m (5,250 ft). The study area spans an elevation change of approximately 800 m (2,625 ft).

The climate in the upper section of the study area extends through the transition zone below the montane and is in the high desert life zone with precipitation averaging approximately 36 cm (14 inches) per year as both snow and rain (Harris et al. 1997). The lowest sections of GSENM, around 1,200 m (3,950 ft), are in the desert climate zone and receive around 15 cm (6 in) of rain annually (Doelling et al. 2003). In the six months prior to sampling in October 2002, precipitation averaged 10 cm (4 in) in the Sheep Creek vicinity and in June 2003 precipitation averaged 8 cm (3 in) (MesoWest Precipitation Monitors 2002). Precipitation measurements were averaged between the two nearest precipitation stations, Bryce Canyon Airport (2,300 m / 7,585 ft) and Between the Creeks (1,860 m / 6,100 ft).

Stable isotope and tritium data were collected in order to test the hypothesis that water from each sample location is emerging from a different aquifer. In this study, the stable isotope data are being used to examine the climatic conditions in which precipitation was formed before becoming groundwater. The tritium data are being used to determine if water in the aquifers were recharged before or after the 1952-1964 period of atmospheric nuclear weapon testing. Together this information will indicate if waters from the sample locations are from distinct aquifers or if they are from the same source.

Figure 2. Modified map of the Colorado Plateau and Basin and Range Physiographic Provinces with study area (S. Robson and E. Banta 1995).

Hydrogeology

The Grand Staircase section of Grand Staircase-Escalante National Monument (GSENM) is characterized by a series of geologic formations that resemble a flight of stairs. The uppermost sections are called the Pink Cliffs, Grey Cliffs, and White Cliffs (Figure 3). The Pink Cliffs are characterized by the Claron Formation in Bryce Canyon National Park. The Grey Cliffs, comprised of the Dakota Formation, Tropic Shale, and the Straight Cliffs Formation, are in GSENM. The White Cliffs are created by the upper member of the Navajo Sandstone and the lower member of the Carmel Formation in GSENM (Doelling et al. 2003).

There are two main aquifers in the study area: the Straight Cliffs Aquifer and the Navajo Aquifer as well as localized minor and alluvial aquifers (Spangler 1992) (Figure 3). Water samples were collected from the two major aquifers and three minor and alluvial aquifers. The waters emerged from five different geologic formations: the Claron Formation, Straight Cliffs Formation, Entrada Sandstone, Carmel Formation, and Navajo Sandstone.

Stable Isotopes: ^{18}O and D

Isotopes are atoms of the same element with a different number of neutrons and therefore different atomic weights. Stable isotopes remain constant in their forms and are found in different abundances in the atmosphere. Radioactive isotopes decay over time eventually transforming into stable isotopes. For example, tritium, ^{3}H, decays and becomes the stable isotope helium, ^{3}He.

Oxygen has three stable isotopes ^{16}O (99.63%), ^{17}O (0.0375%), and ^{18}O (0.1995%) with ^{16}O and ^{18}O being most abundant in the atmosphere. Hydrogen has two stable isotopes, ^{1}H and ^{2}H, also called deuterium (D) and one radioactive or unstable isotope, ^{3}H or tritium. Oxygen and hydrogen comprise the water molecule making it possible to measure the ratio of heavy to light isotopes $^{18}O / ^{16}O$ and $^{2}H / ^{1}H$ to interpret past climatic data of water.

Stable isotope ratios are reported as delta (δ) in the unit permil (‰) or parts per thousand. The δ values are calculated by the following equation developed by Craig (1961a):

$$\delta = [(R_{sample} / R_{standard}) - 1] \times 1000 \text{ (‰ SMOW)} \quad (1)$$

Where, R equals the ratio of the heavy to the light isotope in the sample or the standard.

Oxygen and hydrogen stable isotopes are often reported relative to a standard called SMOW, Standard Mean Ocean Water, developed by Craig (1961b). Current practices use VSMOW (Vienna SMOW), as it is regulated by the International Atomic Energy Agency (IAEA).

Craig (1961a) developed a relationship between δ^{18}O and δ D using an average of fresh surface waters and precipitation from temperate climates around the world. This line is called the Global Meteoric Water Line (GMWL) and is represented as:

$$\delta D = 8\,\delta^{18}O + 10 \quad (2)$$

Local meteoric water lines (LMWL) are created from samples collected from a localized area and compared to the GMWL. In arid climates, where evaporation is dominant, the slope of the LMWL will be lower and plot to the right of the GMWL. The intercept, also called deuterium

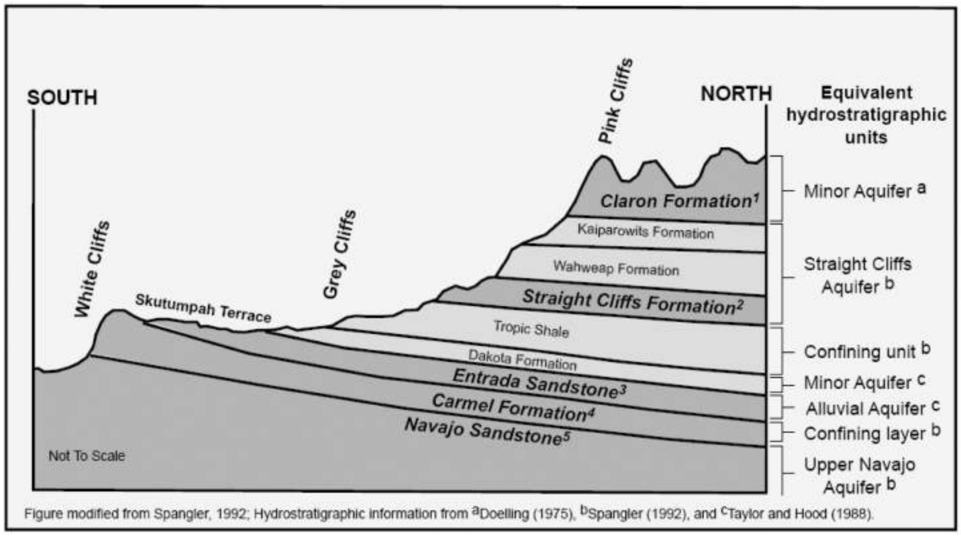

Figure 3. Lithologic and Hydrographic information for geologic formations within the study area. Corresponding lithology and water sample locations: [1]SwSp/SwSu-22.68, [2]SwSp/SwSu-21.13, [3]ShSp/ShSu-12.74, [4]ShSp/ShSu-6.84, and [5]PRSu-0.09.

excess or *d*-excess, reflects the effects of evaporation and climatic conditions, including seasons, in which recharging precipitation originated (Kendall and Coplan 2001). In high humidity conditions, the *d* value will be low. Very high *d* values are found in arid climates, where evaporation exceeds precipitation, and may indicate secondary evaporation occurring to precipitation before reaching the ground surface (Araguas-Araguas et al. 2000).

Isotopic composition of precipitation is affected by distance from the source of water vapor, altitude, temperature of condensation, humidity, and rainout effect. There are also secondary factors like evaporation of the raindrop as it is falling to earth and evaporation from the ground. For all of these situations, the heavy isotopes fall out first leading to heavy isotope depletion as the air mass moves inland, climbs in altitude, or is subject to evaporation. The information derived from correlating $\delta\ ^{18}O$ and δ D in groundwater can also reveal information about the climate when precipitation entered the groundwater system.

Isotopic signatures in precipitation are largely influenced by the temperature of the condensation during formation and the amount of rain that has already fallen from the cloud. In cooler climates and seasons, precipitation samples will plot close to the GMWL indicating less fractionation between the heavy and light isotopes. In warmer climates and seasons, the isotopes will fractionate. The heavy isotopes condense falling out of the clouds before the lighter isotopes which remain in the vapor. Evaporation in surface water has the same effect, concentrating heavy isotopes while the lighter isotopes leave the system as water vapor (Hem 1992).

Tritium: ^3H

Tritium, ^3H, is a radioactive isotope that is present in small amounts naturally in the atmosphere due to cosmic ray spallation. However, it is also present as a result of the nuclear industry. The atmospheric nuclear weapons testing that took place from 1952-1963 created a ‘tritium pulse’ that culminated in 1963 (Clark and Fritz 1997).

Tritium has a half-life of 12.4 years and can replace ^1H hydrogen in the water molecule (Hem 1992). When precipitation infiltrates into the groundwater system it can be used as an ideal tracer for delineating flow path, quantifying aquifer recharge, estimating aquifer residence time, and measuring component mixing. The thermonuclear pulse has allowed scientists to measure recharge and travel time in aquifers that have occurred within the last 100 years (Clark and Fritz 1997).

There are three factors that have an effect on tritium concentration in precipitation: 1) latitude – middle and higher latitudes have increased tritium levels in precipitation, 2) seasons – in the spring, higher tritium levels are measured compared to the winter, and 3) distance from the ocean – continental precipitation has increased tritium activity due to the distance from the less tritiated water of the ocean (Haldorsen et al. 1997).

Tritium is often reported in picocuries L^{-1} (pCi/L) or tritium units (TU), 1 TU = 3.24 pCi/L and 1 TU equals 1 ^{3}H in 10^{18} atoms of hydrogen (Clark and Fritz 1997). There were very few samples that were analyzed for tritium before nuclear weapons testing began, but it is estimated that natural tritium levels were between 2-8 TU (7-26 pCi/L) (USGS 2004). In 1998, Farmer et al. (1998) reported modern precipitation tritium levels to be between 3 - 15 TU (9.6 - 48 pCi/L). As modern tritium levels approach pre-nuclear-testing tritium levels these data become increasingly difficult to interpret.

Methodology

Sample site names were determined by the stream from which they were collected, the source of the water, and the river mileage from the confluence of Sheep Creek and the Paria River. Source streams are identified with the following abbreviations: Sw = Swamp Canyon Creek and Sh = Sheep Creek, PR = Paria River. If the water sample is from a spring, Sp will follow the stream identification, if it is a surface water sample, Su will follow. The letters A and B were used to distinguish between sample years, A = 2002 and B = 2003. For example, ShSp-12.74-B is Sheep Creek, spring sample, 12.74 miles upstream from the confluence with the Paria River collected in 2003 (Figure 1).

Stable isotope samples were collected from eight spring and surface water sites in the Sheep Creek Watershed and one from the Paria River above the confluence with Sheep Creek during spring 2003. Each site was visited once in order to obtain samples and collect field data. Unfiltered samples were collected in 10 ml glass vials with conical plastic insert lids. Samples were then shipped to the University of Nevada, Reno Stable Isotope Laboratory where they were analyzed on a GV Instruments Micromass IsoPrime High Performance Stable Isotope Ratio Mass Spectrometer.

Tritium water samples were collected from seven springs and one surface water site in the Sheep Creek Watershed during fall 2002 and spring 2003. Each site was visited twice in order to obtain samples and collect field data. Unfiltered samples were collected in 1-liter glass bottles with conical plastic insert lids and analyzed in the Environmental Protection Agency (EPA) – Radiation and Indoor Environments National Laboratory in Las Vegas, Nevada. Samples were subject to enrichment, as it was known the tritium concentrations were less than 800 pCi/L. After enrichment, the samples were analyzed in a liquid scintillation counter and results were calculated in the LIMS Chemistry program according to EPA standard operating procedures (Flotard 2004).

Special care was taken to ensure bottles were completely filled so as to prevent any fractionation or evaporation from occurring after the samples were collected.

Results and Disscussion

Preliminary stable isotope results reveal that relative to the GMWL, samples from the Sheep Creek Watershed plot to the right of the line (Figure 4) indicating the climate is arid and evaporation is taking place. In arid climates, where evaporation rates are high, the slope of the $\delta^{18}O$ and δD regression line, or evaporation line, is around 5 (Craig 1961a). The Sheep Creek Watershed regression line (SCW RL) has a slope of 4.8 and d-excess of -38.27‰ confirming evaporation is a factor in the fractionation of the isotopes in this area.

The Sheep Creek Watershed lies on the edge of the Basin and Range and the Colorado Plateau physiographic provinces. Most of the SCW $\delta^{18}O$ and δD data points plot between the Southern Nevada LMWL (Basin and Range province) and the Colorado Plateau Springs Inventory LMWL, with the exception of ShSp/ShSu - 6.84 B (Figure 5).

SwSp - 22.68 B and SwSu - 22.68 B have average isotope values in relation to the other data points. These sample sites are located at the highest elevation and receive precipitation as snow in the winter and rain in the summer monsoonal season. Tritium results indicate that recharge for the aquifer in the Claron Formation has occurred within approximately 10 years (Figure 6). Based on these data it is thought that this water characterizes localized recharge.

SwSp - 21.13 B and SwSu - 21.13 B are located in the Straight Cliffs Formation. The Straight Cliffs aquifer is a principal aquifer in the region supplying water to springs throughout the forma-

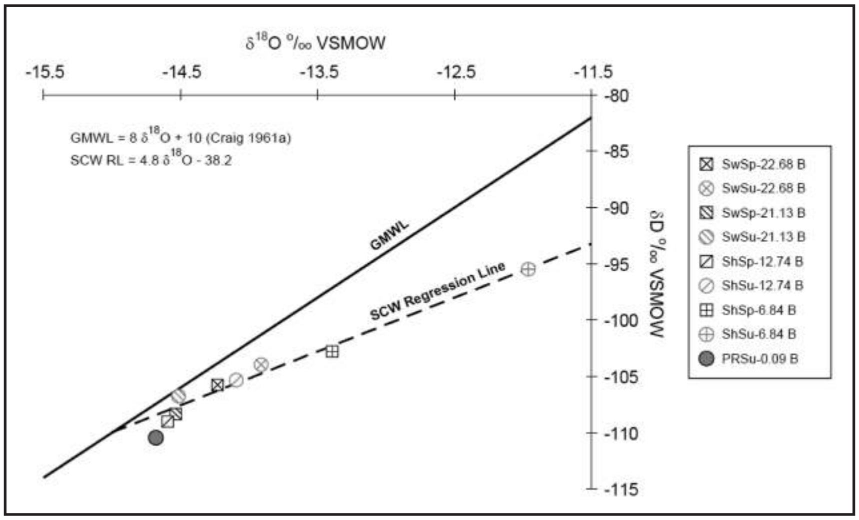

Figure 4. Sheep Creek Watershed and Paria River samples on δ^{18}O vs. δD graph with the Global Meteoric Water Line (GMWL) and the Sheep Creek Watershed regression line (SCW RL). Regressio line excludes PRSu - 0.09 B. δD sample results reported with an uncertainty of +/- 1 and r^2=0.96.

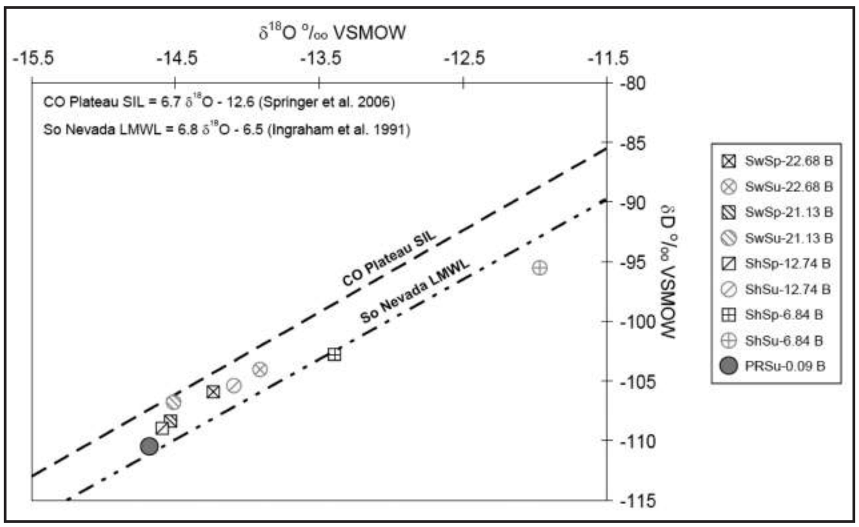

Figure 5. Sheep Creek Watershed and Paria River stable isotope water samples with the Southern Nevada local meteoric water line (So Nevada LMWL) and 2005 Colorado Plateau springs inventory lin (CO Plateau SIL).

tion (Spangler 1992). Tritium results from this study indicate recharge to the aquifer occurring greater than 50 years ago. The isotope ratios from these samples are among the lightest, indicating the least amount of fractionation. SwSu - 21.13 B is slightly heavier than SwSp - 21.13 B presumably due to the longer exposure time to the atmosphere.

SwSp - 21.13 B and ShSp - 12.74 B are located 8.49 miles apart and are separated by two geologic formations including the Tropic Shale confining layer. However, the isotope ratios indicate that the source water for these springs may be shared. Both springs originate flow in gaining portions of the stream. SwSp - 21.13 B emerges from the Straight Cliffs formation and the Straight Cliffs Aquifer. ShSp - 12.74 B emerges in an area that is covered in alluvium between outcrops of the Dakota Formation and Entrada Sandstone (Grand Staircase-Escalante National Monument 2002).

Between SwSp - 21.13 B and ShSp - 12.74 B Sheep Creek infiltrates into the ground. ShSp - 12.74 B is the point at which the creek becomes gaining again. Tritium concentrations indicate that water from these springs was recharged more than 50 years ago (Figure 6). One possible scenario

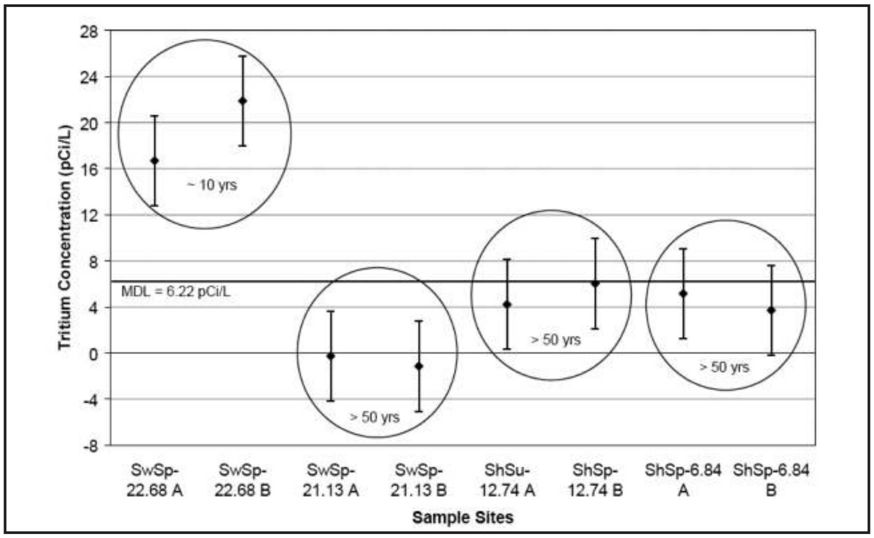

Figure 6. Tritium data from Sheep Creek Watershed spring and surface water sites in 2002 and 2003. Data grouped by sample site (circles) with estimated time of aquifer recharge. Site 12.74 A is a surface water site. method detection limit (MDL) is 6.22pCi/L with 2 sigma=3.91 pCi/L.

is that the source water is the same for these two springs. Water from the Straight Cliffs aquifer seeped through the underlying formations and is contributing to the flow at ShSp - 12.74 B. Another scenario is that the aquifers were recharged during a time of similar climatic conditions. Further investigation is needed in order to answer these questions definitively.

ShSp - 12.74 B is isotopically lighter than ShSu - 12.74 B. The spring location of this sample was along a line of vegetation that indicated a rise in the water table. The water emerging from ShSp - 12.74 B is from a more confined area within the aquifer. ShSu - 12.74 B was located in a wetland area along a seep that emerged from the bottom of the channel bank.

Evaporation is having the greatest effect on the ShSp / ShSu - 6.84 B sample sites. These samples are isotopically heaviest and plot furthest from the GMWL. The fractionation occurring in these samples, concentrating the heavy isotopes in the water, is likely a result of increased evaporation from being in contact with the atmosphere longer than the other water samples.

ShSp - 6.84 B and ShSu - 6.84 B plot distinctly away from the other samples along Sheep Creek. It is unknown where the creek surfaces between ShSu - 12.74 and ShSu - 6.84 but there is a wetland created by a sediment dam from which water is flowing (Figure 1). The water flows over the dam and through the sample site before becoming a losing reach again almost immediately.

The ShSp/ShSu - 6.84 B samples were collected within an hour of one another, in the morning, with water temperatures of 11°C and 24°C respectively however they plot apart on the graph. ShSp - 6.84 B is located in the shade below a rock ledge. ShSu - 6.84 B is in direct sunlight in the creek bed for the majority of the day. The water table in this reach of Sheep Creek fluctuates as the surface water seeps underground, shortening the length of the creek as the day wears on. The increase in *d*-excess indicates higher amounts of evaporation occurring at this site. The continual exposure to the atmosphere has led to increased evaporation. It is possible, that the source water for the spring and surface water sample are not the same. Sheep Creek is flowing through the Navajo Sandstone but it is interbedded with the Thousand Pockets Tongue of the Page Sandstone and the Paria River Member of the Carmel Formation (Grand Staircase-Escalante National Monument 2002). Tritium data for ShSp - 6.84 A and B reveal that the water entered the aquifer more than 50 years ago; however there are no tritium data for ShSu - 6.84 making it difficult to determine if the waters are of different origin.

The next water sample collected was downstream at PRSu - 0.09 B with a water temperature of approximately 26°C. However, PRSu - 0.09 B is the isotopically lightest sample. These two samples nearest one another geographically and having the warmest water temperatures, display the greatest isotopic variation. Preliminary results indicate that the reason is attributed to different source waters.

Water from the Paria River (PRSu - 0.09 B) is the lightest sample. This indicates that, although it is flowing through an arid area, the water is reflective of winter precipitation and snowmelt runoff (Ingraham et al. 1998). PRSu-0.09 B is in the Paria River drainage which runs through the Navajo Sandstone. The primary source of recharge for the Navajo Aquifer is from rain and snow (Freethy 1988). The headwaters of the Paria River are in the Paria Amphitheater bounded by the Table Cliffs at an elevation of approximately 3,000 m (9,850 ft) (Gregory 1951). The colder climate from which the waters of the Paria River originate and the contribution of baseflow from the Navajo Aquifer account for the lighter isotopic composition of this water (Ingraham et al. 1998).

A pattern can be detected between the spring and surface water samples that confirms the conclusion that evaporation has a large influence on the isotopes. For all the paired spring and surface water samples the surface water samples were heavier. However, the isotopically lightest sample was at the base of the creek, the surface water of the Paria River. Based on these data alone it can be shown that Sheep Creek does not have an impact on the water of the Paria River.

Tritium results are limited due to the small sample size. The spring samples from SwSp - 22.68 B have tritium activity levels that indicate aquifer recharge within the last 10 years (Figure 6). Results for the samples that fall below the method detection limit (MDL) have the same levels of tritium as background levels measured by the instrument. These levels of tritium are not sufficient to be able to determine a relative age. The water samples with tritium concentrations in the -1 to 6 pCi/L range are assumed to have been recharged more than 50 years ago, before the thermonuclear pulse.

The water samples from SwSp/SwSu - 22.68 A and B were collected from an aquifer that is presumed to be fed by local recharge. Guay et al. (2006) reported that tritium levels in the river water of the lower Colorado River valley system are around 36 pCi/L (11 TU). Likewise, Farmer et al. (1998) conducted a study on seasonal precipitation in the Las Vegas Valley and nearby Spring Mountains in Nevada. They found that precipitation collected in the valley ranged from 15.7 pCi/L to 35.3 pCi/L from fall through spring. In the mountains, the range was varied from 14.6 pCi/L to 40.7 pCi/L. The tritium levels for this aquifer range from 16 – 22 pCi/L from the fall to the spring, indicating recharge to the aquifer to be recent, approximately within the last ten years.

Tritium values for SwSp - 21.13 A and B, ShSp - 12.74 B, ShSu - 12.74 A, and ShSp - 6.48 A and B sample sites have activity levels below the MDL. These levels are lower than present day atmospheric levels of tritium indicating recharge to the aquifers was prior to the 1950's.

Recent work performed by Northern Arizona University (NAU) in the Escalante region of GSENM (Rice and Springer 2006) reveals $\delta^{18}O$ and δD levels that fall closer to the 2005 Colorado Plateau Springs Inventory LMWL (Figure 7). The recharge area for these springs, based on isotope data, is from a cooler, higher elevation source. The progression eastward, through GSENM, of isotopes becoming increasingly heavier, indicates that the precipitation that falls and recharges the aquifers in the Escalante region is increasingly characterized by the Colorado Plateau province rather than the Basin and Range province.

Conclusions

The preliminary results presented here are intended to be used in conjunction with additional data to gain a complete understanding of the hydrogeological processes in the Sheep Creek Watershed.

Neither the stable isotope data nor tritium data could provide a definitive flow path of the water through the Sheep Creek Watershed. Isotope data revealed preliminary information on different sources of recharge water to various springs but these data cannot be used on their own. There is no evidence of a linear trend along the creek that indicates the interconnectedness of the waters.

Sample sites ShSp / ShSu - 6.84 B and PRSu - 09.09 B are the easternmost sites in the study area and plot closest to the 2005 Colorado Plateau springs inventory line. Based on these data and data from the NAU Escalante Springs Inventory the isotopic signature of water in Grand Staircase-Escalante National Monument traveling east will

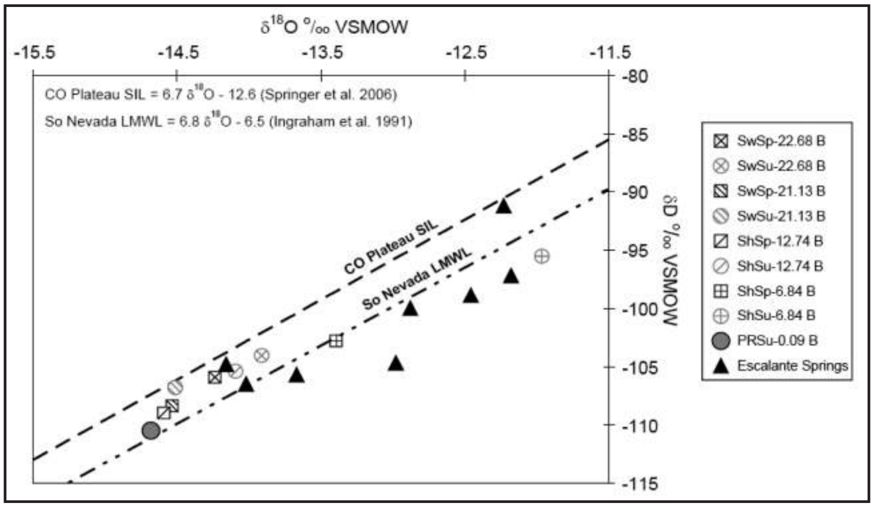

Figure 7. Sheep Creek Watershed, Paria River and Escalante Canyon springs stable isotope water samples with the Southern Nevada LMWL and 2005 Colorado Plateau SIL.

plot closer to the Colorado Plateau springs inventory line.Tritium data indicate sample location 22.68 is from a distinct aquifer with local recharge. The other sample sites are from aquifers that were recharge prior to the 1950's.

Further research is needed, on a large scale, in the western section of Grand Staircase-Escalante National Monument to exam long term and seasonal trends of tritium and stable isotopes in surface and groundwaters. This work would enable the creation of a local meteoric water line for Grand Staircase-Escalante National Monument.

These data, along with major ion and trace metal data, will be used to create a comprehensive picture regarding the hydrogeology and salinity of the Sheep Creek Watershed and its impact on the Paria River.

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The authors would like to thank the people and organizations integral in this project without which it would not have been possible: The Bureau of Land Management, Grand Staircase-Escalante National Monument Headquarters, the University of Nevada, Las Vegas Graduate & Professional Student Association and the Day and Night Scholarship Fund for their financial support. Richard Flotard and Dennis Farmer at the Environmental Protection Agency - Radiation and Indoor Environments National Laboratory and the Nevada Stable Isotope Laboratory at the University of Nevada, Reno for isotope analyses. Special thanks go to the sampling team Joni Vanderbilt, Marylou Zimmerman, Scot Franklin, Pete Vanderbilt, and Jeremy Koonce.

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Use of Springs to Quantify Groundwater and Surface Water Interactions in the Escalante Basin

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ABSTRACT

In June 2006, a set of seven springs and one well were inventoried within the Bureau of Land Management Grand Staircase-Escalante National Monument in accordance with protocols developed jointly by representatives at Northern Arizona University and the National Park Service. Inventories included descriptions of the site, water quality, and discharge as well as collection of water samples for laboratory analysis. The sites were selected to provide information on the source and behavior of groundwater in the area around tributaries at the headwaters of the Escalante River. All of the sites inventoried discharged from the Navajo Sandstone, the predominant geologic unit in the study area.

The majority of the inventoried locations had little to no anthropogenic disturbance. Site elevations ranged from 1,618 to 1,873 meters, and site sizes ranged from tens of square meters to over a hectare (10,000m^2). Many of the spring locations were actually complexes of springs rather than singular orifices. Five springs were hanging garden-type and two were rheocrene-type. Discharges ranged from 44.86 liters per second at the Upper Calf Creek spring complex to 0.079 L/s at the Deer Creek spring.

Geochemical analyses point to a high elevation/winter precipitation recharge source, the Boulder Mountain area to the north of the study area. Isotopic data ($\delta^{18}O$, δ^2H, and ^3H) point to variations in groundwater flow paths and amount of groundwater mixing between the high elevation/winter recharge water and lower elevation/warmer recharge water. Evidence indicates that the higher elevation benches and mesas extending south into the study area are the primary pathways of groundwater from the Boulder Mountain region. Water chemistry is often more similar on either side of these drainage divides than on either side of the drainages themselves.

Introduction;

The Escalante Canyons region of Grand Staircase-Escalante National Monument (GSENM) is typified by a semi-arid climate. Even so, the area contains several perennial tributaries which supply the Escalante River. Most of these creeks are groundwater-derived from the thick sedimentary aquifers of the Escalante region, primarily the Jurassic Navajo Sandstone. The Navajo Sandstone provides the baseflow to several tributaries (Pine, Mamie, Calf, Boulder, and Deer Creeks) in the headwaters region of the Escalante River. These tributaries provide the majority of the baseflow of the Escalante River along its entire 80-mile reach between Escalante, UT and its discharge into Lake Powell (Wilberg and Stolp, 2004).

The Navajo Sandstone aquifer system in the Escalante region and the tributary canyons to which it provides baseflow is not well understood. Much of the recharge to the aquifer occurs in the high elevations of Boulder Mountain to the north and the generally thick, well sorted eolian sandstone of the Navajo acts as a large reservoir and conduit for this recharge. Boulder Mountain is composed of primarily volcanics and volcanic-derived colluvium overlying the Carmel Formation and the Page and Navajo Sandstones. Snow and rains in this area infiltrate through porous media and fractures to recharge the Navajo Sandstone below. To better quantify the relationships between recharge area/season, residence time within the aquifer, flow paths, and amount of aquifer mixing, an inventory of eight locations (7 springs and one well) within tributaries of the Escalante River headwaters (Sand, Calf, Boulder, and Deer Creeks) was conducted. The hypothesis was that springs could provide insight into the behavior and mechanics of the aquifer system supplying them. Physical and geochemical data from each of these eight locations were gathered and an investigation was made into the nature and behavior of groundwater between its source area and eventual discharge from the groundwater system. Physical data such as discharge rate and water-quality parameters including pH, specific conductance, and dissolved oxygen content were collected in the field, and several water samples at each location were collected for laboratory analysis. Geochemical analyses, including stable (^{18}O and ^{2}H) and radiogenic (^{3}H) isotopes, coupled with physical data provided information about the aquifer system that provides much of the groundwater and surface water to the Escalante River within GSENM.

Methods

Inventories conducted at the eight specified locations followed the protocols developed by Northern Arizona University for the Inventory and Monitoring Network of the National Park Service through cooperative agreement (CA 1200-99-009 Task #NAU-117) (Springer and others 2005). Specific processes for site description, water quality, discharge, and sample collection were followed in accordance with protocols developed in this cooperative agreement. Selection of the spring inventory sites was made jointly by NAU and BLM staff. These selections were based on a need to have a spatial distribution of springs wide enough to cover the extent of several of the Escalante River tributaries within the GSENM, but to be grouped closely enough that useful relationships could be generated (Figure 1, Table 1). All eight of the inventoried locations discharged from the Jurassic Navajo Sandstone, the predominant geologic unit in the study area.

Using the field forms developed by Springer and others (2005), data were collected at each of the eight inventory sites. A site description was conducted, with information on site elevation, geomorphic character, slope, aspect, size, condition, and evidence of use and/or disturbance (Table 2). Photos were taken to supplement the written descriptions. Information was gathered on the geologic unit from which the spring was discharging, as well as any other geologic features in the area that may have had some effect on the spring itself (Table 2). The emergence environment, force flowing mechanisms, and the orifice/spring type were described (Table 2). Spring discharge was measured with the method most appropriate for the conditions at each site. Depending on the rate of discharge and the emergence environment, a volumetric container, weir plate (45°), or flume was used. If discharge emerged from several orifices at the site and coalesced into one channel, the combined flow was measured or estimated. If the discharges remained separate, measurements were made at each orifice and a combined discharge was calculated.

Water-quality parameters were collected on-site using a Troll 9000 multi-parameter water-quality probe (In-Situ Corp., Ft. Collins, CO). Measurements of water temperature, pH, conductivity, and dissolved oxygen content were collected simultaneously. Water samples were collected for laboratory analysis. Major cations and anions, alkalinity, total dissolved solids (TDS), nutrients (nitrate, nitrite, and phosphate) and both stable (^{18}O and ^{2}H) and radiogenic (^{3}H (tritium)) isotopes were analyzed from each of the inventoried locations. Tritium samples were analyzed by the Laboratory of Isotope Geochemistry at the University of Arizona. The remainder of the analytical work was completed by the Colorado Plateau Stable Isotope Laboratory at NAU.

Cation and anion data were plotted on Piper and Stiff diagrams using Rockworks2002 (Rockware, Inc., Golden, CO). The Piper diagram is a form of trilinear diagram with two triangular

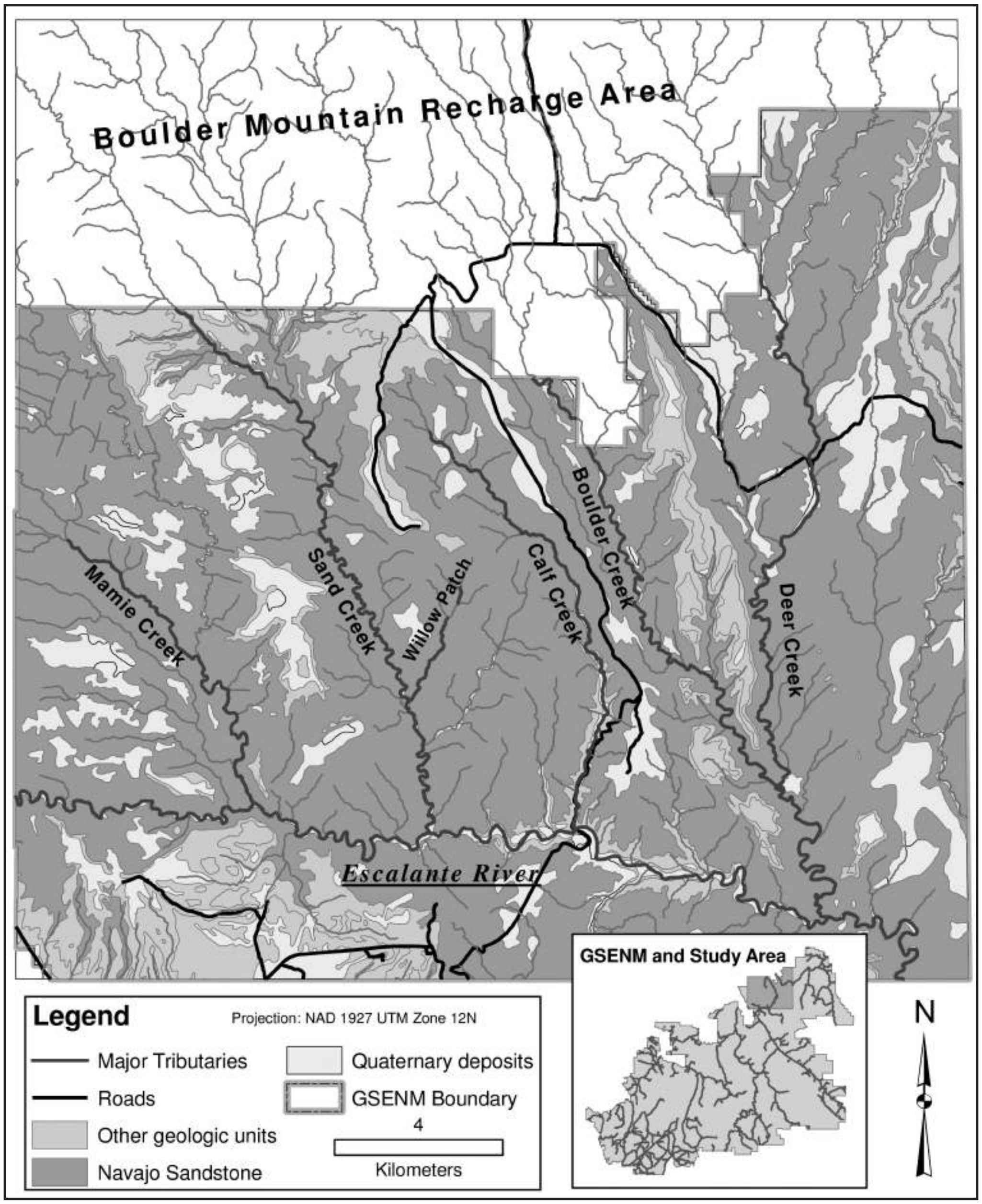

Figure 1. Geology and major tributaries in the GSENM study area.

plots on either side of a 4-sided "diamond" center plot. The sides of the triangles run from 0 to 100 representing the cation (left) and anion (right) concentrations (milliequivalents). Data points in the diamond center plot are located by extending the points in the lower triangles to the corresponding location in the center plot. The Stiff diagram plotting technique uses four parallel horizontal axes extending on each side of a vertical zero axis. Concentrations of four cations (Ca, Na+K, and Mg) are plotted to the left of the zero axis, and four anion combinations (Cl, CO_3+HCO_3, and SO_4) are plotted to the right of the zero axis. The resulting plot is a good indicator of basic water quality and comparison of similar and dissimilar waters.

TDS was plotted against conductivity values measured in the field to quantify a relationship that will assist in estimating TDS concentrations based on field-measured conductivity.

$\delta^{18}O$ and $\delta^{2}H$ values were plotted against Standard Mean Ocean Water (SMOW) and two local water lines representing precipitation at the South Rim of the Grand Canyon (Monroe and others, 2005) and for a series of spring water samples collected on the Colorado Plateau in 2005 (Springer,

Location Name	UTM NAD 27 N	UTM NAD 27 E	Source	Error (m)	Elev. (m)	Elev. (ft)
Upper Calf Creek Spring	4190671	459533	GPS	10	1841	6040
Lower Calf Creek Spring 1 (East)	4186730.6	463149.06	DRG	unknown	1684	5525
Lower Calf Creek Spring 2 (West)	4186711.75	463128.35	DRG	unknown	1682	5519
Sand Creek Shower Spring	4181051	459580	GPS	35	1618	5308
Willow Patch Spring	4186568	460440	GPS	unknown	1734	5689
Dry Hollow Spring	4192283	460867	GPS	15	1873	6144
Deer Creek Spring	4192479	468026	GPS	20	1842	6044
Deer Creek Floodplain Well	4189609.675	468693.8396	BLM Survey	unknown	1744	5720

Table 1. Location data for inventoried springs and well.

Location Name	Slope	Aspect	Site Area	Spring Type	Emergence Substrate	Orifices
Upper Calf Creek Spring	2°	55°	.1 - 1 ha	Hanging Garden	Bedrock (Navajo SS)	Multiple
Lower Calf Creek Spring 1 (East)	50°	180°	100-1000 m^2	Hanging Garden	Bedrock (Navajo SS)	Multiple
Lower Calf Creek Spring 2 (West)	5°	90°	100-1000 m^2	Hanging Garden	Bedrock (Navajo SS)	Multiple
Sand Creek Shower Spring	2°	35°	10-100 m^2	Hanging Garden	Bedrock (Navajo SS)	Multiple
Willow Patch Spring	2°	90°	10-100 m^2	Rheochrene	Sand	Single
Dry Hollow Spring	2°	180°	100-1000 m^2	Rheochrene	Sand	Multiple
Deer Creek Spring	80°	90°	100-1000 m^2	Hanging Garden	Bedrock (Navajo SS)	Multiple
Deer Creek Floodplain Well	NA	NA	NA	NA	NA	NA

Table 2. Site description summary.

et al., 2006). The $\delta^{18}O$ and δ^2H values reported in this text and in the figures represent the average value of two analytical runs.

Tritium data were used to determine the relative age of the spring water. The results allow for qualitative, not quantitative estimates of groundwater age. Tritium is continually generated in the upper atmosphere as a result of cosmic radiation. The base level of tritium content in the atmosphere (and consequently rainwater) increased exponentially during testing of thermonuclear devices between 1955 and 1975 (up to 1000 TU) (Eastoe, 2006). The half-life of tritium is approximately 12.4 years, so relative ages can be estimated based on the presence of tritium as well as the concentration based on the known decay rate (Moran and Hudson, 2005). Tritium in waters precipitated before nuclear testing would have now decayed below laboratory detection limits (0.6 TU). Recent rainwater has tritium concentrations of approximately 5-6 TU (Eastoe, 2006).

Results

Field Data

The eight sites inventoried for this study ranged in elevation from 1,618 to 1,873 meters (5,307 to 6,143 feet) above mean sea level. Site areas were reported in accordance with the NPS field forms (Springer and others 2005) and were categorized as one of several area ranges. The majority of the springs sites inventoried were between 10 and 1000 m^2. Site area was difficult to consistently measure because most of the locations are a system of springs rather than singular orifices. The average site slope was 20.4 degrees, but five of seven spring locations had site slopes of five degrees or less. The average was increased by two steeply-inclined sites (Lower Calf Creek Falls and Deer Creek springs). Site aspects ranged from 35 to 180 degrees, with an average of approximately 103 degrees. Five of the seven springs inventoried were hanging garden-type springs which emerge as a linear array of seeps or drips along contacts between or within geologic units. The presence of these contact springs are often a result of variations in the bedding planes of the eolian deposits of the Navajo Sandstone. Areas with potentially higher silt content such as inter-dune areas between cross-bed sets or the lee sides of dune faces can preferentially locate spring emergence areas (e.g., May et al., 1995). Two of the seven springs were classified as rheochrene springs (Willow Patch and Dry Hollow), which emerge as flowing streams from the orifice. One hanging garden spring (Deer Creek) and one rheochrene spring (Willow Patch) were formed because of fractures located in the bedrock. This distinguishes them from the remainder of the springs which are considered contact springs. All of the inventoried springs emerged subaerially (above ground) and all spring flow was assumed to be gravity-forced (rather than artesian pressure).

Location Name	Discharge (gpm)	Discharge (L/s)
Upper Calf Creek Spring Comlex (west fork before confluence)	456	28.73
Upper Calf Creek (east fork upstream end of seep face near sample point)	37.2	2.34
Upper Calf Creek Complex (downstream end of east fork gaining reach)	256	16.13
Lower Calf Creek Spring 1 (East)	23.5	1.48
Lower Calf Creek Spring 2 (West)	13.4	0.844
Sand Creek Shower Spring	67.8	4.27
Willow Patch Spring	50.2	3.16
Dry Hollow Spring	4.63	0.292
Deer Creek Spring	1.253	0.079
Deer Creek Well	*0.00094	* 0.000059

*Discharge represents pumping rate from well, not spring discharge

Table 3. Discharge data for inventoried springs and well.

In a stark contrast to many of other springs inventoried on the Colorado Plateau (Springer, et al., 2006), the springs inventoried within the study area had minimal to no anthropogenic disturbances such as modifications to the orifice or channel to increase flow or modifications for livestock grazing. The Lower Calf Creek Falls spring location is a popular destination for hikers, but the attraction is the waterfall and there is little evidence of disturbance to the spring systems. The Sand Creek Shower spring has a campsite nearby and is known as a stop for hikers along the Escalante River trail for drinking water and a shower (hence the name). Disturbance to the spring location itself, however, was minimal. The Deer Creek spring is located on private property and is near several irrigated fields and old home sites, but the spring itself had very little evident impact. The remainder of the springs were characterized as "pristine" and had no evidence of disturbance, mostly due to their remote locations.

Discharge rates of the inventoried springs were highly variable (Table 3). It is difficult to compare locations, as a distinction must be made between single orifices and spring complexes. The Upper Calf Creek spring complex, for example, gains from springs in two distinct tributaries, one of which has an approximately 500m-long seeping wall complex. Discharge rates ranged from 44.86 liters per second (L/s) (712 gallons per minute) for the Upper Calf Creek headwaters spring complex to 0.079 L/s (1.253 gpm) at the Deer Creek spring. A stabilized pumping rate of 0.000059 L/s (.00094 gpm) was achieved from the Deer Creek floodplain well (MW-1), but this should not be confused with a spring discharge rate.

Water-quality parameters of temperature, pH, conductivity, and dissolved oxygen were measured at each of the inventory sites (Table 4). Water temperatures ranged from 11.9 to 15.9°C. Five of the eight sampled locations had a relatively neutral pH (6.0-8.0). Three samples were considered moderately basic (pH>8.0). The average pH value was 7.94. Dissolved oxygen content of the sampled sites ranged from 1.58 mg/L to 8.1 mg/L, with an average value of 6.42 mg/L. Conductivity values ranged from 122 µS/cm (Deer Creek Spring) to 726 µS/cm (Sand Creek Shower Spring). Conductivity values were compared to TDS values from the analytical results to develop a relationship between the two values. TDS values ranged from 100 mg/L (Deer Creek Spring) to 530 mg/L (Sand Creek Shower Spring) which mimics the pattern seen in the conductivity results. A linear regression between conductivity and TDS was developed with an equation of TDS=0.713 x Conductivity + 53.5 with an R^2 value of 0.81, making this relationship a relatively useful tool in the study area for field estimating TDS based on conductivity values (Figure 3). Besides the Sand Creek Spring value, all of the sampled locations had TDS concentrations below 500 mg/L, which is the secondary standard for drinking water developed by the U.S. Environmental Protection Agency (EPA).

Geochemical Analyses

Piper and Stiff diagrams (Figures 4 and 5) were created for the cation and anion data (Table 5). Most of the water was of the calcium-sodium, bicarbonate type. Outliers included Sand Creek Shower spring, which had highly elevated chloride content, and Upper Calf Creek spring, which had a

Sample Location Name	Sample Date	pH	Temp C	Cond (us/cm)	DO (mg/L)
Upper Calf Creek Spring	6/1/2006	7.15	13	317	6.2
Lower Calf Creek Spring 1 (East)	6/1/2006	7.4	11.9	149	7.32
Lower Calf Creek Spring 2 (West)	6/13/2006	8.7	15.9	254	7.7
Sand Creek Shower Spring	6/2/2006	8.1	14.3	726.3	8.1
Willow Patch Spring	6/11/2006	7.98	15	163	6.87
Dry Hollow Spring	6/12/2006	7.58	11.9	202	1.58
Deer Creek Spring	6/12/2006	8.65	14.2	122	6.5
Deer Creek Well	6/12/2006	7.95	15.8	285.4	7.11

Table 4. Field water quality parameters for inventoried springs and well.

Sample Location	TDS (mg/L)	Alkalinity (mg HCO3/L)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	NO3 mg N/L	NO2 mg N/L	NH4 mg N/L	PO4 mg P/L
Upper Calf Creek Spring	440	113	14.0	78.4	29.5	4.4	62.3	125.0	0.09	<0.01	0.01	0.25
Lower Calf Creek Spring 1 (East)	160	154	11.3	28.6	8.3	1.8	7.1	8.8	0.14	<0.01	0.03	0.07
Lower Calf Creek Spring 2 (West)	240	154	18.3	32.0	8.3	1.8	13.1	33.9	0.10	<0.01	0.01	0.03
Sand Creek Shower Spring	530	227	34.0	62.5	91.0	7.0	550.8	123.9	0.16	<0.01	0.02	0.02
Willow Patch Spring	140	105	7.0	22.8	5.8	2.1	6.2	12.3	0.37	<0.01	0.02	0.11
Dry Hollow Spring	160	154	7.5	46.0	6.8	1.8	4.0	12.4	<0.01	<0.01	0.03	0.02
Deer Creek Spring	100	74	4.3	20.6	2.1	1.5	13.8	15.1	1.03	<0.01	0.02	0.07
Deer Creek Floodplain Well	240	186	18.8	54.8	5.6	2.7	3.1	44.3	0.02	<0.01	0.04	0.04

Table 5. Cation and anion data for inventoried springs and well.

moderately elevated chloride and sulfate content in comparison to the other waters.

Data for $\delta^{18}O$ and $\delta^{2}H$ were plotted against three standard lines, one representing standard ocean water, one representing meteoric water at the South Rim of the Grand Canyon (Monroe and others, 2005), and one representing values from a set of springs on the Colorado Plateau collected in 2005 (Springer, et al., 2006) (Figure 6). The data points for the Escalante samples scatter closer to the Colorado Plateau spring water line than the other two lines. The probable cause is that stable isotopes in discharging groundwater reflect effects of the partial fractionalization that occurs as a result of water-rock interactions along flow paths. Therefore the Escalante spring water samples would plot closer to this line than one representing ocean or meteoric waters that would have little or no water-rock fractionalization influence. Additionally, many of the springs sampled during the Colorado Plateau inventory of 2005 were in the vicinity of the study area, and include the National Parks/Monuments/Recreation Areas Bryce Canyon, Zion, Cedar Breaks, Capitol Reef, Canyonlands, and Glen Canyon, and therefore may share relatively similar geochemical properties.

The relation between stable isotope concentration and elevation was investigated and it was found that there is no correlation between the elevation of the spring orifice and either $\delta^{18}O$ or $\delta^{2}H$ (R^2 average value 0.069) (Figures 7 and 8). A relation between discharge and $\delta^{18}O$ or $\delta^{2}H$ values has been seen in studies of springs in other areas, but due to the nature of the investigated springs being systems of springs rather than single-point discharges, this relation could not be investigated reliably for the Escalante samples. The data table (Table 6) reports the values for each of the runs as well as the averaged values. $\delta^{18}O$ values ranged from -14.16 to -12.18‰, and $\delta^{2}H$ values ranged from -91.2 to -106.5‰. Generally, winter/high elevation precipitation (especially snow) is more depleted in ^{18}O and ^{2}H than is summer/low elevation precipitation. The more depleted the sample is, the higher the percentage of winter/high elevation recharge the spring water is assumed to have.

While $\delta^{18}O$ and $\delta^{2}H$ values assist in interpreting source location, season, and elevation, tritium (^{3}H) values give an idea of the relative age of the groundwater at the discharge point. Results are reported in tritium units (TU) where 1 TU represents 1 atom of tritium per 10^{18} atoms of hydrogen (Table 6). Tritium values in this study ranged from 0.3 TU to 5.4 TU. Current amounts of tritium in rainwater in the southwest are between 5 and 7 TU (Eastoe, et al., 2004).

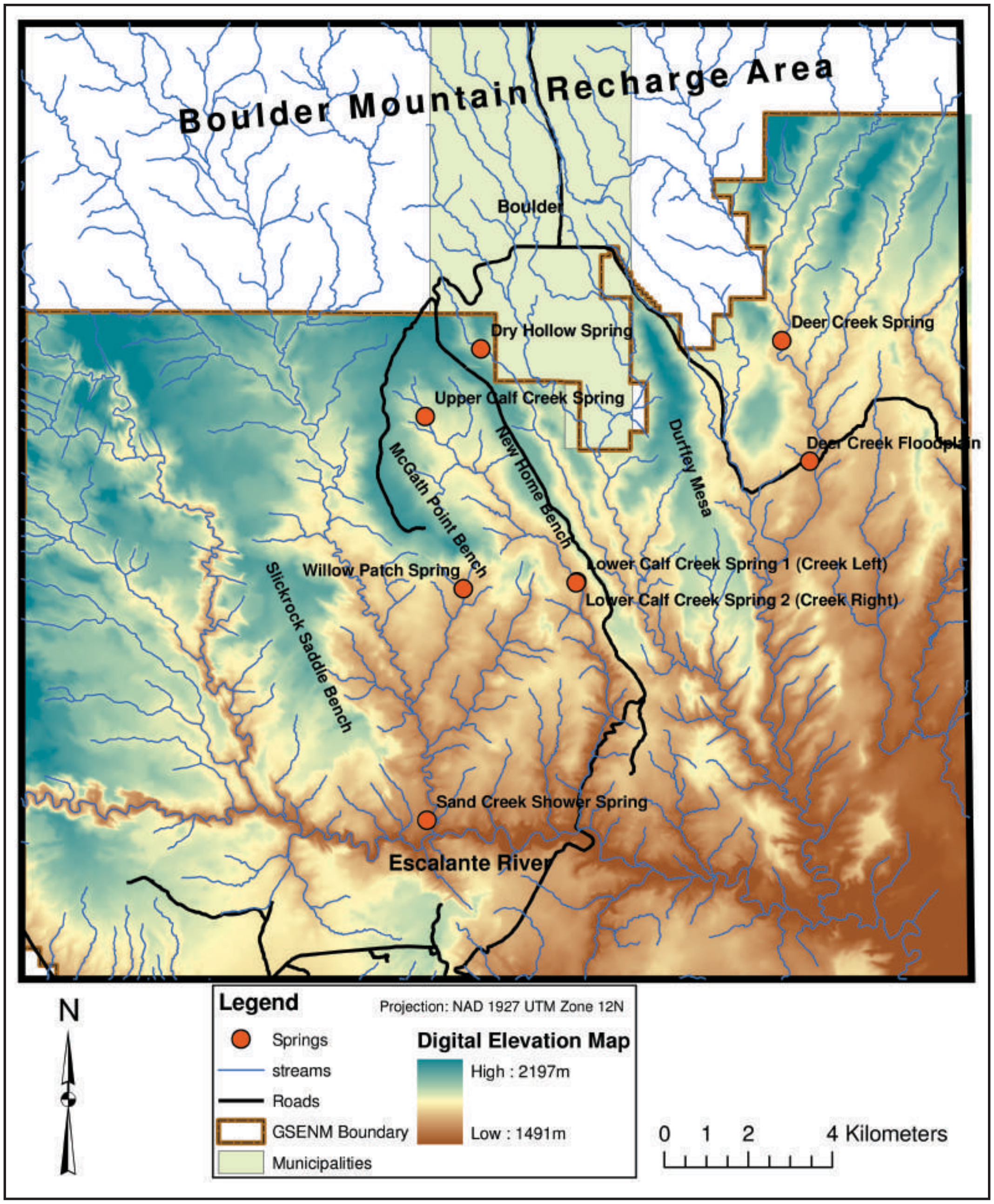

Figure 2. Sample collection sites and elevation shading in the GSENM study area.

Interpretations/Conclusions

Overall Interpretations

The cation and anion data presented in the Piper and Stiff diagrams as well as in Table 5 show relatively similar trends barring the outlier concentrations of chloride in the Sand Creek Shower sample and chloride and sulfate in the Upper Calf Creek sample. These similarities are consistent with a set of springs in relatively close proximity, discharging from the same source rock, and sharing a similar recharge area. The $\delta^{18}O$ and $\delta^{2}H$ values are the most important indicators of the source of the spring water at the inventoried sites. The $\delta^{18}O/\delta^{2}H$ plot (Figure 6) shows that most of the spring locations are quite depleted and represent a predominantly winter/high elevation recharge source. Sand Creek Shower, Lower Calf Creek 2 (west side of creek), and Upper Calf Creek springs were grouped together as the most depleted of the set sampled, and therefore derive most of their discharge from winter/high elevation sources.

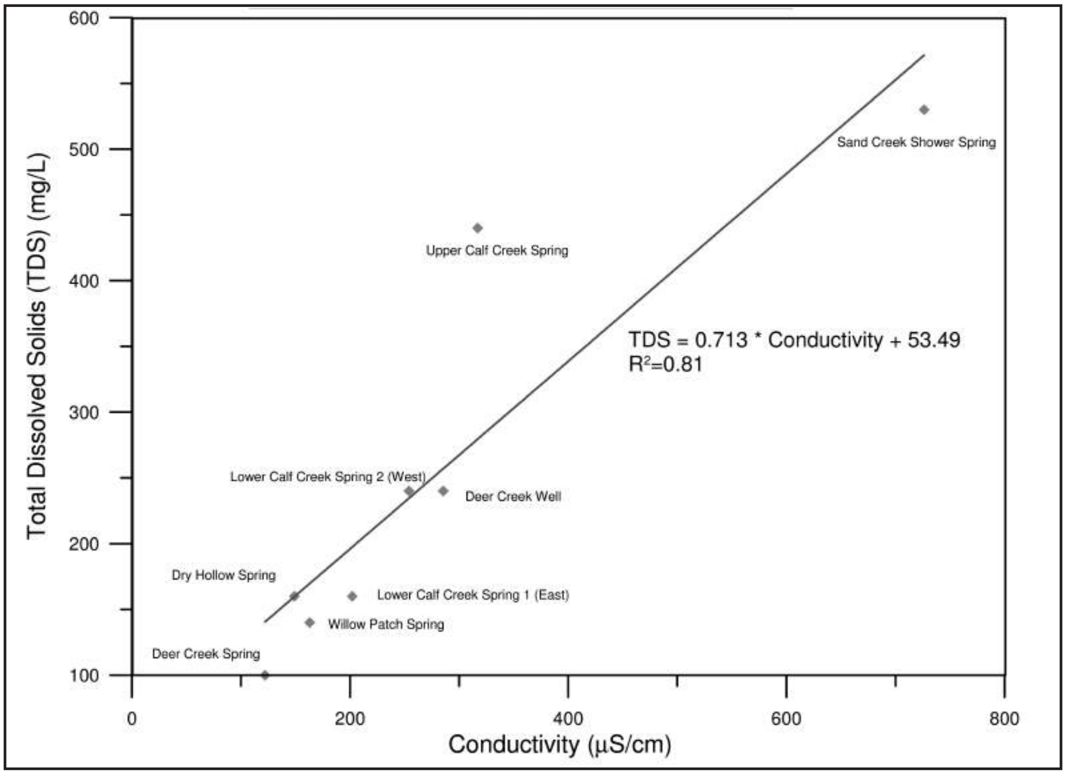

Figure 3. Plot of relationship between TDS and conductivity Escalante Basin groundwater samples.

Tritium concentrations do not have a pattern that would be expected from an area where the majority of recharge water originates from one location. If all groundwater flowed in a generally similar direction at a similar rate, tritium concentrations would be expected to increase away from the recharge area as recharge water precipitated at the height of atmospheric tritium concentration migrated downgradient. Concentrations would then decrease to zero as distance increased from the recharge area and water in the aquifer system was older than the input of nuclear-generated tritium and the amount of natural atmospheric tritium had decayed. The fact that this pattern does not exist supports the hypothesis that there are variations in flow path lengths and differences in the hydraulic conductivity of the Navajo Sandstone in the study area. Variability of this sort was observed when groundwater residence times were calculated for springs discharging from the Navajo Sandstone at Zion NP (Kimball and Christensen, 1996).

It is apparent that canyon-cutting due to overland flow erosion and groundwater sapping in the Escalante River headwaters region is the overriding cause of the location of the springs feeding the tributaries to the Escalante, and may also cause deflection of flow paths of the groundwater being recharged from the high elevations to the north. The cause of the canyons themselves, however, is beyond the scope of this investigation. A lineament and fault analysis of the region would assist in investigating potential regional structural controls on the location and orientation of the canyons in the area. If the canyons in the study area are the locations where groundwater discharges into the Escalante River's tributaries, the un-dissected mesas and benches in the study area may act as pathways to move groundwater from the higher elevations towards the Escalante River before being intersected by canyon cutting. Prominent features such as the benches of Slickrock Saddle, McGath Point, and New Home, and Durffey Mesa may also play a significant role in the flow paths of groundwater in the study area.

Calf Creek Springs

Calf Creek is the only one of the Escalante River tributaries studied that does not have its headwaters in the volcanics/colluvium/ sandstone of the higher elevations north of the study area. The baseflow for Calf Creek is derived entirely from Navajo Sandstone spring discharge within GSENM. The stable and radiogenic isotope as well as the cation and anion data for the three samples

Spring Name	δ^{18}O-run 1	δ18O-run 2	Average	δ^{2}H-run 1	δ^{2}H-run 2	Average	Tritium (TU)	plus/minus
Upper Calf Creek Spring	-13.70	-13.64	-13.67	-105.4	-106.0	-105.7	2.8	0.25
Lower Calf Creek Spring 1 (East)	-12.50	-12.43	-12.46	-99.2	-98.5	-98.9	0.9	0.25
Lower Calf Creek Spring 2 (West)	-14.22	-14.11	-14.16	-105.9	-103.7	-104.8	<0.7 (app .3)	NR*
Sand Creek Shower Spring	-14.05	-13.99	-14.02	-106.6	-106.5	-106.5	1.4	0.31
Willow Patch Spring	-12.64	-11.83	-12.23	-91.0	-91.3	-91.2	5.4	0.3
Dry Hollow Spring	-12.99	-12.97	-12.98	-104.5	-105.0	-104.7	0.9	0.26
Deer Creek Spring	-12.26	-12.11	-12.18	-97.7	-96.7	-97.2	0.8	0.24
Deer Creek Floodplain Well	-12.93	-12.82	-12.88	-98.5	-100.0	-99.3	<0.5	NR*

*NR=Not Reported by lab.
(-12.64), etc. Being re-run by lab.

Table 6. Stable and radiogenic isotope data from inventoried springs and well.

collected in this tributary (Upper Calf, Lower Calf 1 (east) and 2 (west)) point to heterogeneous flow path length and/or hydraulic conductivity as well as level of groundwater mixing depending on which side of the Calf Creek drainage the spring discharges from.

Upper Calf Creek spring is located close to the high elevation recharge area on the volcanic-capped Boulder Mountain in the neighboring Dixie National Forest. δ^{18}O and δ^{2}H values (-13.67 and -105.7‰, respectively) indicate a strong influence of recharge water from Boulder Mountain to the north. Tritium concentration (2.8 TU) indicates relatively young water, with the concentration similar to approximately one tritium half-life based on current meteoric concentrations. The two samples from the Lower Calf Creek Falls springs have interesting results. Lower Calf Creek (1) was collected from the east side of the Calf Creek drainage, while Lower Calf Creek (2) was collected from the west side of the drainage. The two sides differ significantly in virtually every field measurement and laboratory analysis. δ^{18}O and δ^{2}H data for the two sides indicate that the west side of the drainage has a distinctly more depleted signature than the east side. Similar results are seen in the δ^{18}O and δ^{2}H results from Upper Calf Creek spring, which also discharges from the west side of the drainage. The two sides also have a difference in tritium concentration, with the sample collected from the west side having the lowest tritium concentration of all the locations sampled at and estimated 0.3 TU. This concentration was estimated as it was below the laboratory detection limits of 0.6 TU. This tritium value would therefore represent the oldest water collected in this study. The sample from the east side of the drainage had a tritium concentration of 0.9 TU. The differences in these geochemical data as well as other field water-quality parameter and cation/anion data differences between these two locations point strongly to different flow paths in the area between McGath Point Bench and New Home Bench, which border the Calf Creek drainage on the west and east, respectively.

Sand Creek Shower Spring

The Sand Creek Shower spring sample was by far the most distant from the suspected recharge area, as the spring is just a few hundred meters north of the confluence of Sand Creek and the Escalante River, and is also the lowest elevation. This spring was also the most depleted in δ^{18}O and δ^{2}H, indicating that this spring has the highest proportion of high elevation/winter precipitation recharge of the locations sampled. Relatively undissected terrain (compared to the rest of the study area) along the presumed flow path between Boulder Mountain and this spring may allow this water to travel further south before being discharged. In other words, the higher elevations of the Slickrock Saddle Bench extend further south than the area to the east, where the other samples were collected (see Figure 2), allowing groundwater to flow further south without discharging in canyons further north. Tritium was measured at 1.4 TU for the Sand Creek spring. Besides the concentration of the sample from Willow Patch spring, which will be discussed later, only the sample from Upper Calf Creek (close to the recharge area) had a higher tritium concentration. This result points to one of two scenarios. First, the flow path from the recharge area to the spring could be relatively rapid in comparison to others in the area, for this spring is the longest surface distance from the recharge area. Second, some amount of mixing with more recent groundwater could be occurring which is elevating the tritium concentration in

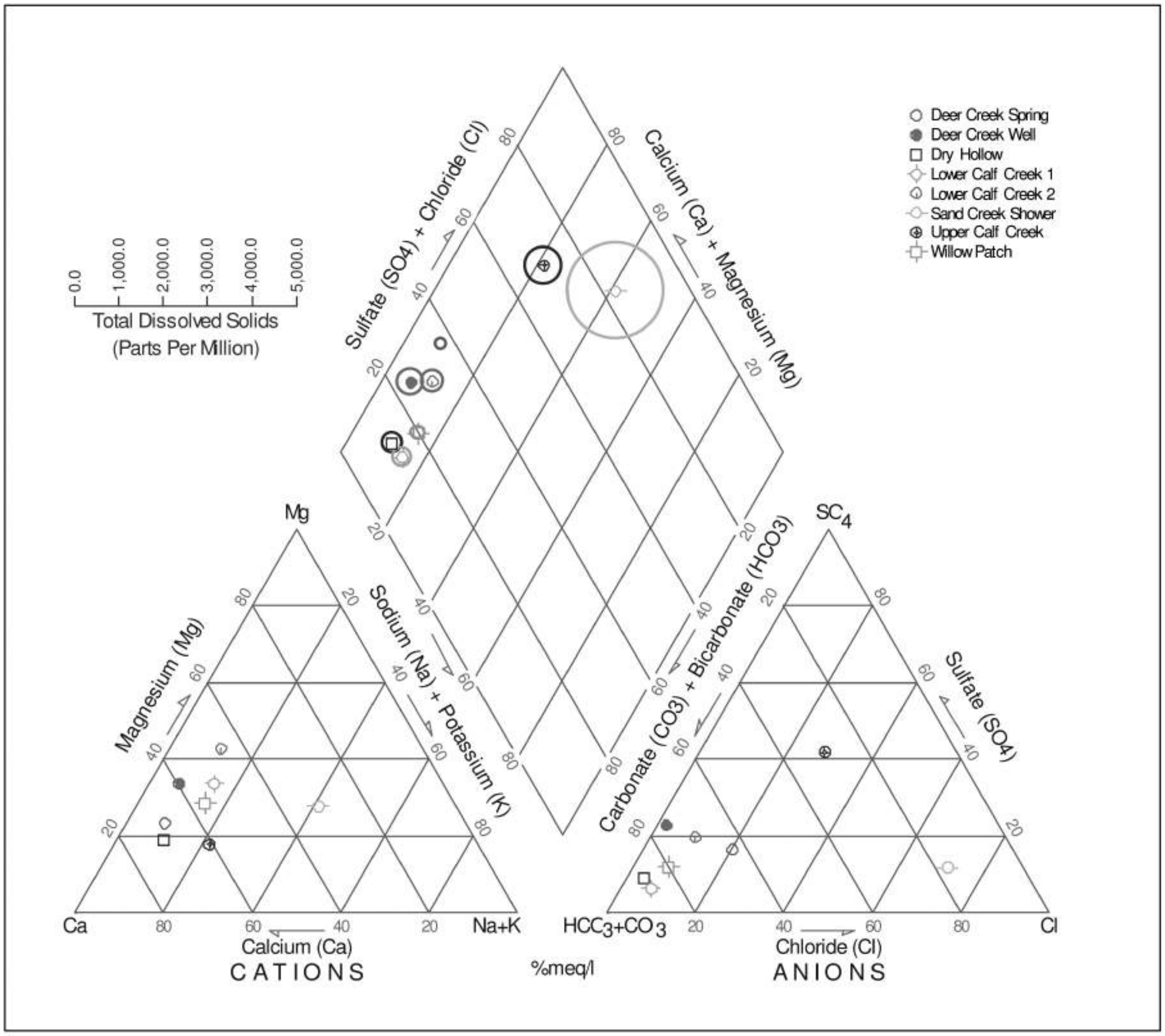

Figure 4. Piper diagram of Escalante Basin groundwater samples.

the spring water. Of these two scenarios, the first seems more plausible, based on the $\delta^{18}O$ and $\delta^{2}H$ data. Sand Creek Shower Spring is the most depleted in $\delta^{18}O$ and $\delta^{2}H$ of all the studied springs. If groundwater mixing were occurring, it is probable that it would be mixing with waters that were less depleted, ultimately skewing the $\delta^{18}O/\delta^{2}H$ plot in the positive direction.

The location of the spring itself is presumed to be influenced by a low hydraulic conductivity lens which may have relatively high silt content. The linear orientation of the spring and the productive discharge distinguish it from several of the other hanging garden type springs visited that often discharge from a thick zone along a wall and seep rather than discharge from one level as sheet flow. The elevated TDS (530 mg/L) and especially conductivity (726 µS/cm) values are dissimilar to all other sampled sites, and support the interpretation that the groundwater has traveled along or has interacted with a material of different geologic composition than the other samples.

Dry Hollow Spring

Dry Hollow spring is located near the upper reaches of Dry Hollow canyon, which is an intermittent tributary of Boulder Creek. $\delta^{18}O$ and $\delta^{2}H$ data plot well below the line representing spring water on the Colorado Plateau. Given that this spring emerges from sand in the drainage rather directly from the bedrock, the position on the plot may be a signature of some evaporation occurring between discharge from the bedrock and discharge from the sand. A tritium concentration of 0.9 TU is the same as the sample from Lower Calf Creek (1), which is farther south but is on the end of the

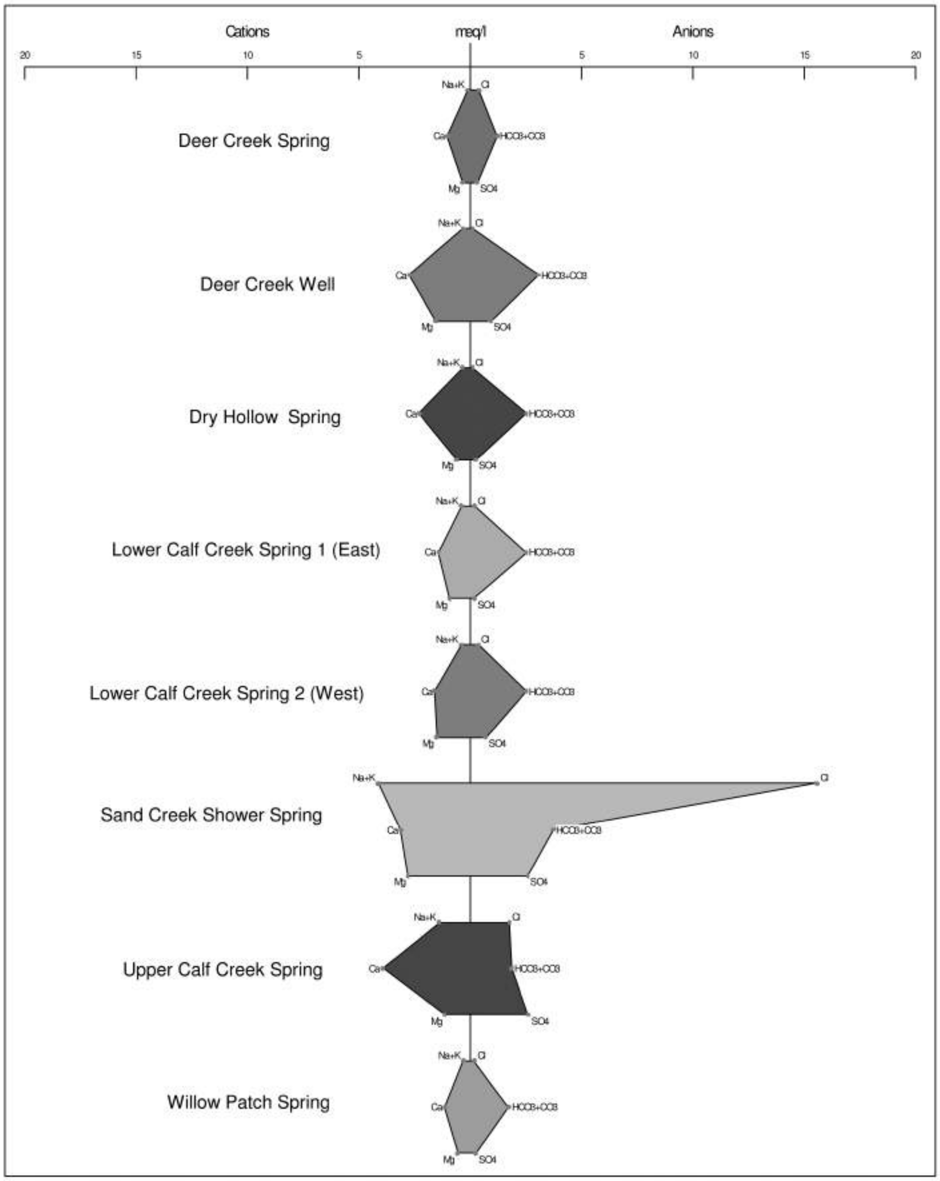

Figure 5. Stiff diagrams of Escalante Basin groundwater samples.

same drainage divide, New Home Bench. In fact, the two locations had very similar pH and temperatures, and identical values for both TDS (160 mg/L) and Alkalinity (154 mg HCO_3/L). These data may suggest a similar flow path supplying groundwater to the two springs. With a discharge rate of 0.292 L/s (4.63 gpm), this spring has little influence on the total input of the studied tributaries of the Escalante River.

Willow Patch Spring

Willow Patch Canyon is a tributary of Sand Creek and enters from the east. Willow Patch Spring was located near the upstream end of the groundwater-fed riparian/wetland area within the canyon. The spring itself provided very little (0.063 L/s, or 1.0 gpm) flow in comparison to the complex of spring discharge that was measured down-channel at 3.16 L/s (50.2 gpm). The spring source was described as a fracture feature, with the fracture more vertical than horizontal. The $\delta^{18}O$ and $\delta^{2}H$ values (-12.23 and -91.2 ‰, respectively) were the least depleted (highest values) of all of the locations sampled. Additionally, the tritium concentration was much higher than any of the other sampled sites, at 5.4 TU. The high tritium concentration is very similar to recent rainwater, and the spring's proximity to the vertical fracture feature in the canyon suggests that the fracture is acting as a conduit for local recharge to enter the

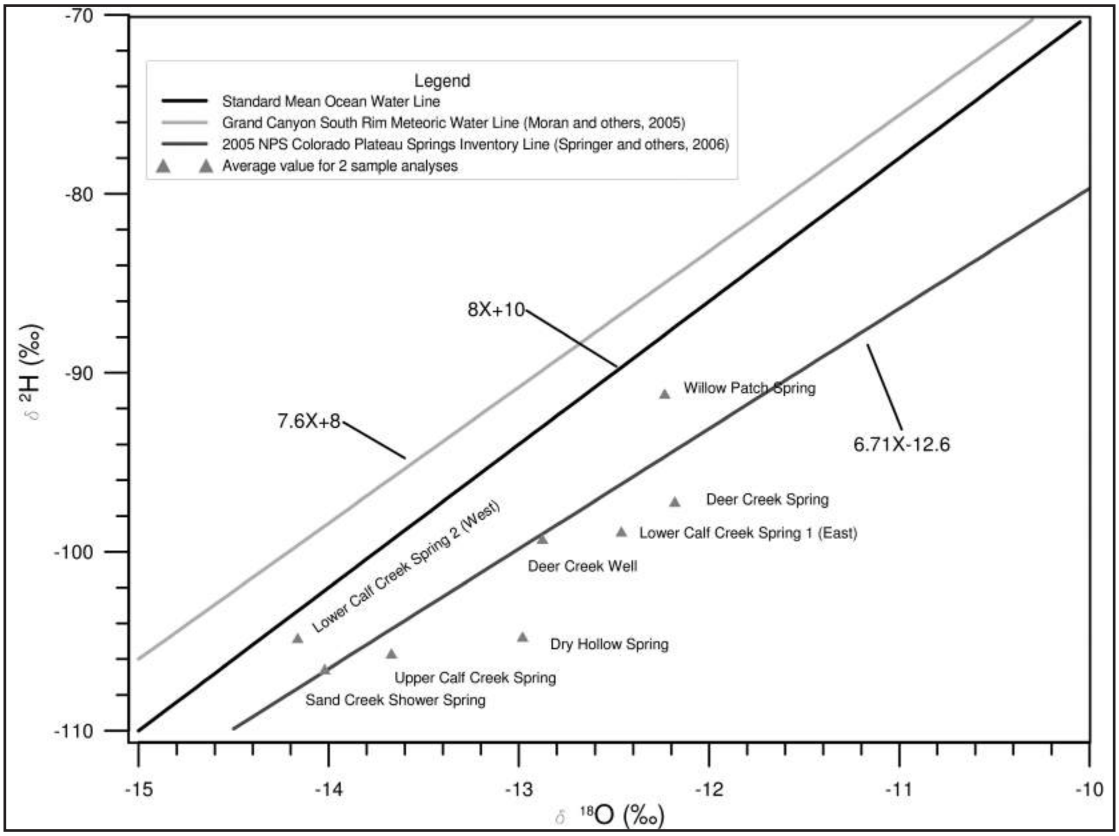

Figure 6. Oxygen/hydrogen isotope analysis of Escalante Basin groundwater samples plotted against oceanic, meteoric and spring water lines.

spring system, providing the elevated tritium concentrations as well as the high $\delta^{18}O$ and $\delta^{2}H$ values from partial mixing of lower elevation-sourced recharge. Based on the implied fracture influence at this spring location, the data is assumed to be not representative of aquifer at that location which is supplying water to the remainder of the spring system in Willow Patch canyon and eventually to Sand Creek.

Deer Creek Spring/ Floodplain Well

The Deer Creek Spring discharges from a wall along the west bank of Deer Creek. The spring emergence is a combination of a bedding plane hanging garden as well as a fracture feature. The fracture runs horizontally parallel to, and is presumed to be influenced by, bedding planes in the Navajo Sandstone. The water issuing from the fracture provides the majority of the discharge at this location. The $\delta^{18}O$ value of -12.18 ‰ is actually less depleted than the Willow Patch Spring sample, but the $\delta^{2}H$ value of -97.2 ‰ is significantly more depleted than the Willow Patch sample. The water sample had a tritium content of 0.8 TU, which is similar to the concentration seen in Dry Hollow as well as that seen in Lower Calf Creek (1). The Deer Creek spring sample was the only one that had a nitrate (NO_3) concentration of over 1.0 mg Nitrogen per Liter (N/L) (1.03). This spring was the only inventoried location that was on private property. Evidence of irrigation on the property and in the surrounding area may have enhanced local recharge in this area and percolated higher nitrate concentrations into the aquifer. This supports an existing hypothesis that there may be a "dome of recharge" in the area around the Town of Boulder from irrigation-sourced infiltration.

The Deer Creek floodplain well (MW-1) was the only non-spring location sampled during the inventory. This shallow (8.2 feet) well was completed in recent alluvium in the Deer Creek floodplain (it extends to, but does not penetrate, the contact with the underlying Navajo Sandstone), and the water had traveled from its presumed bedrock source to the sampling point. The stable isotopes plotted near the center of the eight

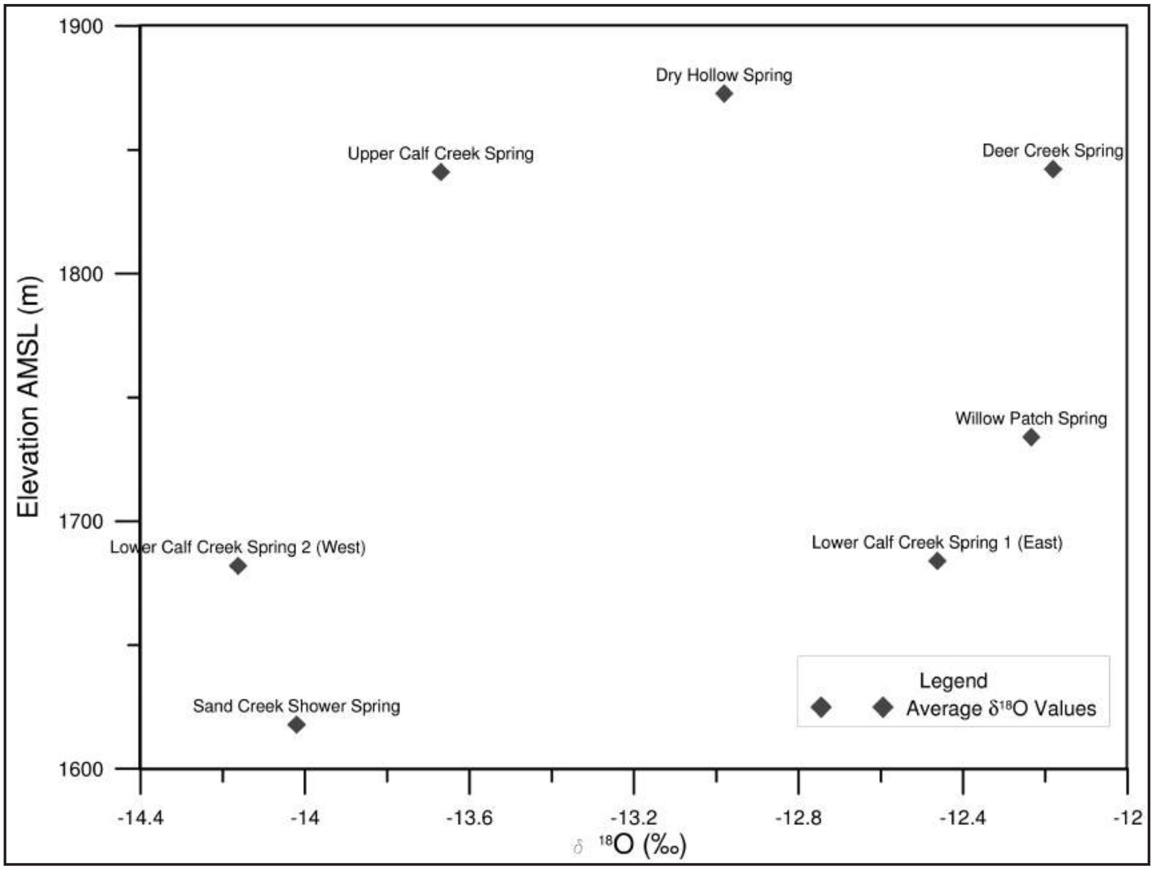

Figure 7. Oxygen-18 concentration vs. elevation Escalante Basin groundwater samples.

samples, and almost directly on the 2005 Colorado Plateau springs line (-12.88 and -99.3‰ $\delta^{18}O$ and $\delta^{2}H$, respectively). The sample was collected using a peristaltic pump. Water quality parameters were measured during pumping until the parameters stabilized and the discharge was considered to be representative of the water in the aquifer rather than the well casing and surrounding filter pack. This location had a low (<0.5 TU) tritium concentration in comparison to most of the rest of the samples analyzed. The stable isotope data point to a potential mixing of Navajo Sandstone derived groundwater with percolated rainwater and perhaps even Deer Creek high-flow/flood water (although the second scenario is unlikely given the known bedrock topography variations in the area), but the tritium concentrations indicate very little to any recent water interactions. A comparison with data from the Deer Creek Spring, the closest sampled spring to the well, show that the well sample is isotopically lighter than the spring sample, is apparently older (based on tritium concentration), and had higher concentrations of most cation and anion components. The differences suggest potential flow path and/or hydraulic conductivity differences between the two areas, although the two locations share the same discharge basin. The Deer Creek well sample displays signatures of a slower flow path in the lower tritium concentration in comparison to the Deer Creek spring sample. The more negative stable isotope values also indicate a higher concentration of high elevation/winter precipitation recharge than the spring sample. The effect of the bedrock fractures at the Deer Creek spring location may result in a faster and more localized flow path, which is supported by the higher tritium concentration and more positive stable isotope values in comparison to the well sample.

Conclusions/ Recommendations

The headwaters of the Escalante River are defined by the input of groundwater into several tributaries, including Sand, Calf, Boulder, and Deer Creeks. The source of this groundwater is the Jurassic Navajo Sandstone, the predominant geologic unit in the study area. Although often described as rather homogeneous, well-sorted eolian sandstone, physical and geochemical evidence point to differences in the transmissivity of this water-bearing unit within the GSENM study area. Based on the results of eight locations inventoried and sampled (7 springs and one well), variations in source location, relative age, and degree of groundwater mixing were identified in the area of these tributaries of the Escalante River. Groundwater discharge from different sides of a drainage divide may be more similar to those from different sides of the same drainage due to flow path differences around existing incised canyons.

The assumptions and interpretations presented in this report are based on single data points for all physical and geochemical parameters discussed. To increase the validity and quality of the results, it is suggested that additional data be collected. Data collected from the other two major tributaries to the Escalante River, Pine and Mamie Creeks, would assist in drawing similar conclusions to ones developed in the study area and therefore support the findings in this report. Winter precipitation geochemical data from the assumed Boulder Mountain recharge area would assist in confirming the source area and better constrain the amount of groundwater mixing occurring between the recharge area and spring orifice. Additionally, in areas where trends are seen along a flow path or on different sides of a drainage, as is seen with the Calf Creek samples, it would be beneficial to collect samples from springs discharging from both sides of the gaining reach between the Upper and Lower Calf Creek falls to confirm or dispute the relationships seen in this report. Finally, the fact that the samples collected for this study are from one time period, relationships and influences based on seasonal differences may not be recognized. In addition to expanding the spatial scope of the investigation, it would be important to expand it temporally as well.

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A Rapid Stream-Riparian Assessment Protocol and its Utility in the Grand Staircase Region, Utah

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ABSTRACT

We developed an improved rapid stream-riparian ecological health assessment protocol for the stream-riparian ecosystems of the Grand Staircase-Escalante National Monument and similar places in the American Southwest. This Rapid Stream-Riparian Assessment Protocol (RSRA http://biology.unm.edu/stacey/RUG-cover.pdf) efficiently evaluates the current ecological health of streams and adjacent riparian areas. The method uses a series of simple but biologically based indicators to measure how much the stream system differs from what would be expected under unaltered (reference) conditions. It incorporates a simple scoring system that can be repeated in different locations and at various times by different people. This method therefore provides the opportunity to develop a regional database that will not only rank the conditions of stream-riparian systems, but also will allow monitoring of stream responses to restoration efforts. We report on citizen-based stream monitoring activities using the RSRA protocol in adjacent watersheds on the Colorado Plateau. These methods are relevant to other watersheds in and around Grand Staircase-Escalante National Monument.

Keywords: citizen-based actions, Colorado Plateau, ecosystem assessment protocols, environmental management, monitoring, multi-disciplinary, riparian, streams

Introduction

Stream-riparian ecosystems, including stream channels, stream margins, fluvial marshes, and terrace meadows, are among the most productive, biologically diverse, and threatened habitats in the American Southwest (Johnson et al. 1985, Knopf et al.1988, Ohmart et al. 1988, Johnson 1991). These stream-riparian habitats consist of areas that are "inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and which, under normal circumstances…support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (U.S. Department of the Interior 1992). They are influenced by various hydrogeologic and geomorphic processes that result from the watershed's historic and contemporary flow patterns, flood disturbance regimes, sediment transport, adjacent upland conditions, and local and regional land management practices (Hupp 1988, Gregory et al. 1991, Malanson 1993, Mitsch and Gosselink 1993, Auble et al.1994, Leopold 1994). As in most arid and semi-arid environments, riparian habitats in the American Southwest support diverse assemblages of distinctive species that are not found in the surrounding uplands. In addition, many upland wildlife species are dependent upon riparian habitats for water, nesting or breeding habitat, and thermal cover during the hotter times of the day (Stacey 1995). Healthy riparian ecosystems are also critical for maintaining overall water quality within the watershed, erosion control, and downstream flood prevention (Gregory et al. 1991).

Despite their great ecological importance and value to human communities, land management activities such as poorly managed grazing, flow regulation and diversion, and channelization have substantially compromised the ecological integrity of many stream, wetland, and riparian ecosystems in the Southwest and throughout North America (Fleischner 1994, Dale et al. 2000). Estimates of riparian habitat loss range from 40 percent to 90 percent among the southwestern states (Dahl 1990), and riparian habitats are considered to be one of this region's most endangered ecosystems (Noss et al. 1995). Although southwestern stream ecosystems have been greatly altered, these systems are highly resilient, and are likely to respond positively and often quickly to improved management practices (e.g., Phillips 1998). As a result, their restoration has become a central focus in both the public and private sectors. Federal agencies, such as the Bureau of Land Management (BLM), Bureau of Reclamation (BR) and the United States Forest Service (USFS), which together control most of the riparian habitat in the Southwest, are under Congressional mandate to manage public lands both for multiple use and long-term ecological sustainability (Federal Land Policy and Management Act of 1976). For example, the Department of the Interior, which oversees the majority of the middle and low elevation federal lands in the Southwest, has adopted a riparian and wetland management policy which establishes an agency goal to: "restore and maintain riparian-wetland areas…and to achieve an advanced ecological status, except where resource management objectives…require an earlier successional stage, thus providing the widest variety of habitat diversity for wildlife, fish, and watershed protection" (U.S. Department of the Interior, USDI, 1991). This policy was adopted in 1991 after DOI determined that only 15 percent of riparian areas in the lower 48 states under USDI management were meeting riparian management objectives (USDI 1991). Most other federal and state agencies, and many private organizations and individuals, have established similar goals or programs for the lands they manage.

Assessment of condition of riparian ecosystems on large land management units, such as those administered by the BLM and USFS, requires a standardized method for determining the current health or functional status of selected stream or river reaches. This is necessary in order to distinguish stream-riparian habitats that are functioning in accord with management program goals from those that require active or passive management. Standardized assessment protocols can help prioritize which reaches and watersheds need the most immediate attention when resources are limited. Standardized assessment protocols also can be used to monitor management and restoration progress through trend analysis.

Many different protocols have been developed to directly or indirectly assess the condition of riparian and associated riverine ecosystems (see examples listed in Stevens et al 2005). Most focus on a particular component or process within the overall system (e.g, channel geomorphology, steamside or greenline vegetation and bank stability, flow regime patterns, aquatic habitat quality, channel morphology, water quality and aquatic invertebrate community composition). While such protocols have helped guide land management decisions, their usefulness has been limited by: 1) their presumption that the component under study is the best "umbrella" to encompass overall ecosystem functionality (e.g., areas rated high in water quality and aquatic invertebrate diversity may not provide suitable terrestrial wildlife habitat, and visa versa); 2) an overly narrow focus; 3) reliance on specialized equipment; and 4) overly time-consuming measurements.

One of the most widely used rapid assessment methods for riparian habitat evaluation at the present time is Proper Functioning Condition (PFC) Assessment, an assessment protocol developed by the U.S. National Riparian Service Team for the BLM. The PFC protocol (USDI 1992, 1993, 1994, 1998) defines proper ecological function primarily in terms of geomorphic processes, and provides a qualitative method to determine the current status of a particular reach. This methodology subsequently has been adopted by other federal agencies charged with managing riparian habitats (e.g., the U.S. Forest Service: Winward 2000). Potential inefficiencies and drawbacks of this method are discussed in Stevens et al. (2005). Geomorphic function is an important but by no means the sole criterion of riparian ecosystem health, and effective assessment should include an efficient, multidisciplinary approach as is described above.

A different approach to riparian habitat evaluation is to examine a broader array of variables that encompass the entire ecosystem. Each variable then serves as an indicator for one or more important components or processes. By focusing on simple yet appropriate measurements and avoiding the use of specialized equipment, these protocols can be completed in a relatively short time and applied to many different reaches in a wide area, a critical requirement for large-scale survey programs. They also can usually be performed by almost any interested individual who has been properly trained and whose work is overseen by an expert. Thus, with proper training, these protocols can become a widely-used and effective riparian ecosystem assessment and monitoring approach, and is an approach useful for educational purposes and generating citizen involvement in land management issues as well (e.g., Fleming and Henkel 2001).

Rapid Stream-Riparian Assessment (RSRA) Protocol

The Rapid Stream-Riparian Assessment (RSRA) protocol was developed by a team of scientists with extensive research and applied experience in the Southwest over the past six years, and is designed to measure the health or functioning condition of riverine and associated river habitats (Table 1). Our goal has been to integrate an efficient, multidisciplinary suite of protocols, while at the same time keeping the method simple enough that it can be completed in the field by trained individuals in a relatively short length of time (3 hours or less). The method is an outgrowth of our work in riparian habitats, including many in the Grand Staircase (Stevens et al. 2005), five seasons of field testing in various watersheds in the Southwest, and independent review of the protocol by numerous academic scientists, agency personnel, environmental activists and concerned citizens. RSRA was designed for use in low and middle elevation reaches of streams in the Southwest where steep ecological gradients create abrupt changes in vegetation between moist riparian soils and upland xeric soil assemblages. However, RSRA is conceptually robust and, with minor adjustments, it should be applicable for use in many other places, such as montane sites or more mesic areas.

RSRA involves quantitative measurements to develop a qualitative assessment of an individual stream-riparian reach. It focuses upon five functional categories of stream-riparian ecosystem characteristics: 1) water quality, 2) stream channel and floodplain morphology, 3) habitat availability and quality for native fish and other aquatic species, 4) vegetation structure and composition (including non-native species), and 5) suitability as habitat for terrestrial wildlife, including threatened or endangered species. Within each of these categories, RSRA evaluates 2-8 variables that reflect overall function and health of the stream-riparian ecosystem.

RSRA uses a quantitative approach to score field indicator variables. Qualitative assessment systems (e.g. PFC) often are based on dichotomous categories, such as “functional/non-functional”, or “yes/no”, which are subjective in interpretation and often difficult to interpret or replicate between site visits, particularly when conducted by different observers. In addition, dichotomous scoring systems do not provide sufficient description of altered ecological processes to indicate whether and which management activities are needed. We used a review of existing assessment and monitoring protocols, our own research experience, and extensive external peer-review to create a 5-point scale for each assessment variable on the checklist (Appendix 1). The maximum score (5 points) is given when that component or process is fully functioning and healthy, and is what would be found in a similar reach that has not been heavily impacted by humans. The minimum score (1 point) is given when the component is completely non-functional or dysfunctional, and incapable of delivering the contributions of that variable to the ecosystem.

Table 1 elucidates some of the principles that guided our selection of the specific variables that are included in the RSRA. For example, RSRA focuses on indicators that not only measure the ability of the system to provide specific functions (e.g., overbank cover that provides shelter and insect drop for fish and other aquatic species), but that also reflect other important ecological processes in the stream-riparian system (e.g., overbank cover also indicates that the channel is well-vegetated and functioning in erosion control during overbank flooding). Should any individual component of the reach be found to be particularly problematic or non-functional, more specialized

Category and Variable	Justification for inclusion in RSRA Assessment
Water Quality: Algal growth	Dense algal growth may indicate nutrient enrichment and other types of pollution which may result in decreased dissolved oxygen inthe water column and affect invertebrates and the ability of fish to spawn.
Water Quality: Channel shading and solar exposure	Sola exposure affects stream temperature and productivity. Decreased streambank vegetation cover, increased channel width, and reduced stream depth increases exposure, raises water temperatures and impactes aquatic life. Native trout usually require cool stream temperatures.
Hydrogeomorphology: Floodplain connection and inundation frequency	Channels that are deeply downcut or incised result in a reduced frequency of overbank flooding into the adjacent flood plain during peak runoff or stream flows. The absence of flooding lowers water tables, reduces nutrient availability in the floodplain, decreases plant gernination, growth and survivorship, and may lead to the loss of riparian vegetation and the invasion of upland species.
Hydrogeomorphology: Vertical bank stability	Steep and unstable vertical banks dominate many southwestern streams, limiting the physical dynamics of aquatic ecosystems and increasing erosion and sediment loads through sloughing off of soils during high flow events. Steep banks may limit wildlife access to water.
Hydrogeomorphology: Hydraulic habitat diversity	Fish and aquatic invertebrate diversity and population health is related to habitat diversity. Features such as oxbows, side channels, sand bars, gravel/cobble bars, riffles, and pools can provide habitat for different species or for the different life stages of a single species.
Hydrogeomorphology: Riparian area soil integrity	Riparian soils reflect existing stream flow dynamics (e.g., flooding), management practices, and vegetation. It affects potential vegetation dynamics and species composition, as well as wildlife habitat distribution and quality.
Hydrogeomorphology: Beaver activity	Beavers are keystone species in riparian systems because they modify geomorphology and vegetation, and reduce variance in water flows and the frequency of floods. Beaver dams and adjacent wet meadows provide important fish and plant nursery habitat.
Fish/Aquatic Habitat Qualifier: Loss of perennial flows	Fish and most aquatic invertebrates require perennial or constant flows to survive. Streams that were originally perennial but are now ephemeral no longer provide habitat for these species unless there are refuges that never dry out (e.g., permanent pools).
Fish/Aquatic Habitat: Pool distribution	Fish use pools, with reduced current velocity and deep water, to rest, feed and hide from predators. Many species use gravel-bottomed riffles to lay their eggs. The number, size, distribution, and quality of pools, and pool to riffle ratios indicate the quality of fish habitat. 1:1 pools to riffle ratios are generally considered to be optimum
Fish/Aquatic Habitat: Underbank cover	Underbank cover is an important component of good fish habitat, used for resting and protection from predators. A number of aquatic invertebrates also use these areas. Underbank cover usually occurs with vigorous vegetative riparian growth, dense root masses, and stable soil conditions.
Fish/Aquatic Habitat: Cobble embeddedness	Low levels of gravel and boulder embeddedness on the channel bottom increase benthic productivity and fish production. The filling of interstitial spaces between rocks with silt, sand, and organic material reduces habitat suitability for feeding, nursery cover, and spawning (egg to fry survival) by limiting space and macroinvertebrate production. Increased embeddedness often reflects increased sediment loads and altered water flow patterns.
Fish/Aquatic Habitat: Diversity of aquatic macro inverte-brates	The density and composition of aquatic invertebrates are strong indicators of stream health, including temperature stresses, oxygen levels, nutrients, pollutants, and sediment loads. Larvae and adult macroinvertebrates provide critical food for fish and other inver-tebrate and vertebrate species in stream-riparian ecosystems.
Fish/Aquatic Habitat: Large woody debris	The amount, composition, distribution and condition of large woody debris (LWD) in the stream channel and along the banks provides important fish habitat for nursery cover, feeding, and protective cover. Streams with adequate LWD generally have greater habitat diversity, a natural meandering shape and greater resistance against high water events.
Fish/Aquatic Habitat: Overbank cover and terrestrial inverte-brate habitat	Overhanging terrestrial vegetation is essential for fish production and survival, providing shade, bank protection from high flows, sediment filtering, and input of organic matter. Overbank cover also is important for terrestrial insect input (drop) into streams, which is a key source of food for fish.
Riparian vegetation: Plant community cover and structural diversity	High cover and structural diversity of riparian vegetation generally indicates healthy and productive plant communities, high plant species diversity and provides direct and secondary food resources, cover, and breeding habitat for wildlife. This affects avian breeding and foraging patterns in particular. Good structural diversity can also reduce flood impacts along banks.
Riparian vegetation: Dominant shrub and tree demography (recruitment and age distribution)	The distribution of size and age classes of native dominant species indicates recruitment success, ecosystem sustainability, and wildlife and fish habitat availability. When one or more age classes of the dominant species are missing, it indicates that something has interrupted the natural process of reproduction and individual plant replacement. In time, this may lead to the complete loss of the species in the area as older individuals die off and are not replaced by younger plants.
Riparian vegetation: Non-native herbaceous and woody plant cover	Non-native plant species profoundly influence ecosystem structure, productivity, habitat quality, and processes (e.g., fire frequency, intensity). Strong dominance by non-native plants may eliminate key attributes of wildlife habitat quality, and may limit ungulate and livestock use.
Riparian vegetation: Mammalian herbivory impacts on ground cover	Ungulate herbivores can affect riparian soils, ground cover, and general ecosystem condition. Utilization levels >10% in riparian zones retard vegetation replacement and recovery. Moderate and higher levels of grazing almost always increase soil compaction and erosion.
Riparian vegetation: Mammalian herbivory impacts on shrubs and small trees	Ungulate herbivores can affect recruitment of woody shrub and trees by clipping or browsing the growing tips of the branches. Con-tinued high levels of utilization lead to the death of the plant and over time can cause the loss of all shrubs and trees in a local area.
Terrestrial Wildlife Habitat: Riparian shrub and tree canopy cover and connectivity	Riparian shrubs and trees often grow in dense patches that provide food, thermal cover, predator protection and nesting or breed-ing habitat for terrestrial wildlife, including many invertebrates, amphibians, reptiles, birds and mammals. These patches are often absent in riparian areas that have been heavily utilized by livestock and other ungulates, or that have been damaged by other human activities. As a result, many native wildlife species may no longer be able to survive in the area. Patches of dense vegetation, both native and exotic, also plays a key role in trapping sediment during periods of over-bank flow.
Terrestrial Wildlife Habitat: Fluvial habitat diversity	Natural processes create a diversity of fluvial landforms, including terraces, bars, oxbows, wet marshes and fluvial marshes, that provide habitats for different species of terrestrial wildlife. Conversely, in a highly degraded system with extensive erosion and downcutting, there may be only a single fluvial form: a straight and single-depth channel and steep banks without vegetation.

Table 1. Field indicators included in the RSRA, and justification for their inclusion. Reprinted from Stacey et al. 2006. Literature citations for justification are included in Stevens et al. (2005).

methods can then be used during subsequent visits to collect additional quantitative information on that variable.

Another important feature of RSRA is that it only measures the current condition of the ecosystem, rather than guessing at an hypothesized future state or successional trend. For example, a particular fluvial geomorphology may lead to a particular potential natural community (e.g., USDI 1993); however, too many other factors come into play during the successional development of riparian vegetation. Stream-riparian systems are highly dynamic and often are subject to disturbances (e.g., large floods) that alter successional trends and make predictions of future conditions difficult. By focusing on current, rather than potential future conditions, RSRA can be used for monitoring and developing baseline conditions, which are useful to measuring future changes in the functional status of the system.

RSRA in the Grand Staircase Region and Colorado Plateau

Previous Studies

Stevens et al. (2005) describes some of the initial "beta testing" of RSRA in four different stream reaches in the Grand Staircase Escalante National Monument. The riparian sites examined included the Gulch, Deer Creek, Harris Wash and Cottonwood Creek. They reported that RSRA documented a much broader array of ecosystem condition issues and more detailed, quantitative information on site conditions than did the BLM's PFC results for those same reaches. While part of the reason for differences may have been the different make-up of survey teams, Stevens et al. (2005) also found substantial differences in the final site scores between the two approaches for those reaches. The PFC assessments conducted by the BLM concluded that three of the four sites (all but Harris Wash), were in proper functioning condition, whereas RSRA indicated that Harris Wash was dysfunctional, Cottonwood Creek and the Gulch were functioning at risk and in need of management attention, and only Deer Creek was functioning properly. These results were primarily driven by field indicators representing fish and terrestrial wildlife habitat, indicators that are underemphasized in the BLM's PFC approach.

One lesson learned from the development of the RSRA protocol was that a simplified version of the protocol was needed that could be easily taught to ranchers, landowners, teachers, conservation activists, agency personal and other interested stakeholders. We held a number of RSRA workshops in Utah and New Mexico with a variety of educated laypeople. These workshops provided feedback that resulted in a streamlined version of the protocol and an easy-to-follow Users Guide (Stacey et al. 2006, http://biology.unm.edu/stacey/RUG-cover.pdf).

On-going Work

The RSRA is presently being used to assess the Mancos River watershed in southwest Colorado. In the summer of 2006, the Mancos Conservation District hired one of the authors (PBS) to survey the entire upper Mancos River using RSRA. Part of this program involved a local stakeholder workshop. County commissioners, Conservation District Staff, National Park Service (Mesa Verde) staff, landowners and other local residents convened in the field to learn about RSRA, how it was used to assess the current health and ecological status of the river, and how to interpret results to prioritize restoration activities. When the Conservation District held a presentation the following winter to share the results of the RSRA surveys, nearly half of the adult population in the town of Mancos turned up at the Community Center to hear about it. Results of the surveys, some of which indicated that the health of the river had declined as it descended in elevation and entered agricultural lands, are provided in Stacey (2007). As a result of the surveys and the enthusiastic endorsement of the watershed communities for using RSRA as a planning and restoration tool, two landowners have offered their riverfront ranches for 2007 restoration demonstration projects.

The Mancos story shows us the utility of RSRA not only for quickly determining the ecological functionality of a river from headwaters to valley floor, but also as a management tool for prioritizing riparian restoration efforts. Therefore, RSRA also may be used as an effective teaching and communication tool because it provides concepts and assessment techniques that a group of stakeholders with mixed (and even contradictory) interests can understand and use to improve the management and restoration of stream-riparian ecosystems.

Future Applications

We hope to repeat the Mancos story in 2008 in a locale much closer to the Grand Staircase region, the Fremont watershed. From its marshy headwaters at 11,000 feet on the Fishlake Plateau, the Fremont River flows south and east through U.S. Forest Service, private, Capitol Reef National Park, state, and Bureau of Land Management lands, flowing though canyonlands desert into the Dirty Devil River at 5,000 feet altitude, and thence into the Colorado River. This route drains a 1,970 square mile watershed. While private lands represent only 5 percent of the watershed area, they occupy approximately 40 percent of the Fremont River's banks.

The Fremont watershed provides an excellent opportunity to use RSRA to integrate public and private concerns and improve stream-riparian habitat management and restoration. An RSRA workshop for local stakeholders is the first step. Ecologists working with a local conservation group plan to systematically assess conditions and conservation/restoration opportunities along the Fremont River and key tributaries using RSRA. Discussions will be held with local residents, including private landowners who want to develop blue-ribbon fisheries and others who wish to purchase key conservation lands and/or establish conservation easements. Much discussion has taken place with federal land managers, including those in Fishlake National Forest regarding the establishment and protection of key riparian reference areas for better understanding the potential functioning of this and other nearby watersheds. RSRA surveys will help identify the best riparian sites for establishment of those reference areas. Thus, RSRA promises to be an invaluable method for bringing diverse stakeholders together with a common language about their watersheds, assessing current conditions, and working toward common goals in river and riparian management.

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Rewind: A Retrospective of Ten Years of Commercial Filming on GSENM, Feedback from and Perceptions of Producers and Directors

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ABSTRACT

Utah has a long history of filmmaking including use of the land for westerns and action adventure films. The Grand Staircase Escalante National Monument hosted various feature film and television crews prior to 1996. This research examined the status and use of the monument for filmmaking since its creation. Ten years of commercial filming permits were examined to determine the type of film and video-making occurring on the monument.

Since its creation as a national monument in 1996 and up to 2006, 24 film, video and photography permits have been issued. Of the 24 permits, 19 were film and video, three were for still photography and two permits were canceled. The number of permits per year ranged from several years with one permit and three years with three permits. The types of productions included eight documentaries including work by National Geographic Explorer, Canada Broadcasting Corporation and a Utah PBS station, KBYU. Two music videos were produced along with two car commercials—one by Honda and one by Subaru. Other productions included a weight loss company promotion, a hunting and guide service promotion and a feature on the legendary missing artist Everett Ruess. The type of the three other productions was not known. The average permit cost was $788.00. Thirteen of the 23 grants or 56 percent indicated a Department of Interior staff member was required to monitor the production. Some of the popular locations included the Paria Movie Set and existing public roads. The production companies came from Canada and the United Kingdom, Utah, Washington, Washington D.C., California, New Mexico, Nevada and several had unclear home offices.

The researcher conducted telephone interviews with several of the producers and GSENM land managers and allowed them to indicate the reasons and purposes for filmmaking on the GSENM:

"We selected Calf Creek Falls for its grandeur and drama. We went in with a very small cast and crew – three dancers, a three person camera crew, so to not impact the environment."

BYU Dance Department
Experimental Dance Video

"(The permit process) is simple. Tell them what you are doing and then there are quite a few forms. You need to provide details and number of people. It was about a two-week process to get approved. We needed insurance forms and then we paid."

Neways International Producer
(weight loss product)

"We produced the film "Vanished – The Story of Everett Ruess." It was my first person narrative and we traced Everett's steps. The film explores how the soul needs wilderness."

Dyanna Taylor - Producer/Director

"Our project meshes well with the Monument designation. We don't have a big impact. We do 3-4 hunts a year at most. We take 4x4 on roads and then hike the rest of the way in for the day, back out for the night. All of our guides are trained in outdoor ethics and know how to protect the land."

Guide/Outfitter
Produces Hunting Videos

"Major motion picture companies will have limited use (of the GSENM) due to their potential impact."

Carol Kershaw
Realty Specialist, GSENM

"The no fly zone and height restriction limits at these places make it difficult for aerial filming. While I agree that they should have rules there so that visitors will not be intruded upon it would be nice if some of the rules were clearer."

Emma Peace
BBC – The Planet Earth

In summary, the GSENM will continue to have spectacular settings for film and video production. Past and potential film producers are aware of and sensitive to continued monitoring and possible additional "red tape" for doing commercial film productions on the monument. Due to the low number of permits issued over the ten-year period, the researcher believes there may be additional small-scale production taking place on the monument without permits. But that is difficult to ascertain. Current policy allows continued use of these public lands for creative film making purposes with the proper permits. New technology with smaller equipment and less obtrusive crews may allow more production without compromising the resource.

Water Quality and Riparian Land Use of Eight Streams and Three Reservoirs in Southern Utah, Outside the Boundaries of GSENM

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Author's note: Data updated through 2007

ABSTRACT

Data are presented from a study of water quality of eight southern Utah mountain streams and three reservoirs measured over the period June, 2004 through December, 2007 (Fig. 1). Seven physical parameters were measured monthly at high, mid, and low elevation zones using a Yellow Springs Instruments multi probe system model 556 (temperature, conductivity, total dissolved solids, salinity, dissolved oxygen, pH, and oxygen reduction potential). Nitrates and phosphates were measured using the Hach model 890 colorimeter. Stream velocity was measured using the model FP 101 Global Water Corporations Flow Probe.

Using salinity as an indicator of water quality, five of the eight streams had lower salinity (0.07 ppt) at high elevations and higher salinity (0.20 ppt) at low elevations. This suggests that minerals are being picked up and suspended as the stream goes down in elevation. Three streams had higher salinity at high elevations (0.21 ppt) and lower salinity downstream (averaged 0.14 ppt). These have headwaters in a cattle pasture, a campground, or an elk and deer wildlife meadow, suggesting the influence of land use practices.

Using phosphate as an indicator of water quality, four of the streams had lower phosphate (average of 0.19 ppm) at high elevations and higher phosphate 0.283 ppm at the low elevations. This suggests a stereotypical "pristine mountain stream" where nutrients are picked up from substrate or riparian runoff as the stream goes down in elevation. Four streams, however, had higher phosphate (average of 0.362 ppm) at high elevations and lower phosphate (0.239 ppm) at low elevations. The headwaters of these streams are in a cattle pasture, or a campground, and two are in relatively pristine, undisturbed watersheds.

Water quality data from the three mountain reservoirs are presented in Fig. 3 (Panguitch Lake, Red Creek Reservoir, and Navaho Lake). Phosphate and Nitrate concentrations were greater in Red Creek and Navaho reservoirs (phosphate 0.31 and 0.28 ppm, respectively and nitrate 0.19 and 0.22 ppm, respectively) than Panguitch Lake (phosphate 0.19 ppm and nitrate 0.09). Salinity, Electrical Conductivity, and other physical parameters, however, were very similar among the three reservoirs. Future studies should focus on nutrient funoff issues of these reservoirs.

pH values compared among the 8 streams were all alkaline (above pH 7). Whole creek (all elevations) averages ranged from 7.63 to 8.14 (Fig. 2). Within each stream, pHs were higher at upper elevations in 5 of the eight streams.

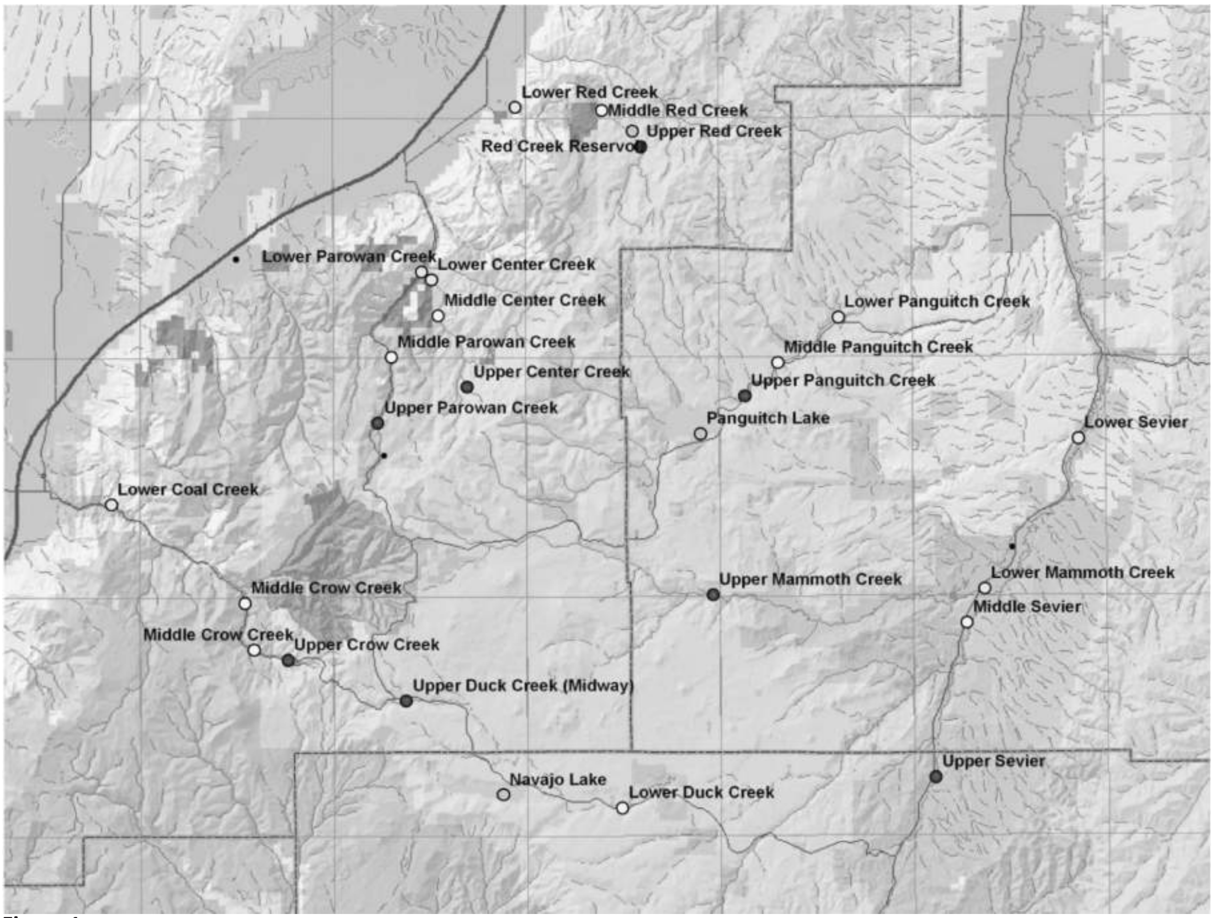
D.O. readings were always above the ambient air saturation levels. Whole creek averages (all elevations) ranged from 76.8% to 85.3% saturation (Fig. 2) and 9 to 11 ppm D.O. There was a highly negative correlation of elevation with % D.O. saturation. Without exception, D.O. saturations and concentrations were lower at high elevations and higher at low elevation, probably due to high velocity and rocky stream beds.

Electrical Conductivity, Total Dissolved Solids, and Salinity. Whole creek (all elevations) EC ranged from 117 to 337 micro Semens per cm (Fig. 2). EC values were lower at higher elevations except two creeks (Sevier River and Coal Creek) that had highest EC at high elevations. The two streams with high EC values at higher elevations originate in a cattle pasture and U.S.F.S. campground, respectively.

Total Dissolved Solids (TDS) and Salinity showed the same trend of lower readings at higher elevations except in the two streams that originate in a cattle pasture and a Forest Service Campground.

Stream velocity or speed (mph) was positively correlated to EC, TDS, and Salinity with lower speed correlated to lower EC, TDS, and Salinity readings, i.e. streams had slower speeds at higher elevations and lower EC, TDS, and Salinity.

Plant nutrients **Nitrogen and Phosphorus** (as Nitrate or Phosphate) in whole creek (all elevations) averaged from .22 to .344 ppm Phosphate and .08 to .30 ppm Nitrates (Fig. 2). Four streams had lower Phosphates at higher elevations and 4 streams had higher PO4 at upper elevations. Likewise with Nitrates, 4 streams showed lower NO3 at higher elevations and 4 streams had higher NO3 at higher elevations. These mixed messages suggest the need for further study of the roles of substrate vs. land use as determinants of water quality of these small mountain streams.


Lower Red Creek
Middle Red Creek
Upper Red Creek
Red Creek Reservoir
Lower Parowan Creek
Lower Center Creek
Middle Center Creek
Middle Parowan Creek
Upper Center Creek
Upper Parowan Creek
Lower Panguitch Creek
Middle Panguitch Creek
Upper Panguitch Creek
Panguitch Lake
Lower Sevier
Lower Coal Creek
Middle Crow Creek
Middle Crow Creek
Upper Crow Creek
Upper Mammoth Creek
Lower Mammoth Creek
Middle Sevier
Upper Duck Creek (Midway)
Upper Sevier
Navajo Lake
Lower Duck Creek
Figure 1.

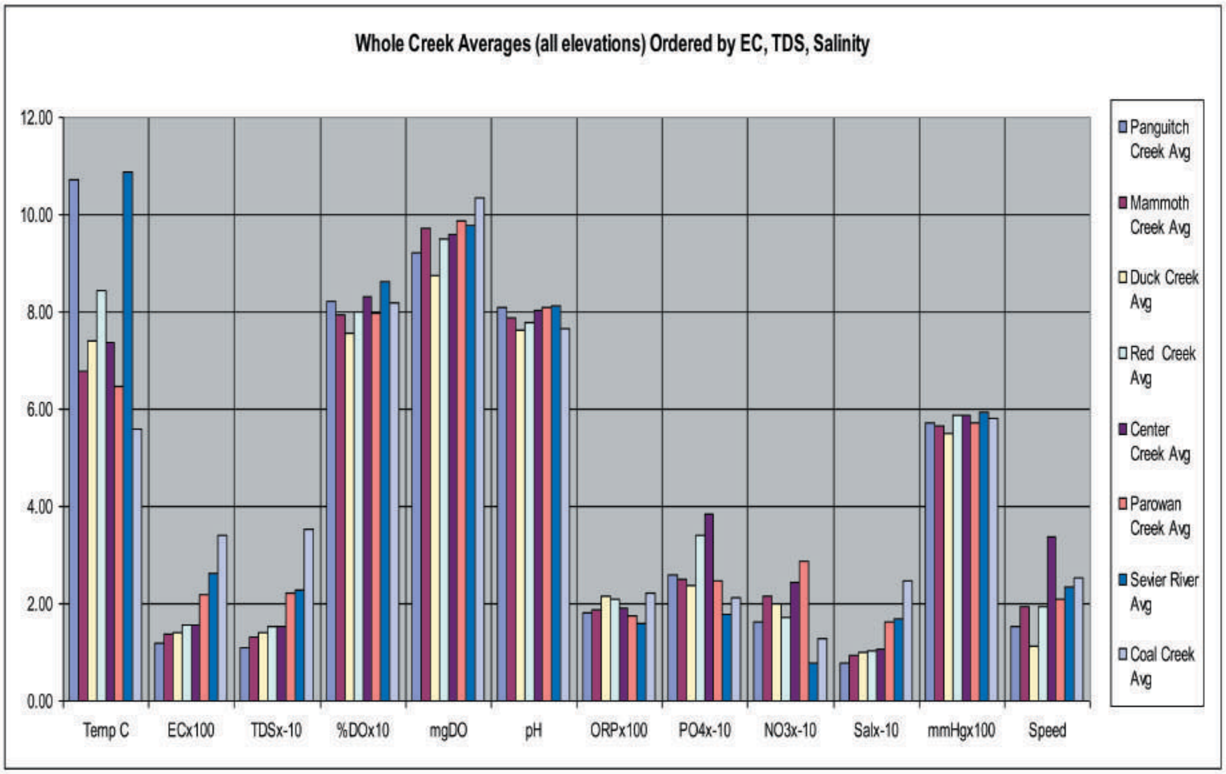


Figure 2.

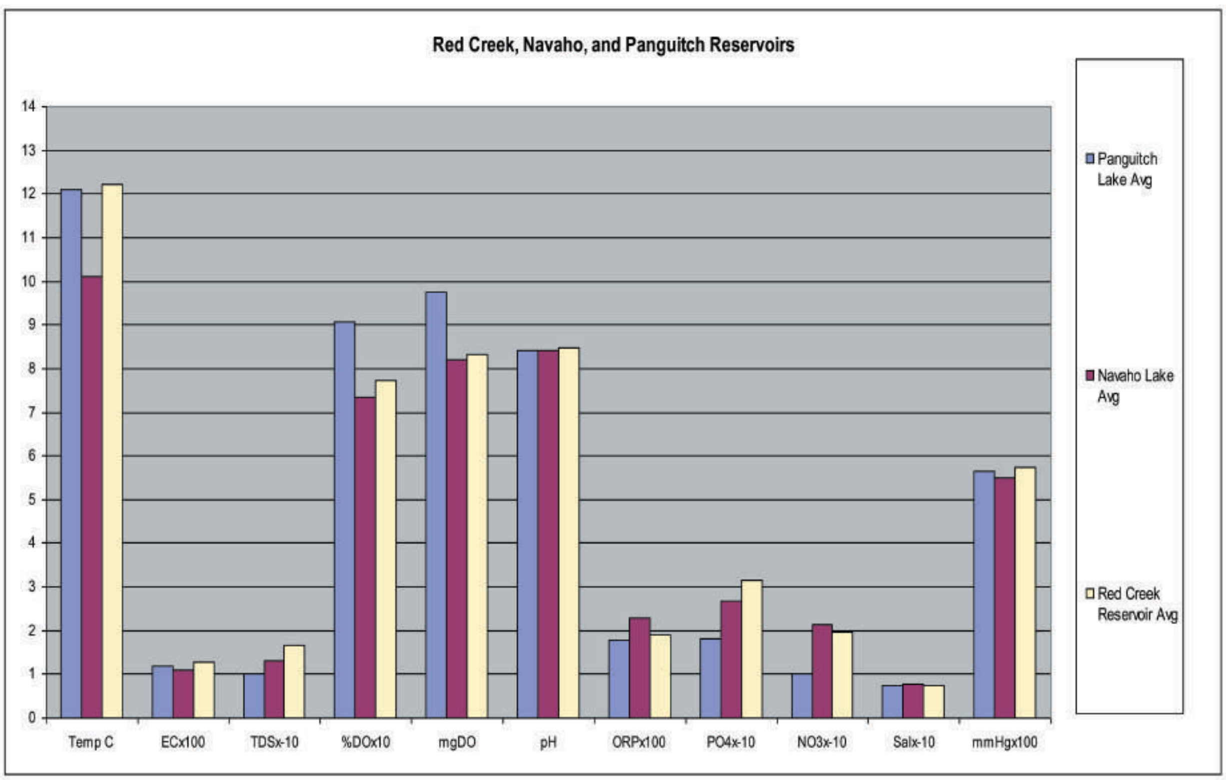


Figure 3.

Utah BLM's Celebration of the Antiquities Act Centennial (1906-2006)

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ABSTRACT

The Utah Bureau of Land Management (BLM) is joining other federal, state, and private organizations in celebrating 100 years of historic preservation since the passage of the Antiquities Act. Numerous statewide events and projects are planned. These projects bring together partners, including local communities, research organizations, avocational groups, Native Americans, and the tourism community. The BLM's celebration of the Antiquities Act Centennial reiterates the agency's commitment to cultural resource stewardship. Join the Adventure: Honor the Past, Shape the Future is BLM's central message to the public, and the agency's duty as well.

Sleuthing Epicenter Direction from Seismites: Cretaceous Wahweap Formation, Cockscomb Area, Grand Staircase-Escalante National Monument, Utah

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Editor's note: This project resulted in the following publication:

Hilbert-Wolf, Hannah L., Edward L. Simpson, Wendy S. Simpson, Sarah E. Tindall, and Michael C. Wizevich. 2009. "Insights into syndepositional fault movement in a foreland basin; trends in seismites of the Upper Cretaceous, Wahweap Formation, Kaiparowits Basin, Utah, USA." *Basin Research* 21(6): 856-871.

ABSTRACT

Within the Cockscomb Area of Grand Staircase-Escalante National Monument, Utah, the upper and capping sandstone members of the Upper Cretaceous Wahweap Formation contain discrete zones of soft sediment deformation. Examination of types and distribution of the soft sediment deformation indicates that these features satisfy the rigorous criteria for seismic origin. These criteria include 1) laterally continuous horizons, 2) deformation horizons separated by nondeformed zones, 3) soft sediment deformation structures that have experimental analogs, 4) association with a seismically active area (sediments were deposited during faulting), and 5) geographic variation in intensity.

Detailed examination of seismite fold axes shows a systematic change in orientation from north to south. Mean orientations of fold axes rotate progressively from east to south along the Cockscomb. A qualitative intensity scale of soft sediment deformation based on field observations and experimental data from literature was constructed. This scale varies from 0 (no deformation) to 5 (intense disruption of stratification). From north to south, a progressive change from 5 to 2 was observed along the contact between the upper and capping sandstone members.

When the trends of fold axes coupled with changes in intensity ratings are plotted on a map of the field area, they indicate a radial pattern whose point of origin is north and west of the study area. Assuming the fold axes are parallel to the direction of propagation, this pattern is consistent with the geometrical spreading of earthquake waves originating from epicenters north and west of the study area.

Keywords: Cockscomb, Upper Cretaceous, Wahweap Formation, sediment deformation, seismite fold axes

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Sequence Stratigraphy and Controls on Fluvial Architecture in the Straight Cliff Formation, Southeastern Utah

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ABSTRACT

Preliminary results suggest that the John Henry Member of the Straight Cliffs Formation in the Kaiparowits Plateau (south central Utah) contains two additional sequence boundaries than formerly thought. Previous interpretations describe only one sequence boundary within the John Henry Member located near its base. It was identified by a change in facies; specifically fluvial overlying lower shoreface. In the eastern Kaiparowits Plateau, this sequence boundary is represented by a correlative conformity composed of shoreface packages. A similar pattern is seen in the middle of the John Henry Member; estuarine facies overlie shoreface deposits that transition into consecutive lower shoreface packages towards the east. This is potentially an additional sequence boundary within the John Henry. Secondly, the uppermost sandstone unit within the John Henry appears to be nonmarine in nature along the eastern border of the Kaiparowits Plateau, as evidenced by channel lags and high-angle trough cross-beds. This interpretation differs from previous analyses that interpret this unit as a marine sandstone. If this sandstone body is in fact fluvial, it overlies marine sands and muds and thus represents a second additional sequence boundary within the John Henry Member. Ongoing work will verify these findings and trace these and previously interpreted sequence boundaries into nonmarine strata. The Straight Cliffs preserve the transition between these two paleoenvironments and correlations will be made by physically walking out surfaces within dip-oriented canyons. Moreover, microanalyses of mudstones and coals within the nonmarine are anticipated in order to obtain more precise locations of nonmarine sequence boundaries. These data will provide an extremely accurate correlation between these two environments; enabling an analysis of the relationship between sea level and fluvial architecture as well as an assessment of existing fluvial architecture models.

Keywords: Straight Cliffs Formation, John Henry Member, sequence stratigraphy, fluvial architecture

Biogeochemical and Ecological Impacts of Livestock Grazing in Semi-arid Utah Grassland and Pinyon-Juniper Landscapes

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ABSTRACT

Domestic livestock grazing is one of the most extensive land-use practices in the intermountain west. Effects of historical livestock grazing on the soil fertility of the region are difficult to assess because few large ungrazed areas remain. In this study, we utilize relict and currently grazed grassland and pinyon-juniper landscapes in order to assess differences in soil fertility. We specifically compare soil organic carbon and nitrogen content. We use these variables because soil organic matter influences cation exchange capacity (CEC), aggregate stability, and the energy supply central to the release and availability of nutrients for primary production and is therefore a key indicator of soil quality. Additionally, for grassland sites we assess differences in plant cover and the spatial distribution of soil resources. Results show that grazed grasslands have 50 percent less soil organic carbon and nitrogen than relic. This lower amount of soil organic carbon in grazed grasslands is also associated with 38% less vegetation cover and the clustering of soil resources. As a result grazed grassland areas have a greater proportion of bare ground than relict and this bare ground is more nutrient depleted. In pinyon-juniper landscapes differences in tree canopy and soil organic carbon content is difficult to assess due to variability in tree age. Soil organic carbon content is similar among relic and grazed sites when tree age structure is not taken into account; however, when tree age is accounted for relic landscapes have significantly more understory soil organic carbon.

Keywords: livestock grazing, historic, soil fertility, cation exchange capacity

Toad Population Dynamics in Altered Semi-arid Riparian Systems: Differences in Size Class Distribution as an Indication of Chronic Riparian/Aquatic Ecosystem Disturbance

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Laura J. Lingenfelter

Sena Nissen

Renata Platenberg

Kim Plengemeier

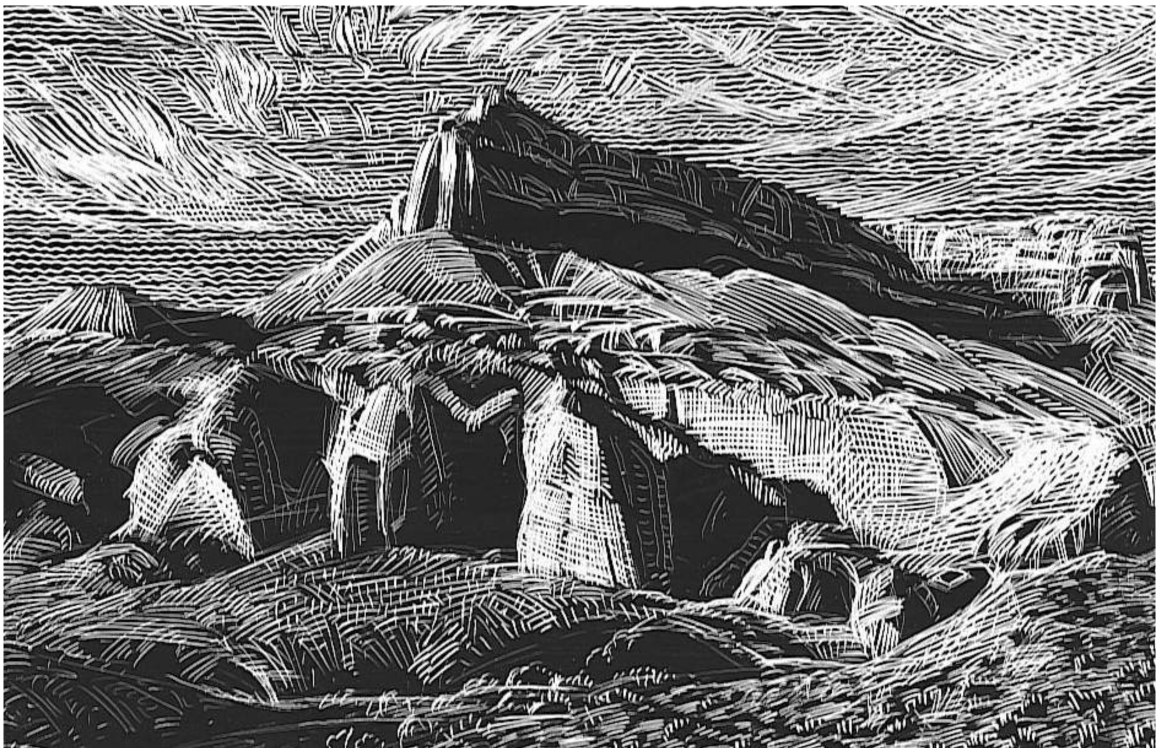
Matt Van Scoyoc

ABSTRACT

Specific land uses, such as off-road vehicle (OHV) use or livestock grazing and trampling of riparian zones can affect amphibian populations by altering habitat quality as well as through direct interactions (e.g., crushing of individuals by vehicles or livestock). Activities that affect reproductive success can yield a population size structure that differs from an area without that activity. Trampling of eggs by cattle or OHVs may result in fewer metamorphs available for recruitment into the adult population. We are surveying populations in different parts of Salt Creek Cañon, Canyonlands National Park and areas in the Grand Staircase-Escalante National Monument where recent changes in management could affect reproductive success of toads. We predicted that more metamorphs would enter populations with fewer disturbances of eggs and tadpoles; size structure would show more small toads. Results of surveys and pitfall traps from 2000-2002 will be presented. Analysis of the toad population size class distributions in the two riparian systems may indicate chronic riparian ecosystem disturbance.

Keywords: toads, semi-arid riparian systems, diversity, ecosystem disturbance

Additional Material



Establishment of the Grand Staircase-Escalante National Monument by the President of the United States of America
September 18, 1996
A PROCLAMATION

The Grand Staircase-Escalante National Monument's vast and austere landscape embraces a spectacular array of scientific and historic resources. This high, rugged, and remote region, where bold plateaus and multi-hued cliffs run for distances that defy human perspective, was the last place in the continental United States to be mapped. Even today, this unspoiled natural area remains a frontier, a quality that greatly enhances the monument's value for scientific study. The monument has a long and dignified human history: it is a place where one can see how nature shapes human endeavors in the American West, where distance and aridity have been pitted against our dreams and courage. The monument presents exemplary opportunities for geologists, paleontologists, archeologists, historians, and biologists.

The monument is a geologic treasure of clearly exposed stratigraphy and structures. The sedimentary rock layers are relatively undeformed and unobscured by vegetation, offering a clear view to understanding the processes of the earth's formation. A wide variety of formations, some in brilliant colors, have been exposed by millennia of erosion. The monument contains significant portions of a vast geologic stairway, named the Grand Staircase by pioneering geologist Clarence Dutton, which rises 5,500 feet to the rim of Bryce Canyon in an unbroken sequence of great cliffs and plateaus. The monument includes the rugged canyon country of the upper Paria Canyon system, major components of the White and Vermilion Cliffs and associated benches, and the Kaiparowits Plateau. That Plateau encompasses about 1,600 square miles of sedimentary rock and consists of successive south-to-north ascending plateaus or benches, deeply cut by steep-walled canyons. Naturally burning coal seams have scorched the tops of the Burning Hills brick-red. Another prominent geological feature of the plateau is the East Kaibab Monocline, known as the Cockscomb. The monument also includes the spectacular Circle Cliffs and part of the Waterpocket Fold, the inclusion of which completes the protection of this geologic feature begun with the establishment of Capitol Reef National Monument in 1938 (Proclamation No. 2246, 50 Stat. 1856). The monumentholds many arches and natural bridges, including the 130- foot-high Escalante Natural Bridge, with a 100 foot span, and Grosvenor Arch, a rare "double arch." The upper Escalante Canyons, in the northeastern reaches of the monument, are distinctive: in addition to several major arches and natural bridges, vivid geological features are laid bare in narrow, serpentine canyons, where erosion has exposed sandstone and shale deposits in shades of red, maroon, chocolate, tan, gray, and white. Such diverse objects make the monument outstanding for purposes of geologic study.

The monument includes world class paleontological sites. The Circle Cliffs reveal remarkable specimens of petrified wood, such as large unbroken logs exceeding 30 feet in length. The thickness, continuity and broad temporal distribution of the Kaiparowits Plateau's stratigraphy provide significant opportunities to study the paleontology of the late Cretaceous Era. Extremely significant fossils, including marine and brackish water mollusks, turtles, crocodilians, lizards, dinosaurs, fishes, and mammals, have been recovered from the Dakota, Tropic Shale and Wahweap Formations, and the Tibbet Canyon, Smoky Hollow and John Henry members of the Straight Cliffs Formation. Within the monument, these formations have produced the only evidence in our hemisphere of terrestrial vertebrate fauna, including mammals, of the Cenomanian-Santonian ages. This sequence of rocks, including the overlaying Wahweap and Kaiparowits formations, contains one of the best and most continuous records of Late Cretaceous terrestrial life in the world.

Archeological inventories carried out to date show extensive use of places within the monument by ancient Native American cultures. The area was a contact point for the Anasazi and Fremont cultures, and the evidence of this mingling provides a significant opportunity for archeological study. The cultural resources discovered so far in the monument are outstanding in their variety of cultural affiliation, type and distribution. Hundreds of recorded sites include rock art panels, occupation sites, campsites and granaries. Many more undocumented sites that exist within the monument are of significant scientific and historic value worthy of preservation for future study.

The monument is rich in human history. In addition to occupations by the Anasazi and Fremont cultures, the area has been used by modern tribal groups, including the Southern Paiute and Navajo. John Wesley Powell's expedition did initial mapping and scientific field work in the area in 1872. Early Mormon pioneers left many historic objects, including trails, inscriptions, ghost towns such as the Old Paria townsite, rock houses, and cowboy line camps, and built and traversed the renowned Hole-in-the-Rock Trail as part of their epic colonization efforts. Sixty miles of the Trail lie within the monument, as does Dance Hall Rock, used by intrepid Mormon pioneers and now a National Historic Site.

Spanning five life zones from low-lying desert to coniferous forest, with scarce and scattered water sources, the monument is an outstanding biological resource. Remoteness, limited travel corridors and low visitation have all helped to preserve intact the monument's important ecological values. The blending of warm and cold desert floras, along with the high number of endemic species, place this area in the heart of perhaps the richest floristic region in the Intermountain West. It contains an abundance of unique, isolated communities such as hanging gardens, tinajas, and rock crevice, canyon bottom, and dunal pocket communities, which have provided refugia for many ancient plant species for millennia. Geologic uplift with minimal deformation and subsequent downcutting by streams have exposed large expanses of a variety of geologic strata, each with unique physical and chemical characteristics. These strata are the parent material for a spectacular array of unusual and diverse soils that support many different vegetative communities and numerous types of endemic plants and their pollinators. This presents an extraordinary opportunity to study plant speciation and community dynamics independent of climatic variables. The monument contains an extraordinary number of areas of relict vegetation, many of which have existed since the Pleistocene, where natural processes continue unaltered by man. These include relict grasslands, of which No Mans Mesa is an outstanding example, and pinon-juniper communities containing trees up to 1,400 years old. As witnesses to the past, these relict areas establish a baseline against which to measure changes in community dynamics and biogeochemical cycles in areas impacted by human activity. Most of the ecological communities contained in the monument have low resistance to, and slow recovery from, disturbance. Fragile cryptobiotic crusts, themselves of significant biological interest, play a critical role throughout the monument, stabilizing the highly erodible desert soils and providing nutrients to plants. An abundance of packrat middens provides insight into the vegetation and climate of the past 25,000 years and furnishes context for studies of evolution and climate change. The wildlife of the monument is characterized by a diversity of species. The monument varies greatly in elevation and topography and is in a climatic zone where northern and southern habitat species intermingle. Mountain lion, bear, and desert bighorn sheep roam the monument. Over 200 species of birds, including bald eagles and peregrine falcons, are found within the area. Wildlife, including neotropical birds, concentrate around the Paria and Escalante Rivers and other riparian corridors within the monument.

Section 2 of the Act of June 8, 1906 (34 Stat. 225, 16 U.S.C. 431) authorizes the President, in his discretion, to declare by public proclamation historic landmarks, historic and prehistoric structures, and other objects of historic or scientific interest that are situated upon the lands owned or controlled by the Government of the United States to be national monuments, and to reserve as a part thereof parcels of land, the limits of which in all cases shall be confined to the smallest area compatible with the proper care and management of the objects to be protected.

NOW, THEREFORE, I, WILLIAM J. CLINTON, President of the United States of America, by the authority vested in me by section 2 of the Act of June 8, 1906 (34 Stat. 225, 16 U.S.C. 431), do proclaim that there are hereby set apart and reserved as the Grand Staircase-Escalante National Monument, for the purpose of protecting the objects identified above, all lands and interests in lands owned or controlled by the United States within the boundaries of the area described on the document entitled "Grand Staircase-Escalante National Monument" attached to and forming a part of this proclamation. The Federal land and interests in land reserved consist of approximately 1.7 million acres, which is the smallest area compatible with the proper care and management of the objects to be protected.

All Federal lands and interests in lands within the boundaries of this monument are hereby appropriated and withdrawn from entry, location, selection, sale, leasing, or other disposition under the public land laws, other than by exchange that furthers the protective purposes of the monument. Lands and interests in lands not owned by the United States shall be reserved as a part of the monument upon acquisition of title thereto by the United States.

The establishment of this monument is subject to valid existing rights.

Nothing in this proclamation shall be deemed to diminish the responsibility and authority of the State of Utah for management of fish and wildlife, including regulation of hunting and fishing, on Federal lands within the monument.

Nothing in this proclamation shall be deemed to affect existing permits or leases for, or levels of, livestock grazing on Federal lands within the monument; existing grazing uses shall continue to be governed by applicable laws and regulations other than this proclamation.

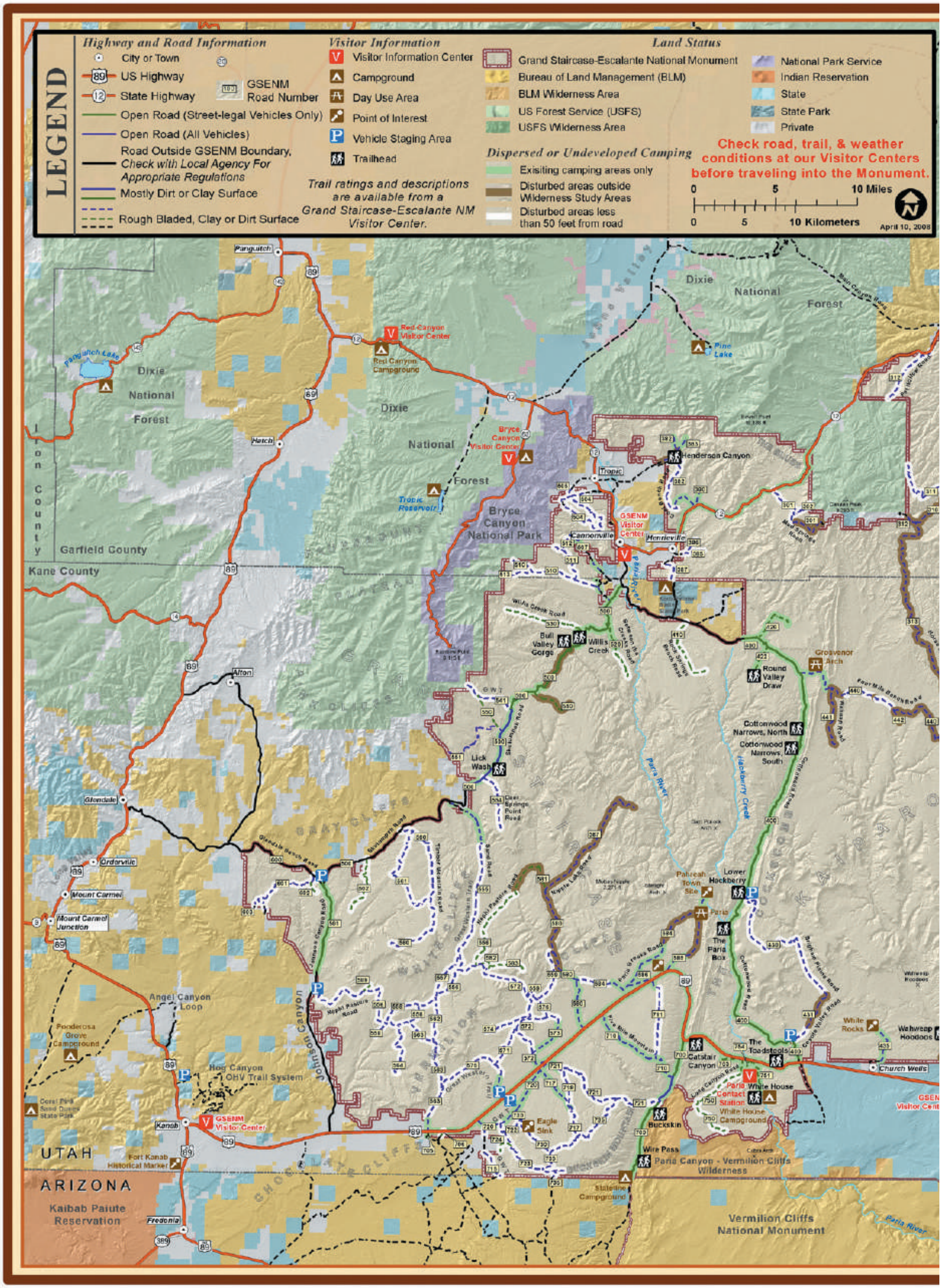
Nothing in this proclamation shall be deemed to revoke any existing withdrawal, reservation, or appropriation; however, the national monument shall be the dominant reservation.

The Secretary of the Interior shall manage the monument through the Bureau of Land Management, pursuant to applicable legal authorities, to implement the purposes of this proclamation. The Secretary of the Interior shall prepare, within 3 years of this date, a management plan for this monument, and shall promulgate such regulations for its management as he deems appropriate. This proclamation does not reserve water as a matter of Federal law. I direct the Secretary to address in the management plan the extent to which water is necessary for the proper care and management of the objects of this monument and the extent to which further action may be necessary pursuant to Federal or State law to assure the availability of water.

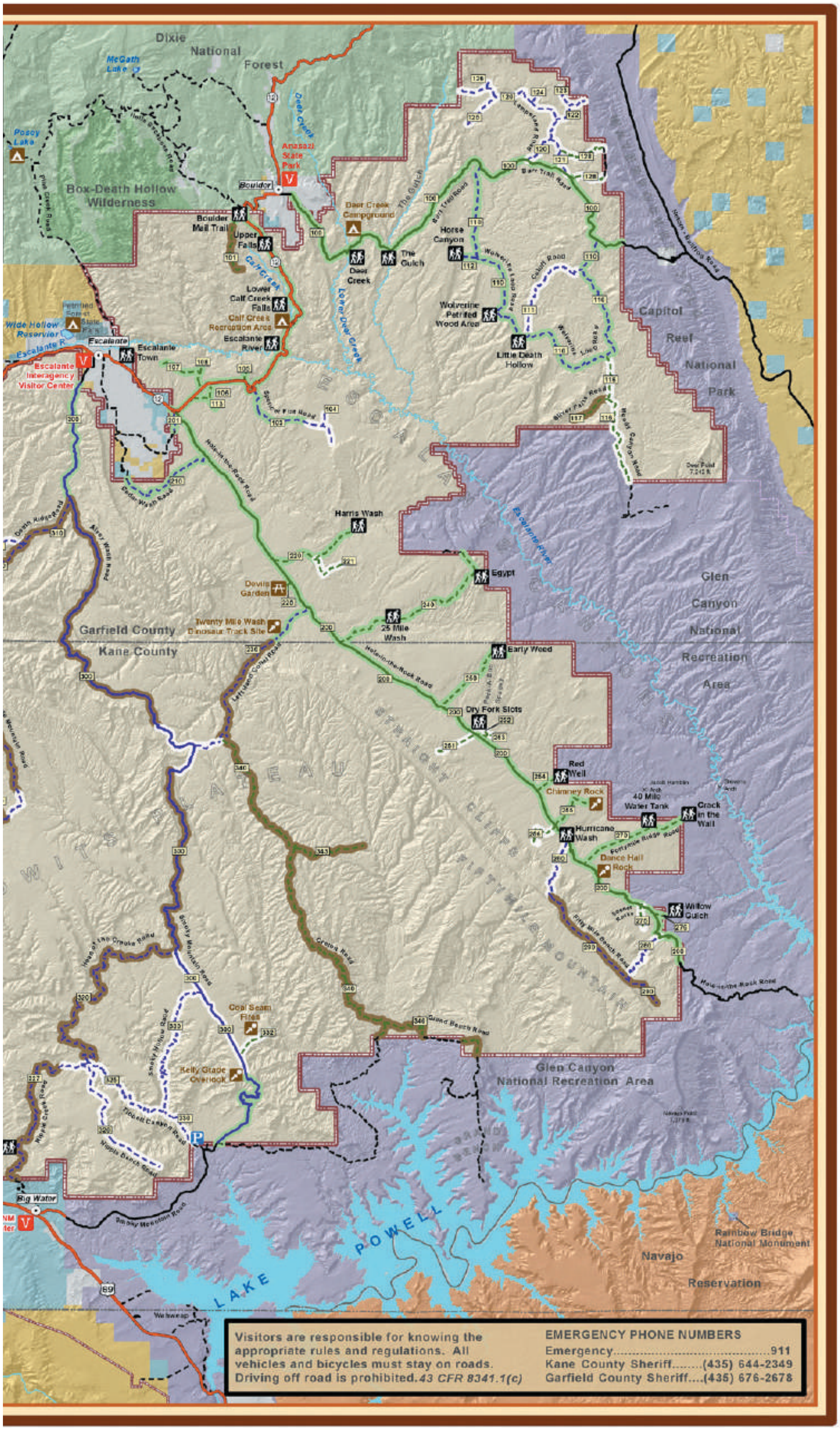
Warning is hereby given to all unauthorized persons not to appropriate, injure, destroy, or remove any feature of this monument and not to locate or settle upon any of the lands thereof.

IN WITNESS WHEREOF, I have hereunto set my hand this eighteenth day of September, in the year of our Lord nineteen hundred and ninety-six, and of the Independence of the United States of America the two hundred and twenty-first.

William J. Clinton

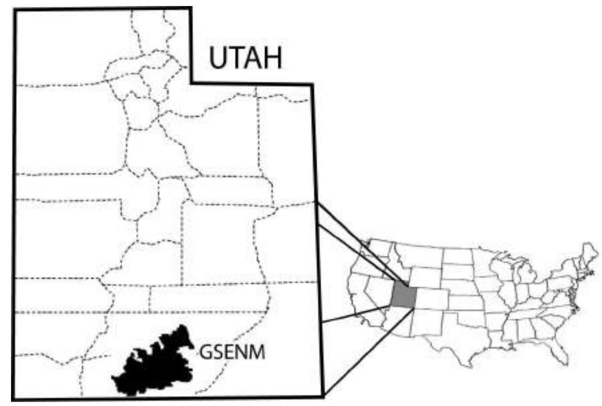

LEGEND
Highway and Road Information
City or Town
US Highway
State Highway
GSENM Road Number
Open Road (Street-legal Vehicles Only)
Open Road (All Vehicles)
Road Outside GSENM Boundary, Check with Local Agency For Appropriate Regulations
Mostly Dirt or Clay Surface
Rough Bladed, Clay or Dirt Surface
Visitor Information
Visitor Information Center
Campground
Day Use Area
Point of Interest
Vehicle Staging Area
Trailhead
Trail ratings and descriptions are available from a Grand Staircase-Escalante NM Visitor Center.
Land Status
Grand Staircase-Escalante National Monument
Bureau of Land Management (BLM)
BLM Wilderness Area
US Forest Service (USFS)
USFS Wilderness Area
National Park Service
Indian Reservation
State
State Park
Private
Dispersed or Undeveloped Camping
Exisiting camping areas only
Disturbed areas outside Wilderness Study Areas
Disturbed areas less than 50 feet from road
Check road, trail, & weather conditions at our Visitor Centers before traveling into the Monument.
0 5 10 Miles
0 5 10 Kilometers
April 10, 2008
Panguitch
Panguitch Lake
Dixie National Forest
Red Canyon Visitor Center
Red Canyon Campground
Hatch
Bryce Canyon Visitor Center
Tropic Reservoir
Bryce Canyon National Park
Pine Lake
Henderson Canyon
Tropic
GSENM Visitor Center
Cannonville
Henrieville
Iron County
Garfield County
Kane County
Alton
Bull Valley Gorge
Willis Creek
Round Valley Draw
Grosvenor Arch
Cottonwood Narrows, North
Cottonwood Narrows South
Lick Wash
Glendale
Orderville
Mount Carmel
Mount Carmel Junction
Angel Canyon Loop
Ponderosa Grove Campground
Hog Canyon OHV Trail System
Johnson Canyon
Kanab
GSENM Visitor Center
Fort Kanab Historical Marker
Pahreah Town Site
Lower Hackberry
Paria
The Paria Box
Eagle Sink
Catstair Canyon
The Toadstools
Paria Contact Station
White House
White House Campground
Buckskin
Wire Pass
Paria Canyon - Vermilion Cliffs Wilderness
Stateline Campground
White Rocks
Wahweap Hoodoos
Church Wells
UTAH
ARIZONA
Kaibab Paiute Reservation
Fredonia
Vermilion Cliffs National Monument
Paria River

Grand Staircase-Escalante National Monument



Visitor Information

Visitor center exhibits share research and scientific discoveries with visitors and students. All facilities have dramatic murals and a topographic relief model of the Monument and surrounding area photographed from the Landsat 7 satellite, 438 miles above earth.



Location map of Grand Staircase-Escalante National Monument within Utah.

GSENM Visitor Center, Kanab

745 E. Highway 89, Kanab, UT, 84741
Phone: 435-644-4680
Theme: Archaeology & Geology

- Large scale archaeology excavation diorama
- 36’ geologic cross-section of the Monument

GSENM Visitor Center, Big Water

100 Upper Revolution Way, Big Water, UT, 84741
Phone: 435-675-3200
Theme: Paleontology & Geology

- Real Late Cretaceous dinosaur fossils on display

GSENM Visitor Center, Cannonville

10 Center St., Cannonville, UT, 84718
Phone: 435-826-5640
Theme: Human Geography

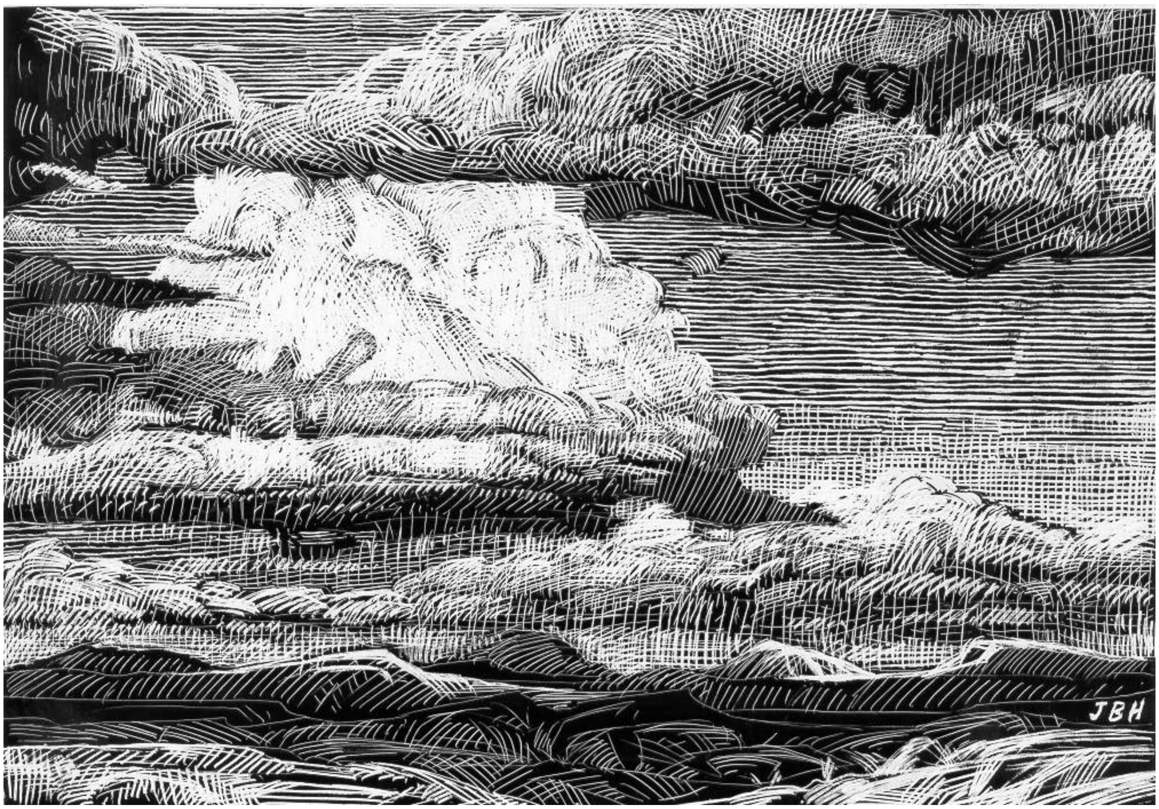
- 19th century pioneer & Paiute life related through oral histories, artifacts, and ethnobotanical garden

Escalante Interagency Visitor Center

755 W. Main, Escalante, UT, 84726
Phone: 435-826-5499
Theme: Ecology & Biology

- Hands on exhibits, photographs, & dioramas encourage learning

Indexes


JBH

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Grand Staircase Escalante Partners

Grand Staircase Escalante Partners seeks to inspire people to understand and experience the beautiful landscape and unique scientific record of Grand Staircase-Escalante National Monument by dedicating volunteers and resources to research, conservation stewardship, and education. Partners is committed to protecting the majestic and unspoiled character of the Monument.

190 E. Center Street
Kanab, UT 84741
(435) 644-4388

www.gsenm.org

Support GSENM and become a Partner today!

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Date

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Name

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Mailing Address

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City, State, Zip

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Phone

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Email

Membership Level		**Check One**
Grand Staircase	$25	☐
Cottonwood Canyon	$35	☐
Kaiparowits Plateau	$100	☐
Paria Canyon	$200	☐
Escalante Canyon	$300	☐
Monument	$1000	☐

	Yes	**No**
Would you like to receive our newsletter?	☐	☐
Would you like to volunteer?	☐	☐

Comments:

In the end, we will conserve only what we love.
We will love only what we know.
We will know only what we are taught.

– Baba Dioum, Senegalese poet –