

Alaska Park Science

National Park Service
U.S. Department of Interior
Alaska Regional Office
Anchorage, Alaska



Science, History, and Alaska's Changing Landscapes

In this issue:

Life and Times of Alaska's Tundra Plants **14**

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Cover Photo: Sheep Hill, Denali National Park and Preserve.
NPS Photograph

Backcover Photo: Collecting data in the Savage River basin in Denali National Park and Preserve.
Article on page 18.
Photograph courtesy of John Blong

Teklanika River Valley ►
Denali National Park and Preserve

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Past, Present and Future Goals for Resource Management in National Parks

By Robert Winfree

For nearly a century, the Organic Act has been the thread that weaves a common purpose through all the national parks.

...to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations.

These words are clear and concise, but in the 1960s, with rising environmental consciousness and controversy, there were calls for more direction for NPS wildlife management. In 1962, Secretary of Interior Stewart Udall assembled a committee under A. Starker Leopold, the eldest son of conservationist Aldo Leopold, to assess wildlife management in the national parks. The Board's seminal recommendations have since influenced the ways in which parks are managed for almost 50 years.

As a primary goal, we would recommend that the biotic associations within each park be maintained, or where necessary recreated, as nearly as possible in the condition that prevailed when the area was first visited by the white man. A national park should represent a vignette of primitive America.

Leopold's panel knew that implementing their suggestions would not be simple. Many areas had already experienced logging, water controls, burning

or unnatural fire suppression, hunting and predator control, and unconstrained grazing by livestock and wildlife. Road construction, trampling by humans and pack stock, invasive vertebrates, insects, plants, and diseases had brought other changes.

Yet, if the goal cannot be fully achieved it can be approached. A reasonable illusion of primitive America could be recreated, using the utmost in skill, judgment, and ecologic sensitivity. This in our opinion should be the objective of every national park and monument.

At the time, many scientists and resource managers were working under the premise that natural ecosystems were fairly stable, or at least followed a predictable ecological succession, and that lands and waters could be maintained in their original condition simply by controlling how they were used. The recent realization that human activity is changing climates across the globe challenges basic concepts of resource management. If prevailing weather patterns, habitats, species distribution, and abundance have developed over hundreds or thousands of years, or more, how would park resources be affected by substantial environmental change that occurs in the span of a few decades or less?

Research reported in this issue of *Alaska Park Science* reminds us that land and seascape change has occurred before. Some places were very different as recently as a few centuries ago, but what would be at risk if change occurs more rapidly in the future? How far should park managers go to preserve historic "baseline" conditions when climate, land cover, fish, and wildlife populations are changing, and what should they do if the changes

appear inevitable? When and where is a "hands off" approach appropriate for managing parks, and when should we give nature some help, either to resist or adapt to change? Many of today's resource managers have experienced the unintended consequences of past decisions: species eradications and introductions, fire suppression, flood control, etc. How will today's resource management decisions appear to tomorrow's managers? It is hard to say, since hindsight is usually clearer than foresight, but the question warrants serious consideration.

In August 2012, the National Park System Advisory Board delivered a report entitled *Revisiting Leopold: Resource Stewardship in the National Parks* to NPS Director Jonathan Jarvis. Broader in scope than Leopold's original charge, the new report focuses on goals, policies, and actions for natural and cultural resource management. Among the committee's more sobering conclusions is that the challenges for park management will "only accelerate and intensify in the future", and that parks need to prepare for dealing with uncertainty. The authors suggest that the predominant goal for NPS resource management should be to respond appropriately to such change.

The overarching goal of NPS resource management should be to steward NPS resources for continuous change that is not yet fully understood, in order to preserve ecological integrity and cultural and historical authenticity, provide visitors with transformative experiences, and form the core of a national conservation land- and seascape.

Revisiting Leopold calls for extending NPS management strategies to larger landscapes beyond park borders, protecting habitat for climate refugia, critical migration

Figure 1. Dall Sheep in Denali National Park and Preserve

Photograph courtesy of John Blong



Photograph courtesy of John Blong

Figure 2.



NPS photograph

and dispersal corridors, and strengthening park resilience, with consideration to time scales many generations into the future. The committee calls for prudence and restraint in park management, more fully embracing the precautionary principle, maintaining or increasing current restrictions on impairment, and avoiding actions that could irreversibly impact park resources and systems in the future, with decisions informed by broader scientific inquiry, both internal and external to the NPS.

NPS Director Jarvis has committed to a thorough review and discussions on the report's recommendations with NPS employees, members of the scientific and parks communities, and managers of other protected areas, before NPS decides how to move forward with the report. The Alaska Region has engaged in those discussions.

The complete 2012 Leopold Revisited report at: http://www.nps.gov/calltoaction/PDF/LeopoldReport_2012.pdf

The original 1963 Leopold Report is available at: http://www.cr.nps.gov/history/online_books/leopold/leopold.htm

Figure 3.



Bridging the Cold War: Dave Hopkins and Beringia

By Scott Elias and Klaus Dodds

As recent visitors to the Alaska park service office in Anchorage, we were on a quest to discover what the archives might reveal about a remarkable scholar and his role in enhancing understanding of the ancient land bridge (with its own distinctive climatic regime) that once connected Asia and North America. The scholar in question was the late Dave Hopkins, a long-term employee of the U.S. Geological Survey (USGS) who devoted his life to understanding this ancient landscape encompassing northeastern Siberia, Alaska, and the Yukon.

What struck us as interesting about Hopkins' long career was not only his commitment to work with and learn from Alaska Native communities, but also his willingness to make connections with Soviet colleagues in the midst of the Cold War. Our project was designed, therefore, to investigate how scientific collaboration and knowledge production evolved in one of the most strategically sensitive regions of the world.

As was well understood by the late 1940s, Alaska, Siberia, and the Arctic Ocean, because of their physical location, represented the political and geographical frontlines of the Cold War. There was a pressing need on both the Soviet and the U.S. sides to improve understanding of the geophysical and environmental characteristics of these regions, as they were being transformed into militarized and securitized zones rapidly, where civilian access was limited.

Figure 1. Victor Ivanov (NEISRI/RAS Magadan) and David Hopkins shake hands in front of an old banner in the town of Provideniya, southeast Chukotka, Russia, in 1991. This was the first of three years of joint field work in Chukotka and Northwest Alaska to compare the glacial history on both sides of Bering Strait.

Photograph courtesy of Julie Brigham-Grette

In the aftermath of World War II, scientists faced a predicament. On the one hand, science was supposed to be an activity driven by curiosity, knowledge transfer, and cooperation. International boundaries, in this ideal view of science, are an irrelevance; however, scientists working on areas such as Beringia faced a profound dilemma. How would it be possible for American scientists to understand the environmental histories of the Soviet Far East if it was not possible to carry out field visits? Moreover, would U.S. scientists be allowed any contact with their Soviet counterparts? In addition, the relevant authorities must believe these scientists were interested only in the pursuit of knowledge about past climates and past environments.

Because of the atmosphere of suspicion between the two superpowers, the idea that science was politically disinterested (or not capable of being used as a cover for secretive activity) was not taken seriously. By May 1948, the border between Alaska and Siberia was closed, as mutual suspicion hardened between the two sides. Ironically, just a few years earlier, American pilots were flying war materials to the Russians by way of Alaska. This Alaskan-Siberian connection was severed by the Cold War.

So, our research into the life and work of Dave Hopkins focused on how it was possible for this academic interest in Beringia to develop during the Cold War. We travelled to the NPS archives in Anchorage, and to the University of Alaska Fairbanks, to try and understand his role in this process. It became immediately clear that there are three factors that help explain why he was successful: credibility, networking, and resourcing.

An Agent of Science

Scientific advances may come about by a combination of patient experimentation, luck, considered judgment, and funding. Dave Hopkins' career reminds us that

there may also be other factors at play as well. Hopkins had credibility with a wide variety of stakeholders including Alaska Native communities, NPS managers, and U.S.S.R. counterparts. His role as an employee of an agency of the U.S. government also gave him the kind of job permanence, stability, and prestige that fostered respect and trust from his Soviet colleagues. Hopkins was passionate about his interest, and in the late 1940s he was working on the geological history of the Seward Peninsula, based in Nome. Under the auspices of the USGS Terrain and Permafrost Section, he was studying beach deposits in an attempt to understand better the ancient land bridge. He travelled widely in Alaska, and was not afraid to drive forward his research efforts via a combination of scientific innovation, interdisciplinary collaboration, and personal networking.

Hopkins' credibility in Alaska was due in part to the strong relations he developed with Alaska Natives and other local residents. In 1948, he met an Inupiaq man, William Oquilik, who was a resident at Mary's Igloo. Oquilik was born in the 1890s and possessed a portfolio of traditional stories about the landscape, people, and environment. He told Hopkins a story about a series of disasters that befell the people of the Seward Peninsula. The first of these disasters was described as a great mountain blowing up, with great rumbling of the earth, smoke and fire, with red hot rock coming out of the mountain top and rolling down the slopes. Hopkins interpreted this story as the local description of the eruption of the Lost Jim lava flow on the northern Seward Peninsula. This lava flow has subsequently been dated to 1,600 years ago. This is just one example of local indigenous knowledge that helped Hopkins understand the landscapes of the Seward Peninsula when he began doing his earliest fieldwork. It showed a



Photograph courtesy of Julie Brigham-Grette

Figure 2. David M. Hopkins in July 1987 on the coast of Kotzebue Sound, Baldwin Peninsula, just south of Kotzebue, Alaska.



Photograph courtesy of Julie Brigham-Grette

Figure 3. David Hopkins, Victor Ivanov, and Anatoly Lozhkin (both of the NEISRI/RAS Magadan) relaxing after a day of field work at Pilgrim Hot Springs, Seward Peninsula, in 1991.



Photograph courtesy of Jerry Brown

Figure 4. Discussions in two languages were carried out by this group of American and Russian permafrost scientists while they were floating down a river in the Yakutia region of northeastern Siberia during the 1969 excursion of the IGU Periglacial Commission. From left to right: Gerald Richmond, Evgeny Katasonov, Gunar Gravis, Dave Hopkins, Troy Pewe, Pavel I. Melnikov, and Andre Journaux.

willingness that was remarkably progressive to combine indigenous and scientific knowledge and practices.

Hopkins also listened carefully to other Alaskan residents such as the bush pilot, John Cross. While Cross was flying Hopkins around the Seward Peninsula, he pointed out the Trail Creek Caves to him. The following summers, Hopkins enlisted a group of archaeologists to help excavate the site. Artifacts such as stone tools were later discovered and dated to around 8,500 years ago. This was the first important archaeological discovery on the Seward Peninsula. But his most long-standing relationship was with Gideon Barr, an Inupiaq elder from Shishmaref, on the Seward Peninsula. Hopkins acknowledged Barr as an invaluable guide to ‘reading’ the Alaskan landscape, both past and present. Their relationship was incredibly important and long lasting. It was Barr, for example, who provided Hopkins with insights into native settlement history and the oral histories surrounding the Seward Peninsula in particular.

Working as a research scientist at the USGS between 1942-1984, mostly in Menlo Park, California, Hopkins had the opportunity to network with colleagues in the lower 48, and to develop connections with Soviet counterparts from the 1960s onwards. It is worth remembering that Hopkins was one of the first U.S. scientists to work cooperatively with Soviet counterparts. In 1969, for example, he was an exchange fellow of the National Academy of Sciences, which enabled him to meet all the important Beringian scientists in Moscow and Leningrad. These Soviet scientists were keen to have their Siberian sediments and fossils analyzed by western researchers. In the NPS archives, there are fascinating insights into what Hopkins was allowed to take after his first visit to the Soviet Union, including plant samples, volcanic material, glacial clay, pollen, and loess collected by Soviet scientists from multiple sites in the Lena, Amur, and Ob River basins.

Hopkins’ detailed reports of his visits to the Soviet Union record his social and professional networking. He notes, in his private diaries, the bureaucratic obstacles

confronting researchers, but at the same time he shows an uncanny capacity to earn the trust and respect of Soviet colleagues. In 1969, Soviet colleagues allowed him to see their geological and stratigraphic data, which Hopkins concluded was largely “plain incompetent”. He further writes that “field visits in the Soviet Union are rapidly becoming a more realistic possibility and I believe that we are now in a position to insist on equal treatment”.

He brought Soviet and U.S. scholars together, not only in person via symposia and field visits, but also through publications including the highly acclaimed *Bering Land Bridge* (1967). In the University of Alaska archives, there are fascinating records of how Hopkins worked diligently with Soviet authors to ensure their papers were produced to a high standard. His editorial determination is also evident in terms of generating debate about the origins and evolution of the land bridge.

The final element that helps explain Dave Hopkins’ extraordinary influence lies in the area of resourcing. As an employee of the USGS, Hopkins was able to fund visits to the Soviet Union and host visitors, which in turn helped encourage scientific innovation in areas such as geochronology. In 1971, Hopkins hosted the Soviet geologist Olev Petrov in Alaska. Hopkins also encouraged U.S. colleagues such as Allan Cox and Richard Doell to work on marine stratigraphy in the Bering Sea and consolidated his academic contacts with other colleagues at the University of California, Berkeley and Harvard, in the areas of paleobotany and plant stratigraphy. In 1963 with USGS funding, Hopkins travelled to the Kenai Peninsula with Jack Wolfe, a paleontologist specializing in using fossil leaves to reconstruct past climates in northern North America. Hopkins’ strategic sense of inter-disciplinary collaboration was vital in his determination to lobby for support of studies in marine geology and plant botany.

The changing geopolitics of the Cold War played a part as well. In the early 1970s, improving relations facilitated new opportunities for scientific exchanges. A visiting scientist exchange agreement was the main

catalyst for U.S.-Soviet interaction. Hopkins invited Soviet scientists to Menlo Park, and gave his visitors the opportunity to date samples and access basic laboratory equipment such as microscopes. In April 1972, the Director of the Geological Institute of the Academy of Sciences (A.V. Peyve) visited Dave Hopkins and the USGS. Hopkins realized that cross-strait scientific cooperation was essential, for Soviet science in general was poorly developed and funded. In 1971, Hopkins undertook a second visit to the Soviet Union and proposed that efforts be devoted to producing a more advanced geological map of Alaska, Siberia, and the Bering and Chukchi Seas. Specimen collection and exchange was judged to be critical for future scientific development, and Hopkins returned again in 1973 to encourage further collaboration. He met a receptive audience with many Siberian-based colleagues keen to swap materials, take their U.S. counterparts to ‘forbidden places’, and circumvent bureaucratic restrictions.

These three factors—credibility, networks and resources—played their part in encouraging the NPS to propose, in 1971, a ‘Russo-American Land Bridge International Park’. The proposal did not develop any further until the early 1990s, but its genesis in the early 1970s owes much to Hopkins’s collaborative activities. In 1992, for instance, the NPS and the University of Alaska Fairbanks were able to collaborate with Russian counterparts (e.g. the Geological Institute in Moscow, the Komarov Botanic Institute in St Petersburg, and the Pacific Institute of Geography in Vladivostok) and undertake an inventory of Arctic biota as well as execute anthropological research relating to the Seward Peninsula and Chukotka Peninsula. Importantly, colleagues were able to visit field sites on both sides of the Bering Strait, compare regional deposits, and reflect on cross-strait linkages. Such cross-strait exchanges were, of course, pioneered by Hopkins and his Soviet colleagues including Olev Petrov and Andrei Sher, some 20 years earlier.

As we reflect on the recent announcement concerning the establishment of a trans-boundary

area of shared Beringian heritage, the role of Dave Hopkins will continue to loom large. We believe, however, that there is more research to be done on the period between the mid 1960s and late 1980s in charting not only how Alaskan communities continued to contribute to understanding past environmental history, but also U.S.-Soviet collaboration, field visits, and exchange of materials. The archival materials in the NPS, in combination with the archives housed in the University of Alaska, deserve further examination.

Efforts to bridge the gap between Russian and American scientists were also vigorously pursued by some Russian scientists in the 1960s through the 1990s. We wrote about one of these Russian trail blazers, Andrei Sher, in a recent article (*Elias and Dodds 2011*). But, there is more work to be done, and we hope to carry out further interviews and archival research in Russia in the future.

We are looking for Inupiaq and Yup’ik people who worked with Dave Hopkins and other field scientists in western Alaska since the late 1940s. If you have stories that you would be willing to share, we would love to hear from you. Please contact Scott Elias (s.elias@rhul.ac.uk) or Klaus Dodds (k.dodds@rhul.ac.uk). Thanks!

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Life and Times of Alaska's Tundra Plants: How Long Do They Live, and How Are They Responding to Changing Climate?

By Daniel F. Doak and William F. Morris

On Wednesday, March 29, 1911, officials drove a copper spike in Kennecott, Alaska to complete construction of the Copper River and Northwestern Railroad that linked the Kennecott copper mines to the port of Cordova. That day was more than 100 years ago, and Kennecott is now part of the Wrangell-St. Elias National Park and Preserve (WRST). On the alpine ridges that look down on Kennecott, hikers will find moss campion plants (*Figure 1*), which were already centuries old on that historic day, even though each is only about the size of a dinner plate. We have been studying these plants for more than 17 years, but many of them will certainly still be alive when we, like the Copper River and Northwestern Railroad, are things of the past. As we describe below, we conduct research on this and another species to answer questions about the longevity and general ecology of tundra plants, as well as how they are being influenced by climate change in the Wrangells and across North America.

Figure 1. Moss campion is one of the most easily recognized tundra plants. When in flower, the pink cushions brighten a variety of arctic and alpine habitats, including the most barren fellfields such as this ridge near McCarthy, in Wrangell-St. Elias National Park and Preserve.

Photograph courtesy of Tracy S. Feldman

Figure 2. Even after many years of growth, moss campion plants may only have a single whorl of leaves and be far smaller than a penny.

Figure 3. Moss campion cushions are comprised of many branch tips, tightly packed together. They are thus like a miniature tree, but with all the branches squashed together.

Photograph courtesy of Rachael Mallon

Moss campion (*Silene acaulis*, in the carnation family) begins life when a seed germinates to produce a seedling with two small seed leaves and a single tiny root. Each year, the main stem of the young plant produces a new whorl of leaves at its tip, and the root grows deeper. This stage, in which the plant has only a single above-ground growing point, may last for many years. Indeed, some of the plants we found in this stage 17 years ago are still in this stage today (*Figure 2*). If the plant survives, its single shoot will eventually branch to produce two tips, which themselves may eventually branch, and so on, to produce the multiple growing points you see if you closely examine a large plant (*Figure 3*). However, each branch elongates very little from the point at which it originated on the “parent” branch, giving larger plants a compact, pin-cushion-like shape. This growth form is adapted to the harsh tundra environment. In summer, the short branches keep the leaves close to the ground surface where the wind is lower and the air temperature is higher, even on cold and windy days. Moreover, the low growth form means the plant is quickly covered with snow in autumn, which insulates and protects the plant from the extremely cold and dry winter conditions.

While the above-ground growing points are undergoing branching, the root tip may branch as well, to produce multiple roots. However, the plant retains a single taproot (*Figure 4*). This deep taproot is an adaptation to the unstable, rocky soil in which moss campion typically grows, the surface of which is often subjected to frost heaving in winter that would quickly destroy more shallow-rooted species. Overall, the form of a moss campion plant is like that of a miniature tree that has had its trunk shrunken and shoved into the ground, so that all we see when we look down on the

plant are its branch tips and their whorls of leaves. In addition, we have found moss campion has a life cycle which also resembles that of a long-lived tree.

So how do we know that these small plants are likely to be so old? Many of the largest plants that we marked 17 years ago are still alive today, so we know from direct observation that they live at least that long. But to better estimate the lifespans of these plants (which do not make anything equivalent to the annual rings of a tree that allow direct aging of individuals) we have measured the growth that each of hundreds of plants achieve in each year and also the fraction of plants of all sizes that survive from one year to the next (*Figure 5*). We measure the size of each plant as the surface area of the cushion, and record changes in that area from year to year as growth. Some plants also shrink, often due to exposure to cold winter conditions during snow-free periods (*Figure 6*).

Using this information, we can calculate, assuming the rates of annual growth, shrinkage, and survival have remained relatively constant in the past, how old a newly germinated seedling will be, on average, at successive sizes, or the so-called “age of residence” of a cohort in each size class (*Cochran and Ellner 1986*). Using this approach, we estimate that plants larger than about 6 inches in diameter (200 cm² in area) are on average about 200 years old, and some of them may be substantially older (*Morris and Doak 1998*) (*Figure 7*). This longevity was a great surprise to us, and was the most interesting outcome of our initial work on moss campion. Given this longevity, when we go hiking in the mountains, we try to respect our elders, and avoid stepping on any moss campion plants.

In 2001, we greatly expanded our work and shifted our focus to the question of how climate determines the geographical distributions of tundra plants. Answering



Photograph courtesy of William F. Morris

Figure 4. A moss campion cushion that was overturned by a brown bear (*Ursus arctos*), perhaps in search of insects. The compact, short branches and the single taproot can easily be seen.

this question is important for predicting the ecological effects of the rapid ongoing climate change in Alaska and other northern regions. But we are equally interested in the more basic issue of why species have the distributions that they do. While some species of plants and animals have severely restricted ranges, many live across huge areas, and it is not clear why they “fail” outside this area: in other words, what sets the limits to their ranges? Thus, we sought to design a study that would let us understand what limited populations of moss campion across a large swath of its impressive range in western North America, including sites from Alaska's North Slope to the Colorado Rockies (Figures 8-9).

We also expanded our work in another, crucial way: to strengthen our ability to generalize about climate effects, we added a second study species, the alpine bistort, *Polygonum viviparum* (also called *Bistorta vivipara*). This plant, a member of the buckwheat family, is also a tundra specialist in North America. Bistorts are reasonably long-lived, but their growth form is very different from that of moss campion. As with moss campion, we collect data on survival, growth, and reproduction



Figure 5. To measure growth, survival, and reproduction of moss campion plants, we establish transects that we revisit each year. Along each transect, we mark and map the locations of individual plants. This transect is near Kennecott, Alaska, with Castle Rock in the background.



Figure 6. Moss campion cushions shrink as well as grow. The grey and brown part of this plant died the previous winter. Some plants continue to shrink until they die, while others regrow.

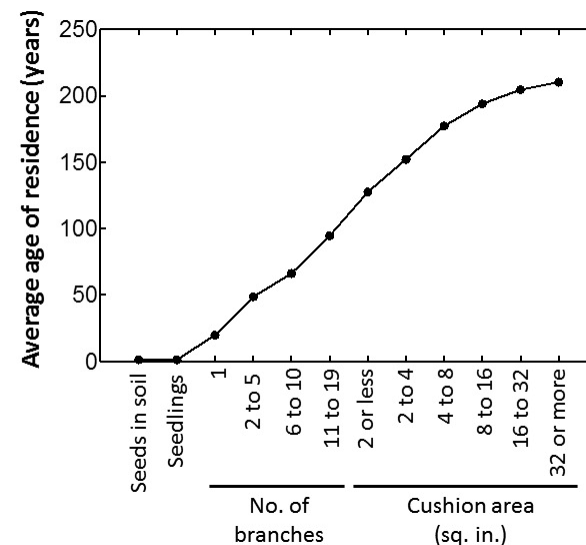


Figure 7. The estimated average age (in years) at which a cohort of moss campion plants in the Wrangell Mountains is in successively larger size classes. Size is measured by the number of branches (if 20 or more branches) or by cushion area (in square inches). Because growth is variable, some plants in a size class will be considerably younger, and some considerably older, than the average.



Figure 8. The sites of our expanded study of tundra plant ecology. From 2001 to 2006, we studied plants at all sites shown except Latir Peak, the southernmost. From 2007 onwards, we included sites at Latir Peak, but due to logistical constraints have stopped working in the Canadian Rockies. Red dots indicate the northernmost and southernmost locations of moss campion in western North America.



Photograph courtesy of William F. Morris

Figure 9. Our northernmost sites are near Toolik Lake Field Station on the north side of the Brooks Range. Here, our two study species live in arctic tundra, and generally are most abundant in more sheltered locations. This view shows one of our moss campion sites, with the Brooks Range in the distance.



Figure 10. A key component of our research toolkit is an array of multicolored plastic toothpicks, with which we mark – and hence relocate – individual plants. Here, a dense clump of bistorts shows how we can distinguish nearby plants.

for our bistort plants each year (*Figures 10-11*).

By 2006, we had collected data on a total of 35,386 plant-years for moss campion and 23,980 for bistorts. We then assembled this information and looked at what it indicated about climate effects on the basic ecological responses of the two species, as well as what these patterns told us about likely climate change effects. One of the most obvious effects we saw was that some demographic rates (i.e., birth, survival, and growth rates) deteriorated in populations closer to the southern range limit while others improved. In particular, survival and reproduction generally declined but growth was generally faster at the south-

ernmost site, trends we saw in both species (*Figure 13*).

We also wanted to ask whether climate was responsible for these spatial patterns. To do so, we used weather stations near each of our sites to obtain the mean growing season temperature for each year in each region, and we employed satellite data to estimate how long the ground was snow-free in each year, which determines the length of the growing season. Our results show that both growing season length and temperature have effects on many demographic rates (*Figure 13*), and that these effects largely explain the latitudinal patterns we see. Overall, both the warmest and the coolest conditions generally led to lower

values of multiple demographic rates, while intermediate conditions resulted in better performance (*Figure 13*).

The final thing we did was to take the effects of climate on different demographic rates and ask what they mean for population growth, which results from the combined effects of all these rates. The results show that a broad range of intermediate climate conditions can support high population growth rates, but that when conditions are either too warm or too cool, populations are predicted to collapse. In a warming climate, this implies that with gradual warming, we should expect to see relatively stable populations of tundra plants, but past



Figure 11. As with bistorts, we use multicolored party toothpicks to mark the smallest moss campion plants. In particular, we choose the areas around some large moss campion for intensive study of seedling appearance and survival. This photograph shows such a 'mother plant' in the upper right (covered with brown, upright seed capsules) and the toothpicks marking tiny offspring in the foreground.

some climatic tipping point—which will not be the same for each species—we should expect rapid population declines. One value of this finding is that it explains a common observation of climate change scientists – while some species have shifted ranges and shown strong responses to ongoing climate change, many have not. Our work suggests that this is exactly what we should expect, but that the lack of responses we have seen in many species up to now is no guarantee of future stability.

Long-term ecological studies such as ours have a perverse logic: the more data you have already collected, the more mundane, but also the more useful, each new

year of data becomes. We are lucky to have received continuing permission to work at all our sites, in particular WRST (Figure 14). Continuing financial support from the National Science Foundation means we will collect at least five more years of data in this study. Just as exciting is that our work in North America has interested European researchers: both moss campion and bistorts also grow in Europe, and we and European collaborators have now established moss campion study populations from the Spanish Pyrenees, to the Swiss Alps, to central and northern Sweden. Comparing the demography of plants in these sites with what we find in western North America

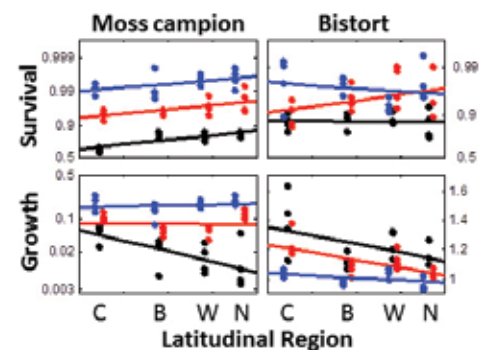


Figure 12. From south to north, survival increases but growth declines. Small, medium, and large plants are shown in black, red, and blue, respectively. Regions are Colorado (C), Banff National Park in Alberta, Canada (B), the Wrangell Mountains (W), and Toolik Lake, on the North Slope (N).

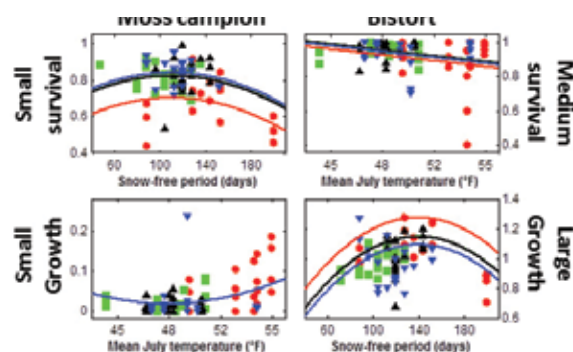


Figure 13. Responses of one survival rate and one growth rate for each species to mean July temperature or snow-free period. Colors show regions: red = Colorado, green = Banff, black = Wrangell, and blue = the North Slope.

will test whether we have identified the general mechanism setting the range limits of tundra plants, and provide an even richer set of climate regimes with which to understand effects of changing climate on plant distributions.

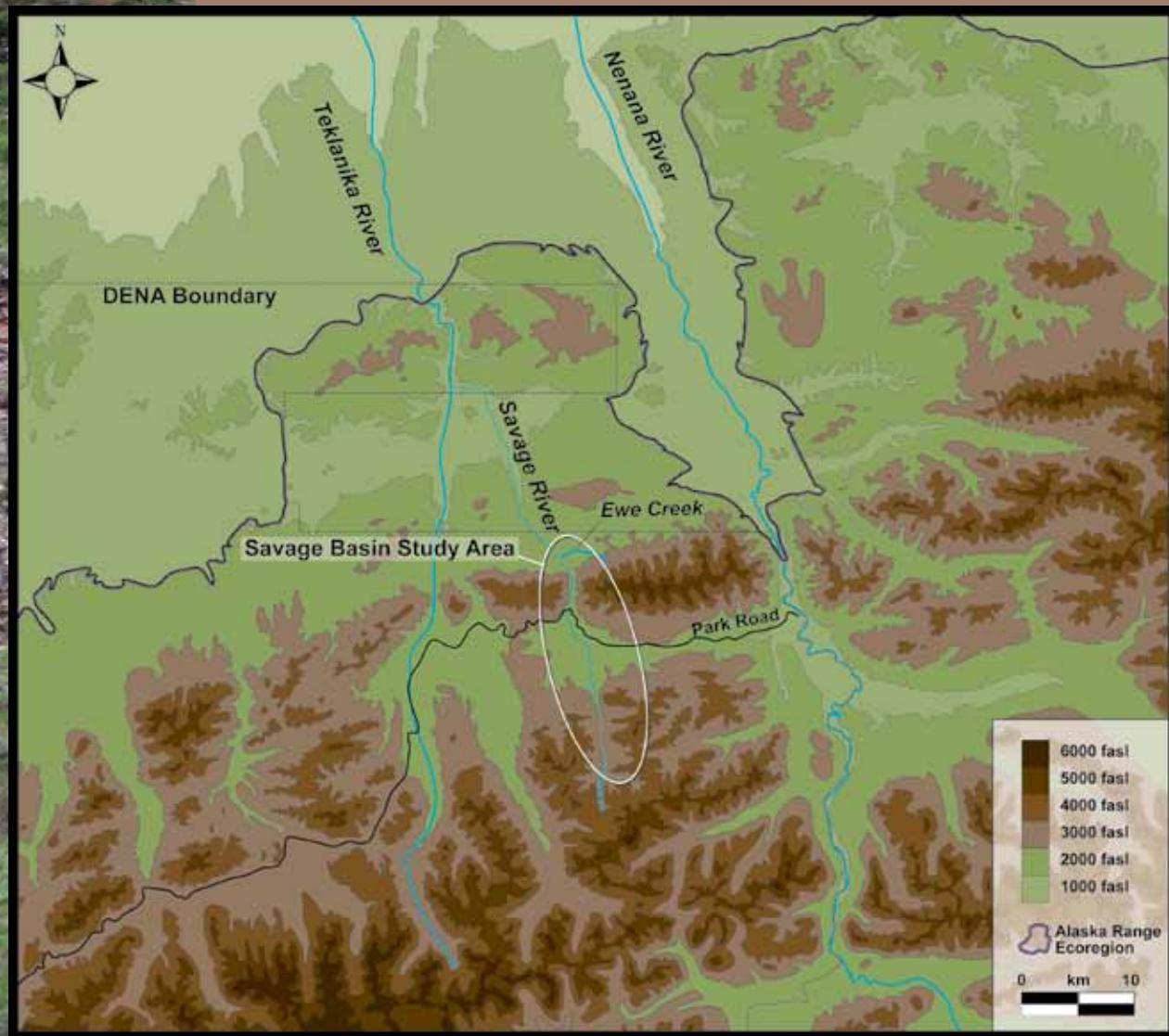
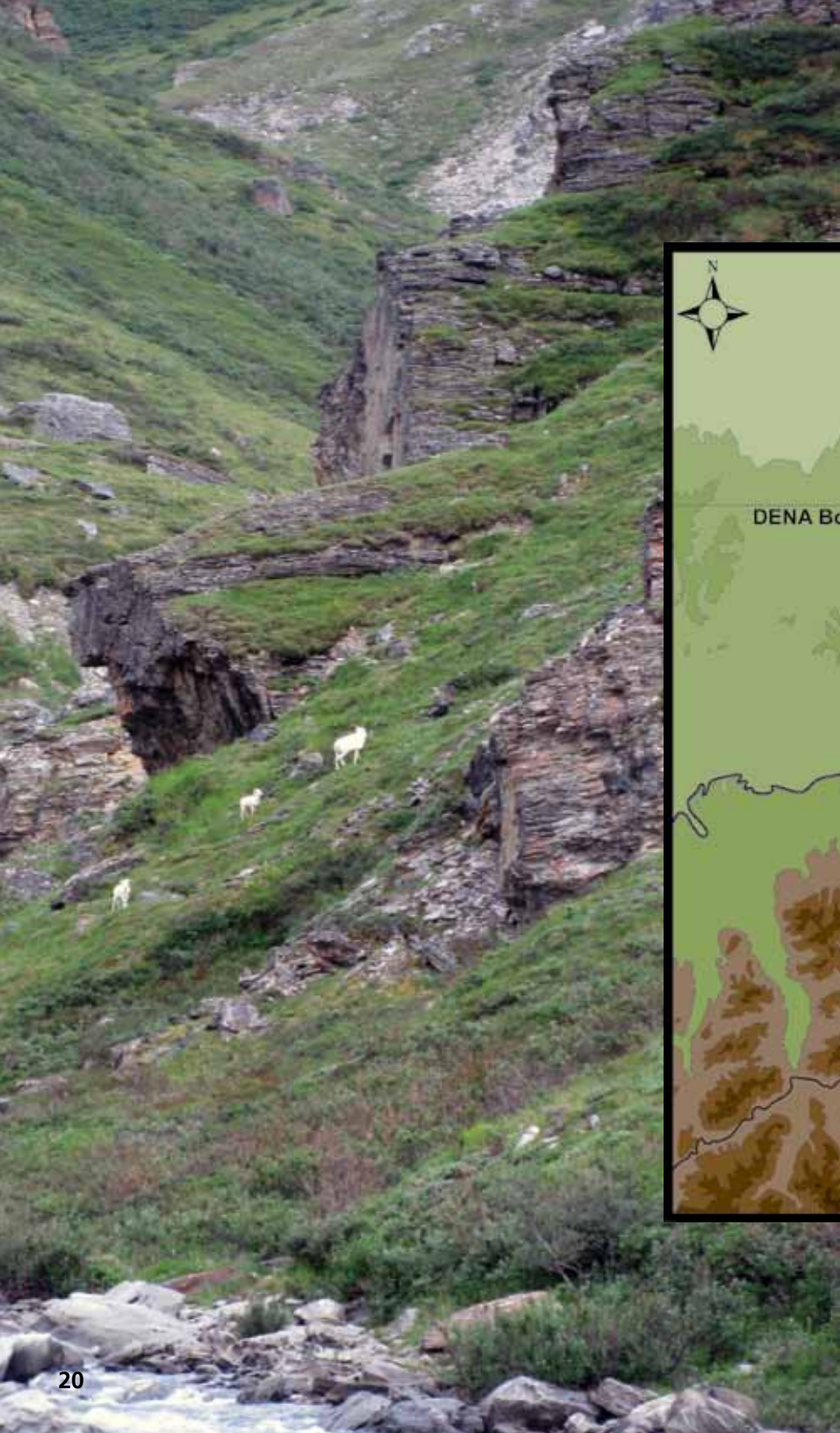


Photograph courtesy of Rachael Mallon, used with permission.

Figure 14. While we spend much of our time in the field staring at the ground or at handheld computers, this long-term project also means we spend many weeks in some of the most beautiful parts of the Alaskan mountains each year.

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Prehistoric Hunter-Gatherers in the Savage River Uplands, Denali National Park and Preserve

By John Blong

*Took a trip . . . down Savage River Trail.
That trail is a bear. (Davis 1980)*

In retrospect, I should have heeded NPS archaeologist Craig Davis' words when planning our backcountry trip north along the Savage River Trail through the steep-sided Savage canyon in Denali National Park and Preserve (Denali) (*Figure 1*). Our destination was the confluence of the Savage River and Ewe Creek (*Figure 2*), where we camped for one week and excavated three archaeological sites. The trail was difficult, but the chilly wet weather and one-week worth of camping and archaeological excavation equipment on our backs made it even more so. In the end our trip proved worthwhile, and we collected important information on prehistoric hunter-gatherer activity in Denali.

Our research in the Savage River basin is part of an ongoing study investigating how prehistoric hunter-gatherers lived and hunted in the mountainous uplands of the central Alaska Range, from earliest colonization at the end of the last ice age to less than 1,000 years ago. Emerging archaeological evidence suggests that upland landscapes of central Alaska were seasonally important to early humans (*Holmes et al. 2010, Wygal 2010*). When and how humans adapted to this landscape is unknown. Research also suggests prehistoric hunters

Figure 1. Dall sheep on the Savage River Trail.

Photograph courtesy of Heather Smith

Figure 2. (Map) Savage Basin study area in the Alaska Range Ecoregion.

adjusted their hunting technology to target caribou and sheep in the uplands, taking advantage of abundant tool-stone (stone suitable for tool-making) to fashion bifacially worked stone projectile points instead of the osseous inset-microblade projectile points preferred for lowland hunting (*Potter 2011, Wygal 2010*).

Assessing these hypotheses is difficult because the majority of well-documented archaeological sites in central Alaska are located in the lowlands of the Nenana and Tanana river valleys, whereas in the uplands of the central Alaska Range, few prehistoric sites have been fully documented. The Savage River project was part of our effort to improve our knowledge of upland activities. Our research asks: When did humans first begin targeting resources in the uplands, and what was the environmental context of this use? How did the environment and use of upland resources change over time? How did use of upland resources influence stone tool manufacture, especially bifacial projectile versus inset-microblade weapons?

The Savage River basin is within the upland Alaska Range Ecoregion (*Figure 2*), consisting of rugged mountain ridges and valleys and dwarf-scrub vegetation communities (*Nowacki et al. 2001*), and as such is ideal for studying prehistoric hunter-gatherer upland adaptations. In addition, there are significant park management interests in the Savage basin. More than 400,000 visitors visited the park in 2011 (*DENA 2012 Fact Sheet*); the Savage basin is highly impacted by this traffic and an important place for park managers to protect cultural resources. Given both research and management interests, the Savage River uplands project was developed with three

goals in mind: (1) relocate and update Denali records on nine prehistoric archaeological sites in the upper Savage basin near the Park Road; (2) systematically survey the upper Savage basin for unrecorded archaeological sites; and (3) evaluate the condition and significance of three sites at the confluence of the Savage River and Ewe Creek.

History of Archaeological Research in the Savage Basin

A portion of this project retraced the steps of scientists responsible for the earliest archaeological discoveries in the park. In 1961, Dr. Frederick Hadleigh-West conducted the first extensive archaeological excavations (in what was then known as Mt. McKinley National Park) at the Teklanika West and Teklanika East sites. The discovery of prehistoric archaeological materials in close proximity to the Park Road moved the NPS to enlist Dr. H. Morris Morgan and Dr. Adan E. Treganza to undertake the first planned surveys of park archaeological resources in 1963 and 1964. Their efforts resulted in the discovery of 16 archaeological sites, including five located in the upper Savage basin. In 1980, NPS archaeologist Craig Davis revisited sections of Morgan and Treganza's survey routes to update cultural resource records, and located three more sites in the upper Savage basin (*Griffin 1990*).

Treganza also targeted the Ewe Creek drainage area as a probable location for prehistoric hunter-gatherer activity based on information provided by Dr. Aldoph Murie, the pioneering naturalist, who observed a mineral outcrop (or lick) frequented by large game. Treganza surveyed the drainage, but found no significant



Photograph courtesy of John Blong

Figure 3. Typical elevated landform in the upper Savage basin covered in our survey. Landforms like this often had exposed archaeological material lying on the surface.

archaeological material, and it was not until 1989 that an NPS survey team located three prehistoric sites along a high terrace overlooking the mineral lick (*Lynch 1996*). This research served as the foundation upon which we built our research project in the Savage basin.

2010 Research

In summer 2010, archaeologists from the Center for the Study of the First Americans at Texas A&M University conducted archaeological survey and excavation in

the Savage River basin. In the upper Savage basin, we located previously recorded sites using coordinates and maps from Denali site files and identified landforms likely to have exposed archaeological material using topographic maps and infrared satellite images (*Figure 3*). Archaeological survey consisted of walking exposed surfaces and flagging artifacts, then recording GPS points and tool manufacturing data for each artifact (*Figures 4-5*). Detailed observations were recorded on the setting, condition, and potential significance of each site. Our 2010

survey located four of nine previously recorded sites and six previously unrecorded sites, and we recorded information on a total of 77 stone artifacts, including 59 pieces of flaking debris and 18 flaked stone cores and tools.

At Ewe Creek we used a total station survey device to record detailed provenience information before collecting surface artifacts at three sites (*Figure 6*). We excavated three 1m² test units to search for buried, datable artifact deposits and evaluate the significance of these sites. Our excavations established that there were two “paleosols”, (dark horizons representing a buried former ground surface), containing flaking debris (*Figure 7*). The lowest paleosol contained stone artifacts buried with charcoal wood dated to 4,150±40 radiocarbon years ago, or approximately 4,680 calendar years ago (cal BP). At the Ewe Creek sites we collected 53 stone artifacts, including 39 pieces of flaking debris and eight tools from surface contexts, and six pieces of flaking debris from subsurface contexts.

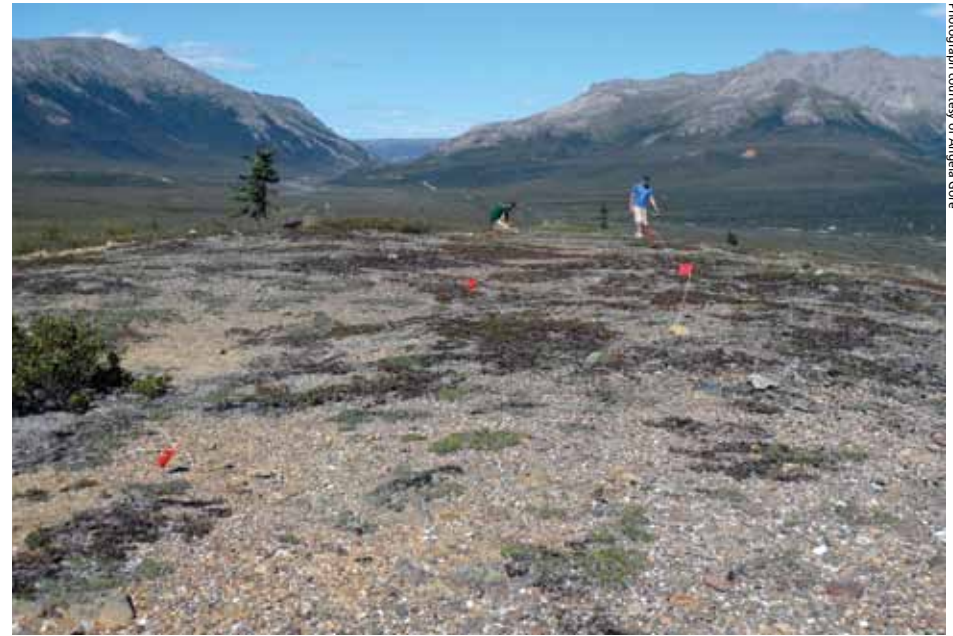
Tool Manufacture

A detailed study of the stone artifacts from the Savage basin indicates that a wide range of stone tool manufacturing activities occurred at these sites, primarily geared towards manufacturing tools from previously prepared stone blanks, as well as re-sharpening existing tools. Stone artifacts from the study area are primarily made of chert, an easily worked stone available from streambeds and gravel bars in the park, indicating that prehistoric hunters were obtaining quality rock from nearby drainages in the basin. The presence of stone projectile points, some of which had fractured upon impact, suggests that hunting was an important activity, but the presence of scraping and cutting tools suggests that carcass and hide processing also may have occurred at these sites (*Figure 8-9*). The small assemblages from the study area suggest short-term occupations: probably hunting camps, where prehistoric toolmakers primarily manufactured bifacially worked stone projectile points.



Photograph courtesy of John Blong

Figure 4. CSFA archaeologists Angela Gore and Tom Jennings scour the exposed ground surface for artifacts in the upper Savage basin.



Photograph courtesy of Angela Gore

Figure 5. CSFA archaeologists John Blong and Tom Jennings collect information on stone artifacts lying on the surface in the upper Savage basin.



Photograph courtesy of Tom Jennings

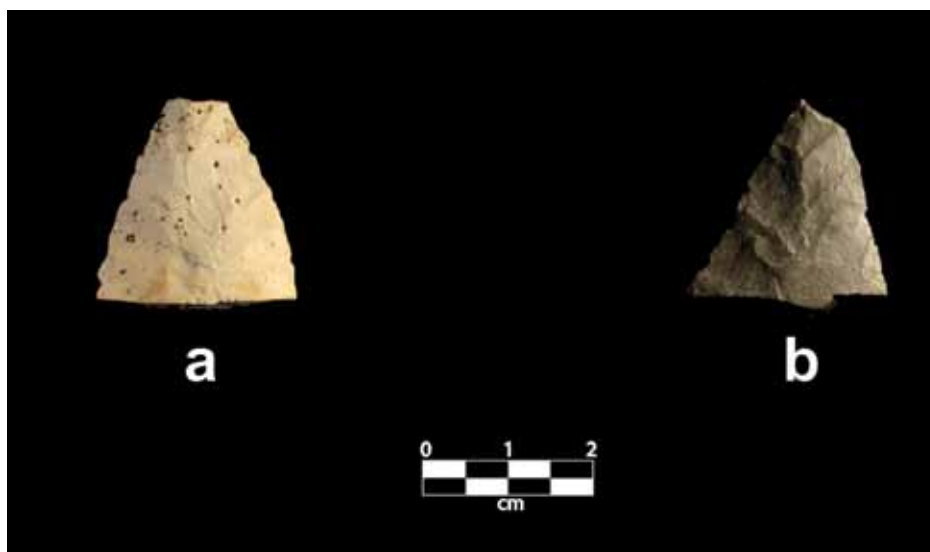
Figure 6. CSFA archaeologists John Blong and Heather Smith collect detailed provenience information on surface artifacts at Ewe Creek.



Photograph courtesy of John Blong

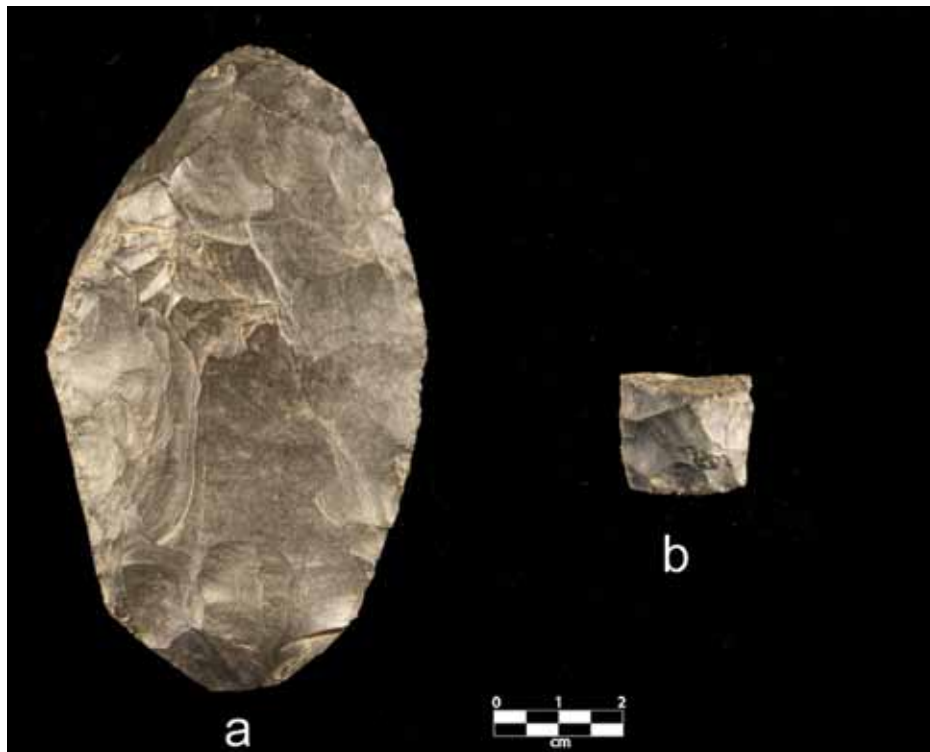
Figure 7. Sediment profile from 1 m² test unit at Ewe Creek showing (a) paleosol containing cultural material, (b) paleosol containing cultural material and charcoal radiocarbon dated to 4,150 ±40 14C BP (4,680 calBP).

Figure 8. Bifacially worked stone projectile tips recovered at Ewe Creek. Artifact (b) has a breakage pattern typical of a projectile point that fractured upon impact.



Photograph courtesy of John Blong

Figure 9. Stone artifacts recovered from Ewe Creek: (a) stone scraping tool likely used for carcass or hide processing, (b) bifacially worked stone projectile point base.



Photograph courtesy of John Blong

Temporal Span of Uplands Occupation

Archaeologists are most interested in artifacts that have been excavated from buried, datable contexts, because they often represent a discrete time period and therefore have more meaning to our understanding of prehistory. Unfortunately, most of the artifacts analyzed for this project were from surface contexts, and could potentially represent thousands of years of human activity. We recovered two lanceolate projectile point fragments, but this type of projectile point is found in assemblages dating from the Pleistocene through the late Holocene, and is often not useful as a chronological marker (*Holmes et al. 2008*). The buried artifacts from the Ewe Creek sites suggest that hunters occupied the study area as early as 4,680 cal BP, and the surface assemblages probably represent several occupations dating to this time period and younger, indicating that the uplands played an important role in hunter-gatherer lifeways in the middle and late Holocene.

Park Management

We had limited success revisiting previously recorded sites in the upper Savage basin. These sites could have been ephemeral occupations represented by the few artifacts that were collected in the original investigations, or cultural material may have been lost to erosion. A third possibility is that visitors disturbed or collected cultural material at these sites; all five of the unsuccessfully relocated sites are within a 30-minute hike from the Park Road. These results indicate how important it is to document archaeological sites before they are lost. Archaeological survey resulted in the discovery of five previously unrecorded sites, suggesting the future potential for locating additional unrecorded archaeological sites. The Ewe Creek sites are of particular significance because they have buried, datable cultural material in an unique setting adjacent to a mineral lick, and the age of the lowest component is a time not well represented in the prehistory of the region. This project utilized field notes, GPS,

and digital photography to significantly upgrade Denali site record forms and document new sites in the Savage basin, equipping park managers with the information necessary to make cultural resource management decisions.

Summary

Our 2010 field research program in the Savage basin met the three goals outlined in our research design. We successfully updated existing archaeological site records, located unrecorded sites, and excavated and dated artifacts from Ewe Creek, providing park managers with the information necessary to protect important cultural resources.

We also worked towards our two long-term research objectives: documenting prehistoric hunter-gatherer activity in the mountainous uplands of the central Alaska Range, and explaining the factors that influence prehistoric stone-tool manufacture. The data collected during this project suggests that by the middle Holocene, prehistoric people were using the uplands of the Savage basin for short-term hunting needs and collecting tool-stone from nearby drainages to produce bifacially worked projectile points. Future research will continue archaeological survey and excavation in the uplands of the Alaska Range to improve our knowledge of prehistoric use of these landscapes. More information about this project is available (<http://csfa.tamu.edu/>).

Acknowledgements

This research was funded by the Center for the Study of the First Americans Roy J. Shlemon Student Field Geoarchaeology Award and the Murie Science and Learning Center Discover Denali Research Fellowship. This project would not have been possible without the efforts of the 2010 field crew: Tom Jennings, Heather Smith, and Angela Gore.

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Teklanika West: A Late Pleistocene Multi-Component Archaeological Site in Denali National Park and Preserve

By Sam Coffman

Recent excavations at Teklanika West have yielded new data on site chronology and human occupation history. The archaeological site is located in Denali National Park and Preserve (Denali) and is situated on a loess-mantled granitic bedrock bluff overlooking the glacial-fed Teklanika River (*Figure 1*). Significant research has taken place at the site by other investigators since the early 1960s (*cf. Goebel 1992, 1996, Morgan 1965, Treganza 1964, West 1965, 1967, 1975, 1996*), due to the site's location and relatively easy access. These early investigations were largely surface collections of artifacts near the edge of the bluff. However, Fredrick H. West did conduct a series of small excavations at the site (*Figure 2*).

Based on these excavations, West interpreted the site to contain two large occupations (also referred to in this paper as components). The first was an undated occupation with numerous artifacts and some large mammal bones, likely moose (*Alces alces*) (*West 1996*). The second, and older underlying component, was a single undated large occupation, characterized by a microblade-rich assemblage with no associated fauna (*West 1965, 1975*).

This assemblage along with several other sites in interior Alaska was used by West to define the Denali culture complex dating to approximately 10,000 years

before present (B.P.). West's definition of the complex included bifaces, microblades, and wedge-shaped cores (*West 1975*). It is important to note that later excavations at the Dry Creek site north of Healy refined West's definition and ultimately became the type-site for the Denali culture complex. Interestingly, there was an older occupation. Artifacts from this occupation were used to define the Nenana culture complex. The most important aspect of the Nenana complex is that it lacks microblades and microblade technology.

A brief re-investigation of the site by Ted Goebel in 1992 yielded artifacts within a profile and stratigraphically associated radiocarbon dates (*1992, 1996*). The dates and artifacts indicated the site has multiple occupations ranging in age from the early Holocene (~10,000 years) to late Holocene (last 1,000 years). Goebel's investigations indicated Teklanika West was more complex than originally interpreted. His research suggested there might be faunal remains associated with the oldest component at the site. Given the two competing ideas, the 2009 excavations at the site focused on exploring basic questions concerning the site chronology, component (occupation) delineation, technological organization, and subsistence activities (if possible) based on faunal remains.

Stratigraphy

Block excavation was conducted at the site with blocks spaced approximately 16.5 feet (5m) apart to better address site formation and disturbances across

the site and landform (*Figure 3*). The upper Teklanika River valley was glaciated during the late Pleistocene (*Figure 4*) (*Warhaftig 1958*); however, no evidence of glacial activity (e.g. glacial till) was observed during the excavations, confirming the bluff the site occupies is solid bedrock and not glacially related.

Excavations showed the stratigraphy of the site consists of ~20-47 inches (~50-120 cm) of aeolian silt and sand; sediments, soils, and dates are illustrated in *Figure 5*. There are taphonomic disturbances at the site in the form of cryoturbation (frost churning, the result of movement in soil due to freezing and thawing). This was particularly noticeable in the upper sediments - the O, A, and B horizons. A tephra of an unknown source (not the locally known Jarvis Creek ash) is relatively continuous across the site at ~16" (~40 cm) below the modern surface. The C horizon is comparatively intact and lies atop bedrock. Radiocarbon dating illustrates a secure chronology for the site, including the Oshetna tephra (6,502-7,156 years ago) (*Addison and Beget 2010*) above a paleosol or former soil.

Component Delineation

The 2009 excavations showed that the site was more complex than both researchers had originally thought. There was considerable evidence that the site contained multiple components. Tentative component delineations are based on bone-collagen dating of animal taxa associated with lithic artifacts, stratigraphic association, and material type distributions. The two lowest components

Figure 1. Bedrock landform that Teklanika West occupies, overlooking the Teklanika River.

Photograph courtesy of S. Coffman



NPS photograph, Denali National Park and Preserve Archives

Figure 2. Frederick H. West excavating at Teklanika West.

(illustrated as C1 and C2) appear spatially separated, below the paleosol. Component 1 is associated with a *Bison* sp. and has been dated to about 12,600-13,100 years old. It contains two broken bifaces (Figure 6) and a side scraper. This component is unique because it dates to the initial Younger Dryas period (a cool, dry period in the Earth's climate history dating from about 12,800-11,500 years ago) (Mangerud et al. 1974, Meltzer and Holliday 2010). This is a period with very few archaeological components in eastern Beringia, and may represent a transition between the older Nenana and younger Denali culture complexes.

Component 2 is dated to the early Holocene, 9,697-11,246 years old, and also associated with bison (*Bison* sp.). This component contains the highest number of tools recovered from the site. Tools from this component include three strongly convex lanceolate projectile point bases (Figure 6), two end scrapers, two broken bifacial performs, and two microblades. Component 3 is directly associated with the paleosol of the site. Direct dating of charcoal from the paleosol puts the age of this component to between 7,565-7,689 years old. Artifacts from this component include two bipointed lanceolate projectile points (Figure 6), three boulder spall scrapers,

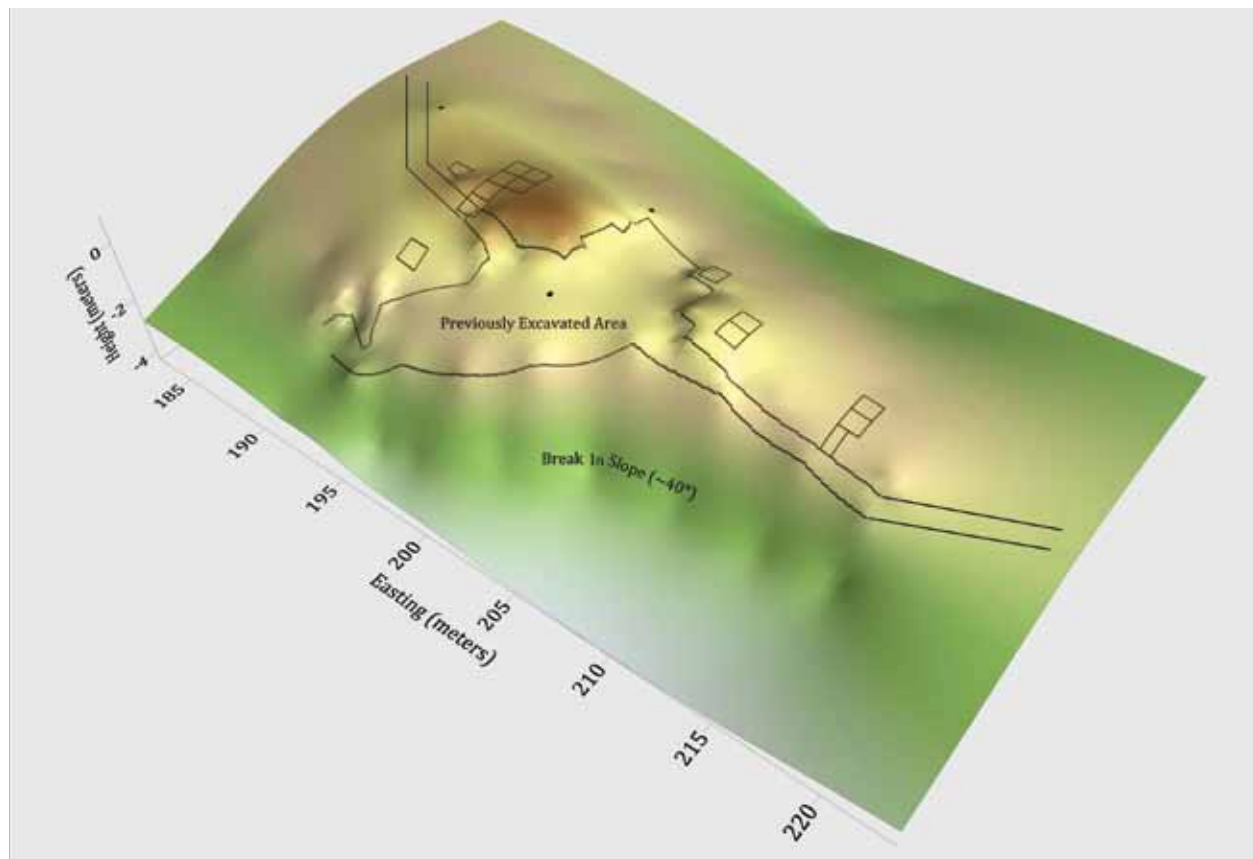


Figure 3. 2009 block positions at Teklanika West.

highly fragmented faunal remains (none of which were identifiable), and microblades. There were four obsidian microblades recovered from this component (Figure 7). Each of these microblades has been geochemically sourced to the Batza Tena obsidian source located near the Indian River, a tributary of the Koyukuk River. The source itself is located approximately ~200 miles (~320 km) from the site, implying the obsidian was either traded or directly procured. Identification of charcoal from the paleosol has been identified as spruce (*Picea* sp.). Spruce is one of the predominate tree species that makes up the boreal forest, and the presence of spruce within the paleosol and at this age would imply that

the boreal forest had or was in the process of being established in the upper Teklanika River valley.

Component 4 at Teklanika West dates to between 2,342-2,514 years old. This component contains caribou (*Rangifer tarandus*) remains. This component shows considerable continuity with Athabaskan subsistence practices. Tools from this component include two lanceolate projectile point bases (cf. Figure 6). These bases share many affinities to those from component 2 and likely represent post depositional disturbance or movement of these artifacts, since both were found in a rodent burrow. The last and youngest component represented at the site dates to the late Holocene, about

1,283-1,417 years old. Component 5 contains Dall's sheep (*Ovis dalli*) remains. Similarly to component 4, component 5 shares a link to Athabaskan subsistence practices and neither component contains microblades.

Based on these most recent excavations at the site, with modern techniques, these data demonstrate the presence of multiple components, including one dating to the late Pleistocene. The relative lack of a microblade industry at the site might relate to the small sample size at present, but the presence of microblades in small samples in components 2 and 3 are consistent with regional continuity of this technology (Potter 2008).

There were no Nenana complex diagnostic materials (tear-dropped shaped projectile points) found in any of the components (Goebel *et al.* 1991). Bison

remains were present at the site during and after the Younger Dryas. Coupled with the bison found at the intermediate Dry Creek component 2 (~11,400-12,200 years old) (Powers *et al.* 1983), this suggests that bison were a reliable resource in the northern foothills of the Alaska Range during and after the Younger Dryas. This strategy in subsistence differs significantly from the later Holocene components that are associated with modern upland ungulates (sheep and caribou).

Current interpretations of two distinct cultural traditions (Nenana and Denali complexes) in interior Alaska separated by the Younger Dryas are more difficult to sustain given older microblade technology at sites in the Tanana River valley (e.g. Swan Point (Holmes 2001) and younger Chindadn points in Cultural Zone 3 at Swan

Point (Holmes 2008)). Interpretations of the Teklanika West data seem to indicate microblade technology was not a key focus at the site. Rather, tool refurbishment and biface production seems to have played larger roles at the site. However, it is still unclear, at present, how the Teklanika West data fits into the broader cultural chronology of the region. What is clear is that a single microblade-rich Denali complex occupation at the site is shown to be incorrect. Additionally, given the new dating of the site, it is now the oldest archaeological site in Denali National Park and Preserve. The site has assisted greatly to elucidate lifeways of early populations in upland regions of the foothills region of central Alaska.

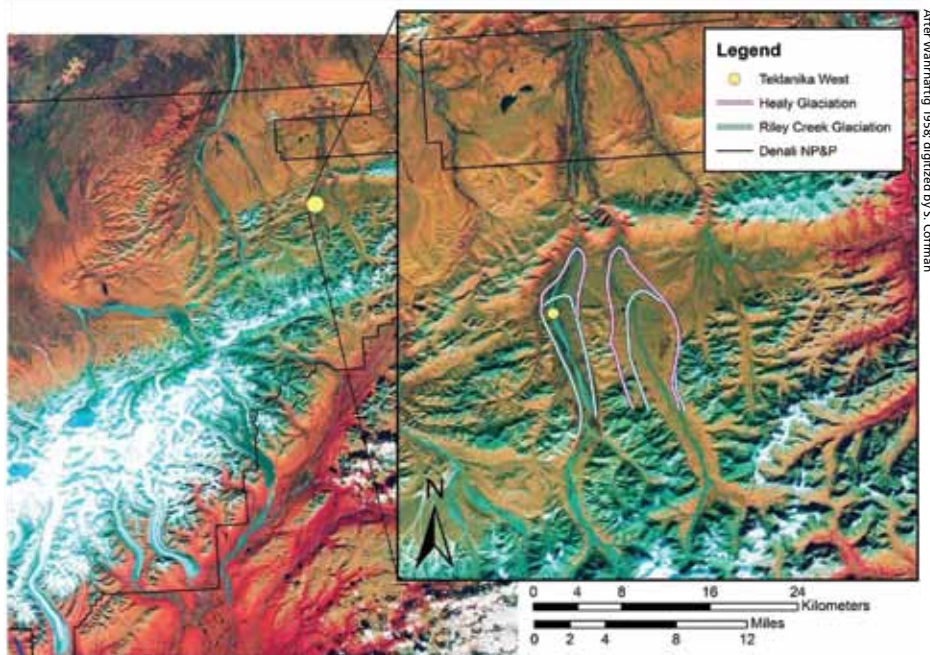
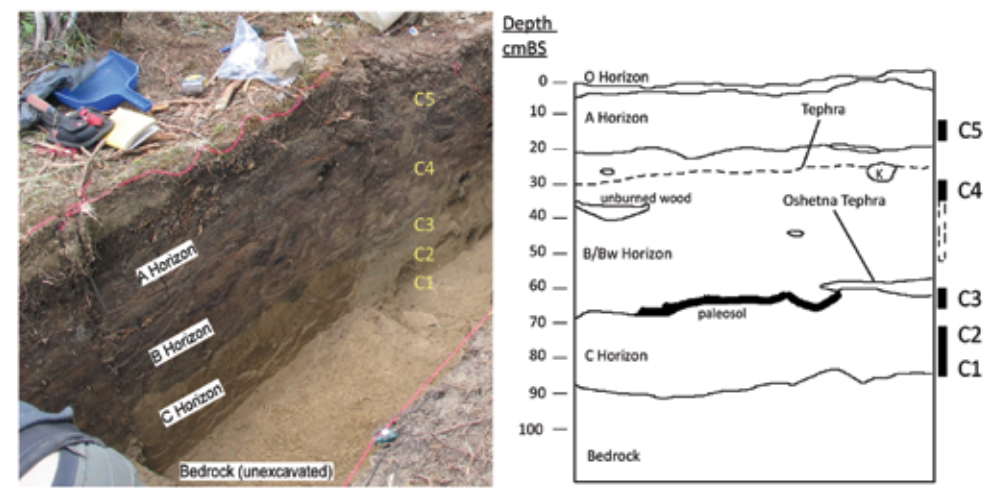


Figure 4. Glacial history of the upper Teklanika River valley.



Component 5 (C5) 1283-1417 years old, Coffman 2011
 Component 4 (C4) 2342-2514 years old, Coffman 2011
 Component 3 (C3) 7565-7689 years old, Coffman 2011
 Component 2 (C2) 9697-11,246 years old, Coffman 2011
 Component 1 (C1) 12,600-13,100 years old, Coffman 2011
 (all dates are calibrated ages before present)
 K = Krotovenia, distributed area
 Dark areas are paleosols

Figure 5. Stratigraphy and dating at Teklanika West.



Figure 6. Bifaces from all components at Teklanika West.



Figure 7. Obsidian microblades from Component 3.

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Collaborative Research to Assess Visitor Impacts on Alaska Native Practices Along Alagnak Wild River

By Douglas Deur, Karen Evanoff, Adelheid Herrmann, and AlexAnna Salmon

The Alagnak (or “Branch”) River drains the eastern front of Aleutian Range peaks, descending through Nonvianuk and Kukaklek Lakes – among the highest-elevation sockeye spawning lakes in the world – and down through complexly braided channels to meet Bristol Bay tidewater. As one of the region’s famously productive salmon rivers, the Alagnak’s banks historically were lined with villages of both Yup’ik and Alutiiq residents, and archaeological data document millennia of human occupation (*Bundy 2007*). Certain twentieth century disruptions brought an abrupt end to year-round settlement. The ‘Spanish influenza’ epidemic at the end of World War I brought dramatic demographic contractions along this river, and federal policies requiring formal schooling for Native youth in the mid-twentieth century induced the relocation of surviving families to places off-river. They regrouped in larger villages, principally in the nearby Kvichak and Naknek River Basins, some not leaving the Alagnak until the late 1960s. Though displaced, many families continued to fish, hunt, and gather plant foods on the Alagnak, often for months at a time, maintaining cabins and Native allotments for this purpose. Into the late twentieth century, food gathered on the Alagnak still served as the

Figure 1. Map of the Alagnak River.

Figure 2. A former village site near the forks of Nonvianuk and Alagnak Rivers that disbanded after the influenza pandemic of 1918-1920. A number of village sites are still apparent along the Alagnak; such locations make appealing campsites to river visitors, creating challenges in light of the cultural and archaeological sensitivity of these sites.

Photograph courtesy of Douglas Deur

foundation of year-round subsistence, and social activities on the river represented a cornerstone of community life. For these people, the Alagnak is conceptualized both as “home” and as a resource-rich refuge, where families can return to harvest subsistence resources, reconnect with their heritage, and briefly escape modern village life.

In recent decades, however, the Alagnak’s natural bounty has been discovered by the outside world. Recreational lodges now dot the river’s lower reaches, and each summer a growing number of recreational fishermen and hunters from the United States, Europe, and Asia arrive on the Alagnak River. River life is further transformed by such unprecedented recreational activities as river rafting – an increasingly popular summertime pursuit for visitors from around the globe. Predictably, these changes have caused friction. Tourist visitation has compounded a number of other recent changes in Alaska Native community life, and Native use of the Alagnak has declined significantly in a generation’s time. Some 67 river miles of the Alagnak were designated in 1980 as one of the nation’s few “Wild Rivers” under ANILCA and the Wild and Scenic Rivers Act, and is now managed with Katmai National Park and Preserve. Still, the pressures on the river continue to expand, raising concerns among some Alaska Native river users that in time these changes might largely eliminate their presence from this valued corner of their traditional territory.

Recognizing that these developments presented the NPS with compliance and planning challenges, Katmai initiated a river management plan as well as several studies (e.g., *Deur 2008, Spang et al. 2006, Zwiebel 2003, Curran 2004*). Following guidance from a 1996 reconnaissance effort by former NPS anthropologist Michele Morseth, Dr. Jeanne Schaaf (Chief of Cultural Resources for Lake

Clark, Katmai, Alagnak, and Aniakchak) called upon Dr. Douglas Deur to initiate a broad ethnographic investigation of visitor impacts on Alaska Native communities through a Cooperative Ecosystem Studies Unit task agreement. The research strategy and methodologies employed as part of this project were somewhat unique. Deur worked collaboratively with an NPS research partner – Lake Clark National Park and Preserve Anthropologist and Alaska Native scholar, Karen Evanoff (Dena’ina). Together, Deur and Evanoff collaborated with residents from the villages of Igiugig, Levelock, Naknek, King Salmon, and Kokhanok in designing the current study. All of these communities possess some contemporary and historical ties to the Alagnak, although their different patterns of river use mean that visitor impacts manifest somewhat differently. With village input, they developed a research plan, identifying appropriate methodologies and envisioning final research products that might best convey community concerns to the outside world. Deur and Evanoff then recruited and helped train two Alaska Native research assistants from these villages – Adelheid Herrmann (Naknek) and AlexAnna Salmon (Igiugig) – to serve as part of a collaborative Alagnak research team. Herrmann and Salmon were able to assist the project’s lead researchers in organizing and conducting interviews and were also able to carry out independent interviews too, adding considerably to the depth of project findings. These local research assistants helped explain project objectives to their communities, while helping to translate and contextualize their communities’ concerns to the lead researchers. The research thus compiles knowledge while also building capacities – preparing the assistants for participation in future research or allowing them to be well-informed guides in future research endeavors

relating to Alaska Native interests on public lands.

While existing NPS and Alaska Department of Fish and Game files suggested a number of direct effects of visitors on the Alagnak (e.g., increased pressure on fish resources, and increased crowding), we predicted that these direct effects would have corresponding indirect effects, which were underreported but often of equal or greater concern to Alaska Native river users (e.g., secondary effects on Native cultural transmission and off-site effects on Native economic practices). The research team identified key people in each community who were knowledgeable about the study area based on personal use or inherited oral tradition. Additional interviewees were identified through “snowball sampling,” in which interviewees were asked to identify additional knowledgeable people in the community. These individuals participated in recorded qualitative interviews in turn, until the reservoir of all identified knowledgeable individuals who were able and willing to participate had been interviewed. Cumulatively, formal interviews were conducted with no fewer than 25 individuals – some being interviewed repeatedly. Interview content was transcribed and reviewed for recurrent

themes, and these themes were assessed with reference to preexisting archaeological, ethnographic, and biophysical data relating to the study area. In addition to conducting formal interviews and archival research to assess indirect effects, the Alagnak research team carried out field visits along the Alagnak River, mapping and photographing cultural sites, recording traditional place-based knowledge, and documenting Alaska Native river users’ concerns.

Visitor impacts on the Alagnak reported by Alaska Native participants in our study included the types of direct and readily quantifiable effects so well summarized in past subsistence research, but often focused instead on indirect, secondary and intangible effects. Of all reported concerns, Native interviewees mentioned bank erosion most frequently, but emphasized indirect as well as direct effects of erosion as being fundamental to their concerns regarding visitor impacts. Native river users report that increased river traffic, often involving jet-boats and other high-speed vessels, has accelerated erosion along portions of the river bank. Native allotments and cabins have been undermined by erosion in turn. Erosion was always part of life on the Alagnak, interviewees

sometimes noted, but today their adaptability to erosion has decreased as they are “locked in” to fixed land boundaries and there are logistical barriers to mobilizing large, youthful work groups. In addition to displacing some river users outright from their cabins and allotments, erosion is said, in turn, to affect riparian vegetation and potentially increase sediment deposition in fish spawning gravels downstream (*Deur 2008, Curran 2003*).

While river crowding was identified as an effect of increased visitation (*Zwiebel 2003*), interviewees made it clear that crowding had secondary effects that were of particular concern. Interviewees noted that summer and fall subsistence hunting was no longer safe in light of visitor densities and had been largely discontinued. Interviewees shared a number of anecdotal accounts of hunters nearly firing a shot at game, only to have river visitors appear in the line of fire from concealed positions in front of, or behind, the intended target along the complexly braided and vegetated river channels. Crowding was also widely believed to have contributed to reduced bear flight distance, which was said to pose new safety threats to Native and non-Native river users alike,



NPS photograph by Karen Eganoff

Figure 3. Igiugig elder, Mary Olympic, being interviewed by her granddaughter, research assistant AlexAnna Salmon, and Principal Investigator Dr. Douglas Deur. Research assistants received training in research methods and then applied these methods in collaborative tasks.



Photograph courtesy of Douglas Deur

Figure 4. Interviewee Annie Wilson inside one of the trapping cabins owned and used by members of her family along the Alagnak River corridor.



Photograph courtesy of Douglas Deur

Figure 5. One of several cabins still maintained on allotment inholdings within Alagnak Wild River boundaries. In recent times, Alaska Natives have used such structures when working on NPS archaeological teams or as trespass officers. “No Trespassing” signs accompany most cabins and allotments, but visitor use of these structures presents persistent challenges.

as bears hold their ground and come into closer proximity to humans than what was recalled historically. Crowding also reduced Native users' sense of solitude and privacy, as impromptu contact with unknown visitors and motor noise encroached on Native visitors' experience.

Many interviewees expressed objections to what are seen as demonstrations of outsiders' "disrespect" toward culturally significant plant and animal species – species whose persistence is traditionally believed to depend on displays of respect and reciprocity through ritual and other means. Clearly, the concept of what constitutes respect and disrespect are embedded in a constellation of values and experiences that are somewhat unique to these communities, which we sought to elucidate through this

research. Disrespectful and risky visitor behavior toward bears and other natural hazards is said to unbalance long-standing relationships and to place Native users at risk – by acclimating bears and by creating situations wherein Native river users must assist in emergency situations. "Catch and release" fishing was also cited as a form of disrespect that might have consequences for Native communities beyond merely material effects. Native users also expressed concern regarding forms of disrespect toward Native peoples and their private lands: interviewees reported trampling and littering, as well as occasional theft and vandalism on Native allotments. These were reported as material inconveniences, but were equally disconcerting to many interviewees as manifesta-

tions of disrespect from visitors, attenuated by perceived race and class bias. In turn, visitor numbers have brought about increased regulation and policing by federal and state authorities – a trend that is welcomed to the extent that it protects Native interests, but is simultaneously lamented as Native individuals increasingly feel that they are being monitored in their own traditional lands.

Visitor numbers are said to have been one of several variables contributing to decreases in traditional economic activity such as fur trapping, with changing game patterns and logistical challenges. Simultaneously, visitors have increased opportunities for cash employment related to NPS resource management, trespass enforcement, and charter operations, while also creating income-generating opportunities relating to the leasing or recreational use of Native allotment and corporation lands. In some cases, decisions about how to balance visitor impacts and economic opportunities pit traditionalists against proponents of modern economic development – a common and occasionally destabilizing dynamic in many Alaska Native communities. Reduced subsistence harvests on the Alagnak and elsewhere have hastened Native economic and technological transformation in the region—some suggest that this has increased Native dependence on outside economies, and adversely affected their "food security," though it remains unclear how proportionally significant displacement from the Alagnak may be in this larger trend. A number of interviewees noted that visitor pressures have changed the seasonality of subsistence river use, and reduced both individual and community reliance on certain species historically obtained during the summer months on the Alagnak, such as king salmon (*Oncorhynchus tshawytscha*).

Cumulatively, the evidence suggests that increased competition for game, increased hazards, and other effects together have contributed to a reduction in Alaska Native use of the river. This has corollary effects that had not been previously reported, including intensified subsistence hunting and fishing on non-NPS lands nearby. Of greatest concern to interviewees among



Photograph courtesy of Douglas Deur

Figure 6. A number of group interviews took place in the course of this research, often facilitating elders' recollections with prompts from other elders in the room. Information from these group interviews were compared with individual and field interviews to provide a more rich foundation for analysis. Here, interviewee Dallia Andrew describes traditional fishing sites with the input of other elders.



Photograph courtesy of Douglas Deur

Figure 7. Initial off-site interviews involved the use of maps and aerial photo mosaics to identify the locations of villages, camps, resource sites, named places, and other elements of the cultural landscape. These were later checked in the field, with the assistance of Alaska Native elders.



Photograph courtesy of Douglas Deur

Figure 8. Interviewees George and Annie Wilson with Lake Clark park anthropologist Karen Evanoff (center), checking field locations by riverboat on the Alagnak.



Photograph courtesy of Douglas Deur

Figure 9. Rafters camping along the Alagnak River in August 2012. Campers occupy riparian islands and shorelines throughout this complexly braided river system throughout the summer months.



Photograph courtesy of Douglas Deur

Figure 10. Remnants of fish smoking houses and other outbuildings that have eroded into Alagnak River in the last two decades.



Photograph courtesy of Douglas Deur

Figure 11. Igiugig elder, Mike Andrew, identifying the place where he was born along Alagnak River. He was born while his family trapped beaver on the river from a tent camp on a channel extending off of the middle river – now a popular staging area for recreational fishermen.



Figure 12. Archaeological excavations at a former village site along Alagnak River in 2004. Work overseen by Dr. Jeanne Schaaf has demonstrated the presence of large, permanent villages along the Alagnak, dating from no later than 2,300 years before present, that utilized riverine resources in ways similar to those described today by Yupik elders. Older sites along the river can be dated to the Paleoarctic tradition, between 7,000 and 9,000 years before present.

these indirect effects, perhaps, is the fact that declining access to the landscape has reduced inter-generational transmission of traditional knowledge pertaining directly to the Alagnak region—the passing on of place-based cultural and biological information from elders to children—potentially eliminating certain domains of cultural knowledge and practice, and affecting communities' sense of identity. Interviewees suggest that the traditional view of the Alagnak as both a home and a place of refuge is generally in decline, and the indirect effects of visitor uses are contributing to this trend.

No doubt, many NPS resource managers share the concerns of Alaska Native river users. Through this research, resource managers have gained an uniquely in-depth view of Native Alaskan perspectives on the landscape, and have access to the tremendous accumulated knowledge of multigenerational Native river users. The work—available publicly from the NPS Regional Office in summary reports by late 2013—gives cultural resource managers site-specific information on places and resources of concern to Native communities and gives natural resource managers testable hypotheses regarding resource trends that can be addressed in future river management planning and research. The work also points toward a variety of compliance implications under

federal law and policy relating to cultural resources and practices of Alaska Native peoples. Already, the work has fostered direct meetings between the park superintendent and Native communities on issues of mutual concern – from collaborative interpretative development opportunities to shared resource protection strategies. The Alagnak research team anticipates that the documentation resulting from this research will 1) aid these communities in articulating their concerns in resource management planning venues, including those indirect effects that are often difficult to enumerate in compliance-driven consultation, 2) identify future natural resource research needs, and 3) serve as a foundation for broader cross-cultural discussion and understanding that might allow continued recreational uses of the river while insuring that the Alagnak will continue to sustain Alaska Native communities – dietarily, economically, spiritually, and culturally – for many generations to come.

“We thank you a hundred times over for bringing us back here,” one of the elders said during the final fieldwork on the Alagnak. We, in turn, thank the elders who guided us on the river, documenting not just visitor impacts, but many other things: important places, stories, oral history, landscape changes, edible and medicinal plants, cabins, genealogy, and traditional

ecological knowledge. A project is truly collaborative when we realize how much we have learned, not just intellectually, to meet our project goals and objectives, but also at the personal level, in our hearts and our heads, that will enhance our perspectives for many years to come. We had the opportunity to learn from the original inhabitants of this land, gaining insights into the impacts of visitors to the Alagnak River area, and also gained a glimpse of the vast knowledge of these original inhabitants while exploring together on the land; this was one of the greatest highlights of this four-year project.

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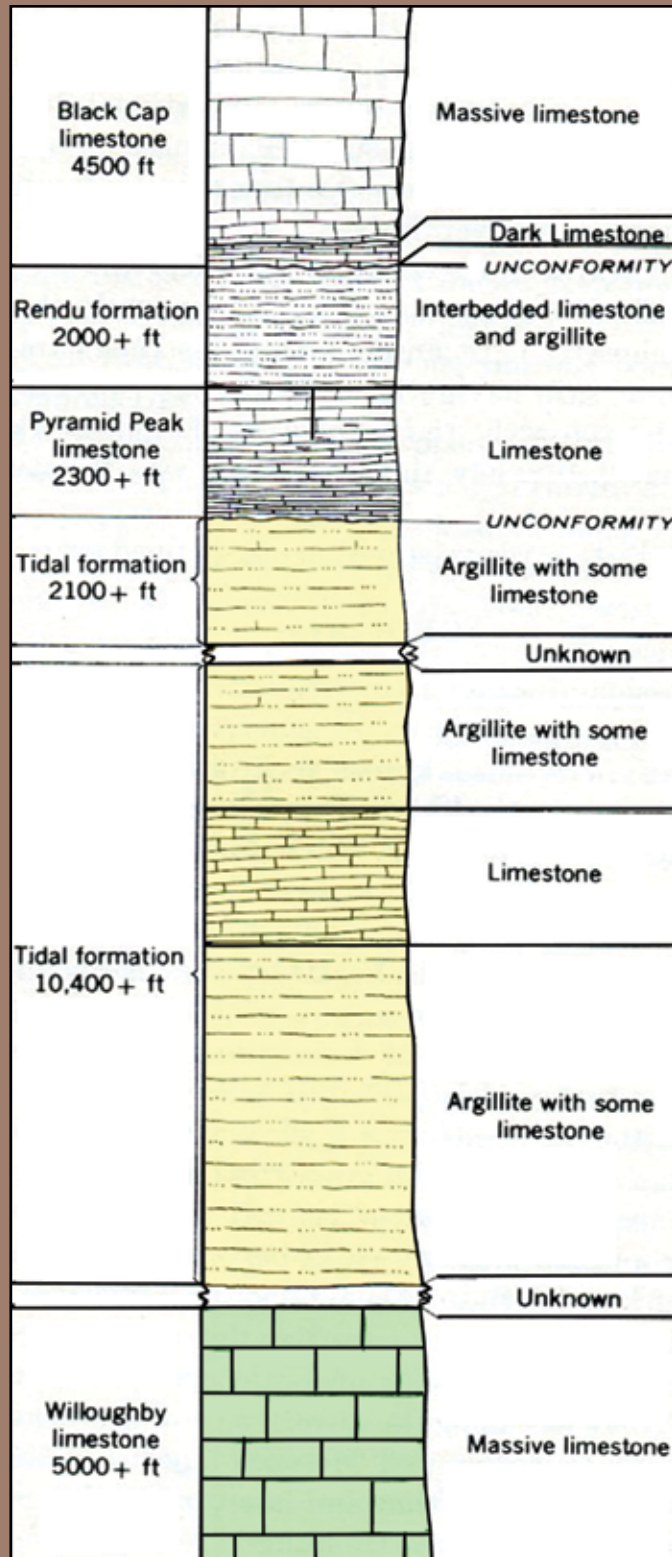
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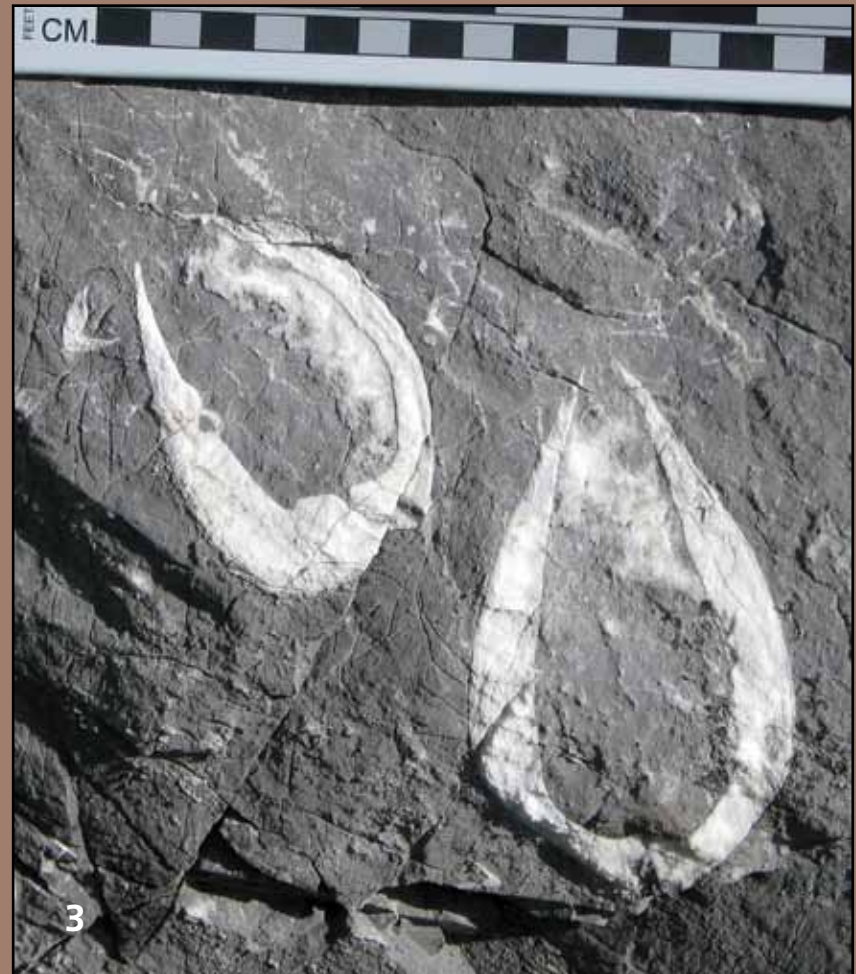
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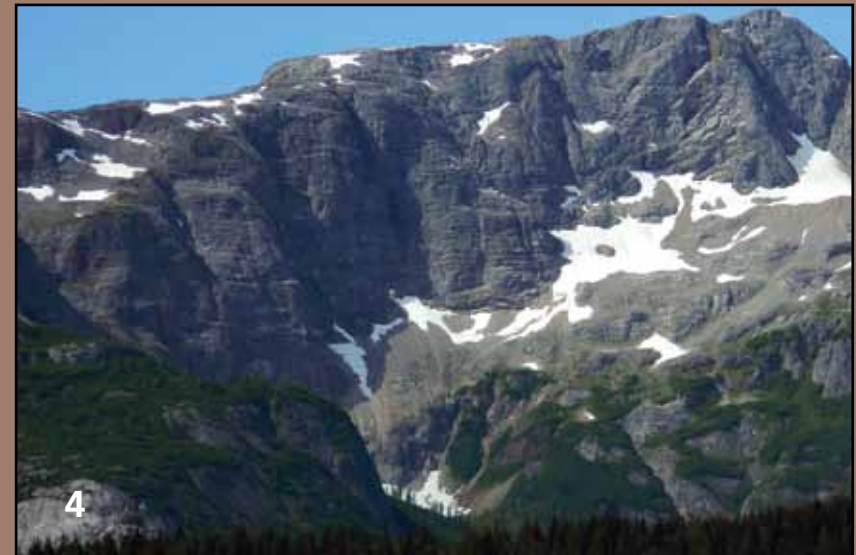
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Shallow and Deep Water Origins of Silurian Rocks at Glacier Bay, Alaska

By David M. Rohr, Robert B. Blodgett, Vincent Santucci, and Ladislav Slavik

Glacier Bay in the northern part of Southeast Alaska (Figure 1) contains a remarkably thick succession of middle Paleozoic (*Silurian and Devonian*) age strata, which were geologically mapped in detail by Seitz (1959) and Rossman (1963). The stratigraphic framework (Figure 2) for the Paleozoic succession of the Glacier Bay area was established by Rossman, who formally named the Paleozoic formations present in the region. These included from presumed stratigraphic bottom to the top: Willoughby Limestone (late Silurian, about 425 million years old); Tidal Formation (late Silurian); Pyramid Peak Limestone (unfossiliferous, age unknown); Rendu Formation (unfossiliferous, age unknown); and Black Cap Limestone (Middle Devonian according to Rossman, but now known to contain Early Devonian

Figure 1. (Map) Silurian strata are exposed on Willoughby and Drake Islands, Marble Mountain, Sandy Cove, and Tidal Inlet in Glacier Bay. Similar Silurian formations are also found to the south on Chichagof Island.

Figure 2. Rossman formally named the Paleozoic formations in Glacier Bay, including the very thick Silurian Willoughby and Tidal formations.

From Rossman (1963)

Figure 3. The large, upper Silurian lagoonal bivalve *Pycinodesma* is locally abundant in the Willoughby Limestone on northern Willoughby Island.

Photograph courtesy of R. Blodgett

Figure 4. Nearly horizontal bedding in the Willoughby Limestone is present on parts of the eastern side of Marble Mountain.

Photograph courtesy of D. Rohr

fauna as well). These rocks are all part of the accreted Alexander terrane. In the Alexander terrane, thick Silurian carbonate shelf facies have been mapped from Prince of Wales Island in the south to Glacier Bay in the north. The limestone lithosome was named the Heceta Limestone (Eberlein and Churkin 1970) on Prince of Wales Island, the Kennel Creek Limestone (Loney et al. 1963) on Chichagof Island and the Willoughby Limestone (Rossman 1963) in Glacier Bay. The north-south trend is offset by the Chatham Strait Fault.

Willoughby Limestone

The Willoughby Limestone was formally established by Rossman (1963) who estimated it to be at least 5,000 ft (1,524 m) thick and to consist of bedded limestones, with the exposures on Willoughby Island representing the most typical section. The name Willoughby Limestone was earlier used by Seitz (1959) without formal definition for Silurian limestone exposures in a small area of Geikie Inlet where he was mapping. He did not establish it as a formal stratigraphic name, obviously deferring to Rossman to name it, as the Willoughby formed a greater portion of his adjacent map area.

The Willoughby contains nearly all illustrated or formally described fossils from the Glacier Bay area. Previous faunal studies on the formation include work on the large, upper Silurian lagoonal bivalve *Pycinodesma* (Figure 3) (Kirk 1927a, 1927b, Kříž et al. in preparation) and associated large gastropods belonging to the genera *Bathmopterus*, *Kirkospira*, and *Coelocaulus* (Kirk 1928, Rohr and Blodgett 2003, Rohr et al. 2003). All of the preceding molluscan papers were based on collections made from restricted lagoonal limestones exposed on a small satellite island lying off the northeast coast (Johnson

Cove area) of Willoughby Island. Two samples from the Johnson Cove area were processed for condonts, but they were barren. Soja et al. (2000) reported on stromatolite reefs and associated lithofacies found in the Willoughby Limestone on the southwest and east sides of Drake Island. Locally abundant brachiopods from western Drake Island collected by us in 2011 are described in Blodgett et al. (2013). The upper contact of the Willoughby Limestone was reported by Rossman to not be recognized.

Not all of Marble Mountain is marble. Marble Mountain was mapped by Rossman as Willoughby Limestone. Totally recrystallized carbonates do occur on the eastern shore of Marble Mountain, North and South Marble Islands, and southern Drake Island. Marble Mountain itself consists in part of noticeably bedded nearly horizontal limestone, about 3,300 ft (1,000 m) thick, without any major structural features (Figure 4). An unpublished USGS collection (66AOv181) made by A.T. Ovenshine from the northern shoreline of Marble Mountain contained recrystallized, indeterminate rugose coral, possibly *Tryplasma* sp., and we observed recognizable textures and fossils in talus on the western shoreline of Marble Mountain in Shag Cove. Rossman observed "...the large flat-lying body of the Willoughby Limestone that caps White Cap Mountain" (Rossman 1963).

Tidal Formation

The Tidal Formation was named by Rossman for a widespread argillaceous unit, which he mapped at Tidal Inlet and around Pyramid Peak and Mount Wright. He reported the formation to be at least 10,400 feet (3,200 m) with an unknown base and an angular unconformable relation with the overlying Pyramid Peak limestone. The typical lithology reported by Rossman is laminated sandy

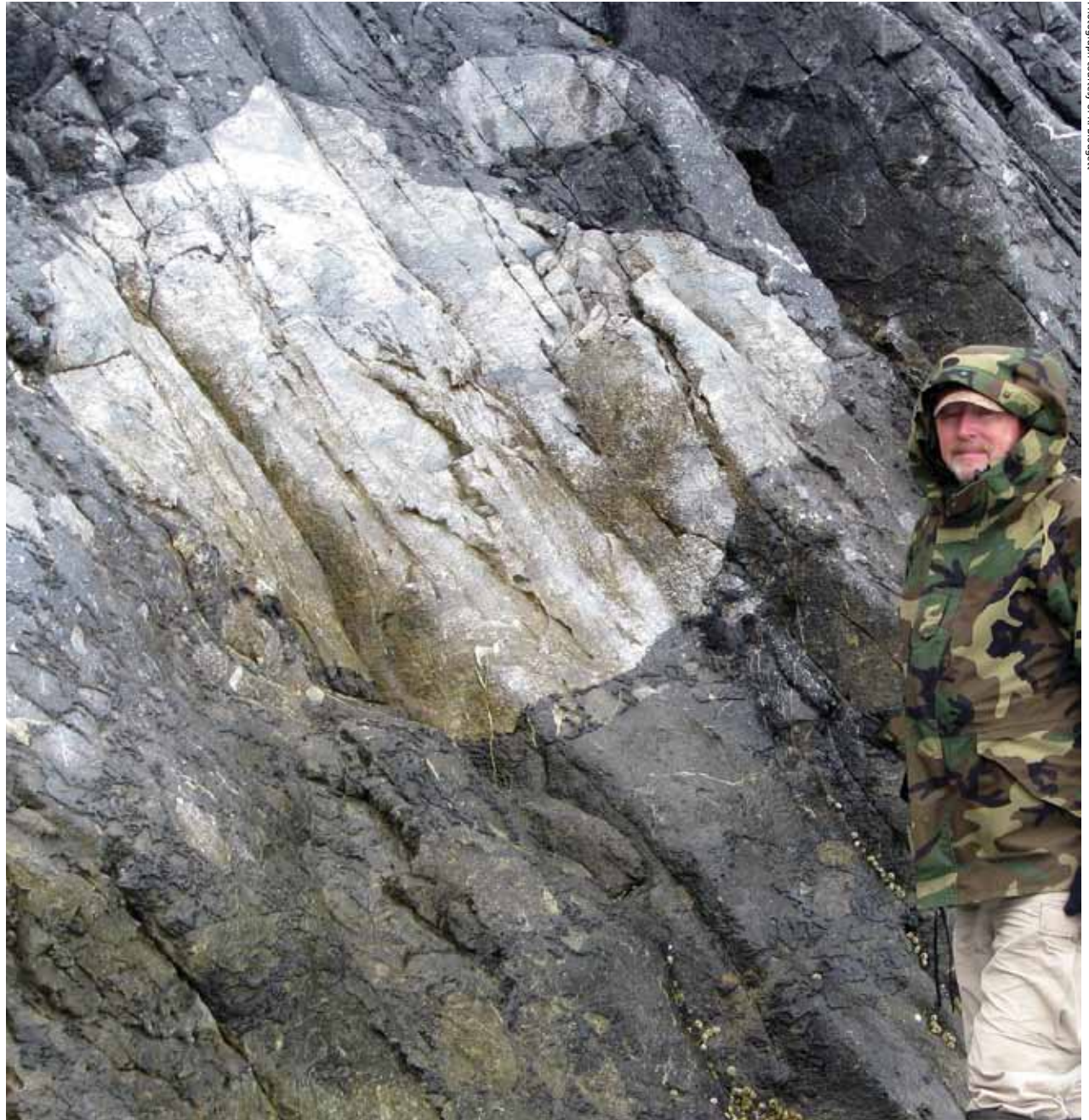


Photograph courtesy of D. Rohr

Figure 5. The typical lithology of the Tidal Formation reported by Rossman is laminated sandy siltstone with abundant shale. Our examination of the shale beds during 2011 at Tidal Inlet did not yield any graptolites or other fossils.

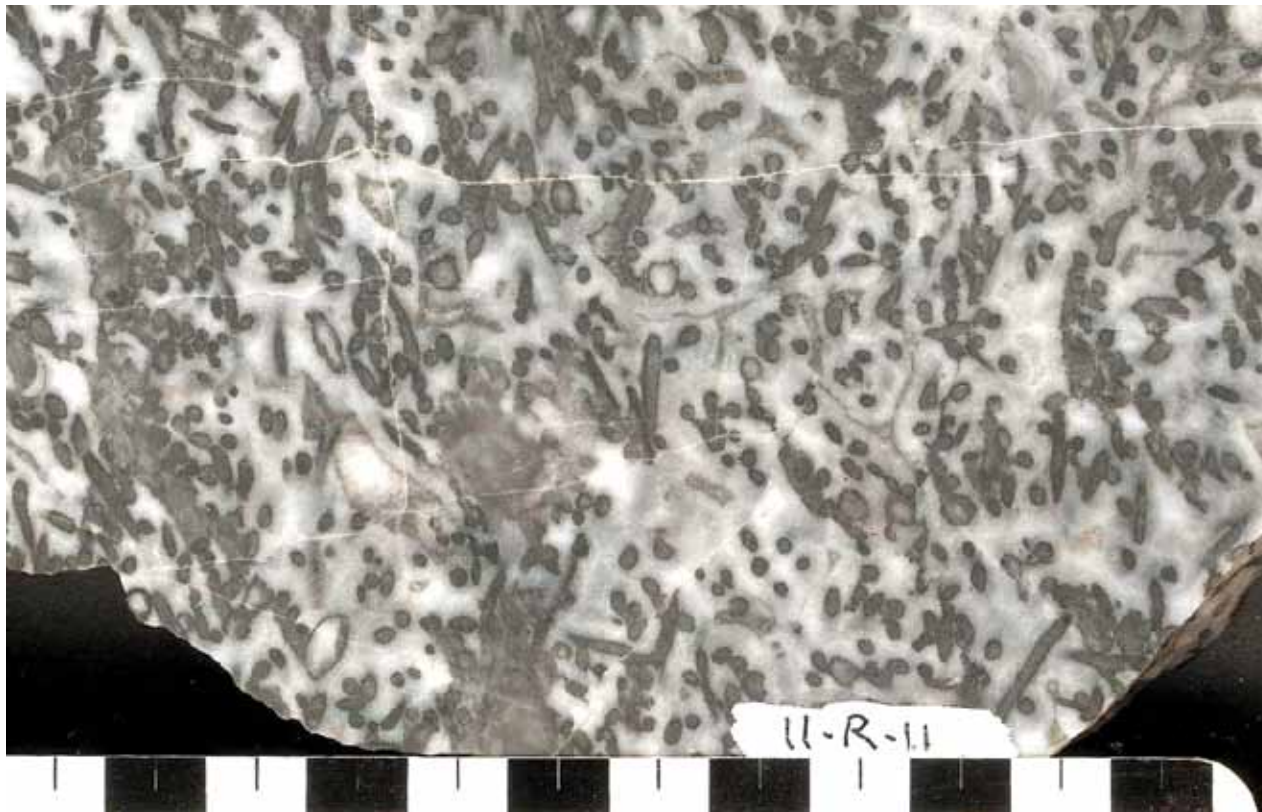
siltstone with abundant shale (*Figure 5*). Our examination of the shale beds during 2011 at the illustrated locality did not yield any graptolites or other fossils. Fossil collections made by Rossman and colleagues were identified by USGS paleontologists Edwin Kirk, Arthur Boucot, and Jean Berdan. Based on these identifications, Rossman assigned an age of late Silurian to the Tidal Formation.

A lithology not reported by Rossman, but possibly included in his middle limestone member of the Tidal Formation, is limestone conglomerate and breccia. These limestones are found along Tidal Inlet (*Figure 6*) and appear to be of similar lithologies as the Willoughby Limestone. One smaller clast (*Figure 7*) contained abundant amphiporoid stromatoporoids characteristic of shelfal or reefal facies. A large olistolith within the Tidal Formation on the southern side of Tidal Inlet (*Figure 8*) is crystalline carbonate. We conclude this enigmatic lithology to represent altered Willoughby Limestone because of its generally massive appearance and its similarity to that found on North Marble Island, southern Drake Island, and the eastern shore of Marble Mountain. Thin-bedded gray limestone (*Figure 9*) at Puffin Island in Sandy Cove may be the equivalent of Rossman's limestone member of the Tidal Formation, which he mapped south



Photograph courtesy of R. Blockett

Figure 6. Limestone conglomerate and breccia occur in the Tidal Formation along Tidal Inlet. Clasts are similar to the Willoughby Limestone.



Photograph courtesy of D. Rohr

Figure 7. A smaller clast in the Tidal Formation at Tidal inlet contains abundant amphiporoid stromatoporoids characteristic of shelfal or reefal facies. The slightly metamorphosed tubular fossils are surrounded by calcite spar cement. National Park Service collection, GLBA-00634.

of Tidal Inlet and on Mount Wright. The limestone in Figure 9 was processed for conodonts, but it was barren.

Talus of large blocks of siltstone along the shore at North Sandy Cove appears to be turbidite beds from the Tidal Formation. We found a single bed with brachiopods. Our limited collection of megafauna from the Tidal Formation in the Sandy Cove area is similar in general aspect to previous USGS collections. Graptolites have been earlier collected from Tidal Formation outcrops during the 1960s. Unfortunately the graptolite collections were noted as being misplaced at the U.S. Geological Survey Western Regional Office in Menlo Park, and never reported upon.

Our Reinterpretation

Rossmann reported the total thickness of the Silurian Willoughby Limestone and Tidal Formation to be at least 17,500 ft. (5,330 m). Our reconnaissance field study during the summer of 2011 indicates the Tidal Formation, instead of overlying the Willoughby, represents a coeval deeper-water facies equivalent of the carbonate platform succession of the Willoughby. The Willoughby is the carbonate shelf to the west and the Tidal filled the basin to the east (Figure 10). This interpretation is also accordant with the spatial distribution of outcrop belts of the Willoughby Limestone and Tidal Formation. The Willoughby is primarily restricted to

the west side of Glacier Bay and Gloomy Knob on the east side, with outcroppings of the Tidal Formation restricted further to the east side of Glacier Bay.

Comparison to Chichagof Island

The geology of northeastern Chichagof Island is similar to Glacier Bay. Although biostratigraphic control for many outcrops is still lacking, we have speculated that the rocks exposed in the Hoonah area represent a Silurian shelf-to-basin transition (Rohr *et al.* 2011). The rock types in the Tidal Formation are similar to that observed in an equivalent unnamed upper Silurian mixed siliclastic and limestone succession on northeast Chichagof Island (Figure 1) in the vicinity of Hoonah (Křtíz *et al.* 2011, Rohr *et al.* 2011, Boucot *et al.* 2012). The latter rocks appear to represent slightly deeper-water, basinal equivalents of shallow platform carbonates of the Kennel Creek Limestone (also containing abundant remains of the bivalve *Pycinodesma* and amphiporoids). The Kennel Creek Formation at its type area is composed of *Amphipora* and *Pycinodesma*, and was deposited in a shallow, shelf environment. Other exposures on northern Chichagof interpreted as slope deposits contain varying amounts of limestone. Quarries near Hoonah contain tabular limestone breccias, sedimentary folds and large, and channel-like lenses. The dominance of limestone suggest a proximal slope facies, close to the carbonate shelf.

Massive metamorphosed limestone with sparry calcite stromatolite structures is very unusual, and appears identical to unaltered parts of the Willoughby Limestone at Glacier Bay as well as the Silurian reefal rocks of southwest Alaska (Clough and Blodgett 1988). Karl and Giffen (1992) and Karl (1996) concluded the Point Augusta Formation represents a basinal, clastic turbidite fan deposit that grades into the Kennel Creek Formation. The Point Augusta Formation is similar to the Tidal Formation in Glacier Bay and consists of conglomerate, massive to medium bedded calcareous graywacke turbidites with associated debris flow deposits, and interbedded limestone.



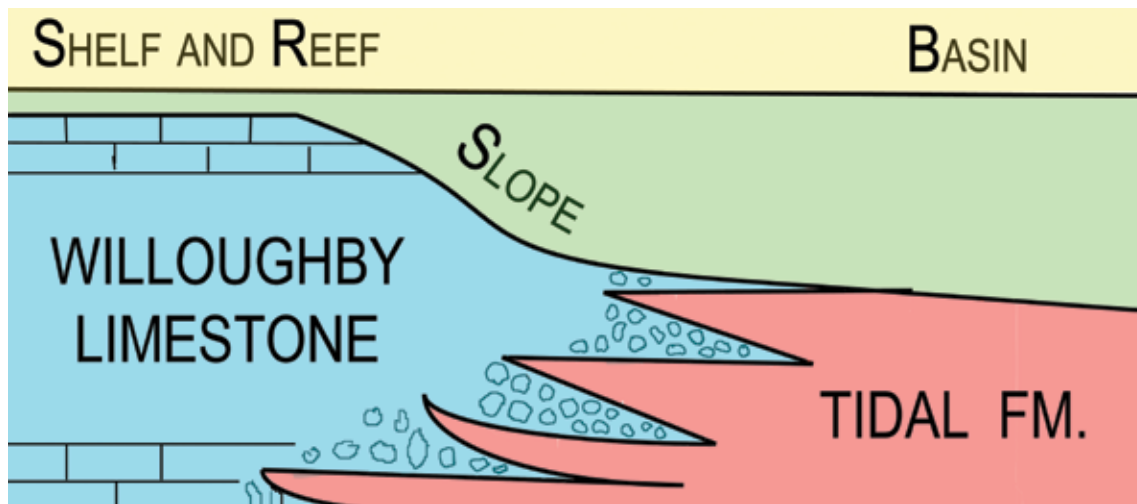
Photograph courtesy of D. Rohr

Figure 8. A large olistolith (arrow) within the Tidal Formation on the southern side of Tidal Inlet is crystalline carbonate, probably representing altered Willoughby Limestone.



Photograph courtesy of D. Rohr

Figure 9. Thin-bedded gray limestone at Puffin Island in Sandy Cove may be the equivalent of Rossman's limestone member of the Tidal Formation.



Photograph courtesy of Douglas Beaur

Figure 10. Generalized cross section of our interpretation of the facies relationship between the Willoughby Limestone and the Tidal Formation.

Conclusions

The great thickness of Silurian strata in Glacier Bay may be explained in part if the Willoughby Limestone and the Tidal Formation are coeval lateral facies representing a carbonate shelf-to-basin transition. This model fits the other Silurian formations seen elsewhere in the Alexander Terrance of Southeast Alaska. Even this interpretation leaves an impressive thickness (5,000-10,000 ft, 1,500 - 3,000 m) of Silurian for further biostratigraphic studies.

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Using Story to Build Stewardship

By David Tomeo

Look! There's a Bird Track

"It was the most amazing thing I ever saw; I'm still processing it," exclaimed field course participant Cheryl Romantz. Three theropod tracks had just been discovered on a remote mountainside in Denali National Park and Preserve. The group of teachers and paleo-enthusiasts were giddy with excitement because of the fossil-rich area they had found. Being the first to see 65 million year old tracks created a 'fossil fever'. Amid the excitement of scrambling for photos someone in the group yelled, 'Look! There's a bird track right next to it!' The lighting had changed just enough for another discovery to appear right at their feet.

Stories like this inspire visitors and motivate educators to develop hands-on park explorations. Education planners throughout the world recognize the power of personal experience and the stories that sustain memories. These personal narratives help create the foundation for park stewardship. In Denali the dinosaur story continues to grow with each group that helps search for new fossil evidence.

Denali's dinosaur story began with Susi Tomsich in June 2005 at an outcrop at the base of Sable Mountain. Dr. Paul McCarthy's field geology group was mapping Sable Mountain; McCarthy stopped the group at the outcrop along Igloo Creek to highlight the significance of the Cantwell Formation and its late Cretaceous age (Tyrell and Sutherland 2006). With the group leaning against the

outcrop, McCarthy explained that fellow paleontologists felt confident that dinosaur evidence would someday be found in the sedimentary rock (Tyrell and Brease 2006). As he described the features they might find in the rock, Tomsich impulsively turned to look where her head had been resting. What she saw was unmistakable. She waited politely for McCarthy to finish his lecture and then blurted out the words that started the story – 'Like this one?' The distinctive three-toed cast was a theropod dinosaur and the start of Denali's fossil fever (Tyrell 2006).

Paleontology is just one of the unique courses in Denali that puts real science in the hands of teachers, youth, and park supporters. As a non-profit park partner, Alaska Geographic coordinates a wide variety of experiential education programs with the goal of fostering life-long stewardship for our public lands. Each time a participant makes a discovery, witnesses a rarely-seen natural event, or simply experiences the beauty and challenge of the Alaskan environment, Alaska Geographic furthers this goal. Communicating science is an important objective, yet it is the opportunity to cultivate personal stories that fulfill the stewardship mission.

Stewardship Through Experience

Communication consultant Andy Goodman likes to remind people that 'nobody ever donates money or marches on Washington because of a bar graph'. With this in mind, Alaska Geographic champions public land stewardship by helping to develop deep connections with our Alaska public lands. These connections are often rooted in an inspiring individual, an intense experience, and the emotion evoked from those interactions. This leads to that final important step, the point at which the visitor becomes an invested steward of the environment.

Exceptional educators strive for this in the activities and stories they share, and they rarely use bar graphs.

In 2002, Alaska Geographic embarked on a new partnership with Denali National Park and Preserve. Traditionally providing only educational products, their mission was expanded to actively engage the public through experiential science education. Where they once provided books about grizzly bears, they now also provide field courses and guided walks exploring the many facets of *Ursus arctos*. These enhanced connections help Alaska Geographic develop a stronger constituency for our public lands.

Using Story To Close The Science Gap

We live in an age where style can influence the public's perception of science (Olson 2009), and in the science education community there is great concern about the decline of scientific literacy (Mooney and Kirshenbaum 2009). In 1959, the chemist and novelist Charles Percy Snow delivered an influential lecture that outlined a societal separation he saw developing—a separation between two areas of human intellectual activity, 'the sciences' and 'the arts'. He went on to describe the separation between the scientists and the non-scientists as a 'gulf of incomprehension'.

Today the size of this gap is debatable, yet across the country in schools and professional conferences, educators are urgently reexamining the effectiveness of their methodology. Investigative writers such as Richard Louv and Michael Pollan are inspiring us to examine how modern society has separated our understanding of nature from our connection to it. Telling people about the importance of a balanced ecosystem is not enough. Educators must build bridges between a person's

Figure 1. Alaska Geographic instructor Larry Montague helps a seminar participant across a creek.

Alaska Geographic photograph



Photograph courtesy of Ron Karpilo

Figure 2. Repeat Photography seminar participants at a historic site in Denali: Hines Creek, July 8, 2012.



USGS photograph by S.H. Carhart

Figure 3. The Stephen Reid Capps Expedition (Capps is at back left) at a food cache they built along Hines Creek in Denali, July 4, 1919.

scientific and artistic intellect—described in some circles as a connection between the head and the heart.

The power of story helps build those bridges and interpretive rangers and teachers use a variety of tools to create compelling presentations and activities. A method championed by NPS interpreters is the use of ‘universal concepts’—emotions common to all humans. Describing recent arctic sea ice data may stimulate a learner’s science intellect, but when the presenter can relate this process to a universal concept, such as ‘safety’ or ‘home’, they build stronger bridges. The effective educator incorporates those emotional connections into their narrative. A learner’s emotions are provoked by the story of the relocation of the 2,000 year old village of Shishmaref due to the loss of arctic coastline (*Bronen 2010*). In his 2008 essay ‘Why Stories Matter’, Marshall Ganz speaks to the power of universal emotions by provoking our audience to ‘get the moral not just as a concept, but as a teaching of the heart’.

Even on Alaska Geographic’s short park excursions,

educators avoid spouting facts and statistics; instead they attempt to weave their own personal experiences with the powerful stories of historical and contemporary scientists of Denali. By including a personal narrative, educators give the audience a better understanding of their values and what inspires them to act. This is another way that visitors can be inspired and think in new ways.

Research Fellows Give Us Stories

Science educators are not only eager for rich data, they also seek fresh stories. The young scientists supported by the Murie Science and Learning Center’s research fellowship are an excellent source for stories.

In 2006 the center began offering research fellowships to support small yet important research questions pertaining to Denali. The initial effort was funded through an education program of a nonprofit park partner, the Denali Education Center. In 2007, with Alaska Geographic’s support, the program was expanded

to all eight partner parks of the Murie Science and Learning Center. To date, more than \$200,000 has been awarded through 54 fellowships in eight park units.

The fellowship program is unique because it is funded entirely by education programs of non-profit park partners. While participants on guided hikes learn about current science, they simultaneously support new research efforts—creating a positive feedback loop.

The Capps-Karpilo Story

In 2011, Ron Karpilo of Colorado State University set out to retrace portions of the 1916 and 1919 USGS expeditions of Stephen Reid Capps. Karpilo aimed to retake many photographs from those early expeditions. Repeated images such as these offer botanists, glaciologists, and geographers a unique view into the past and an examination of the change that has occurred (*Molnia et al. 2007*).

In addition to the historic images, Karpilo also rediscovered a treasure trove of journals and log books from



Alaska Geographic photograph

Figure 4. Seminar participant Bruce Curtis-McLane experiences the hardships of field science in Denali.



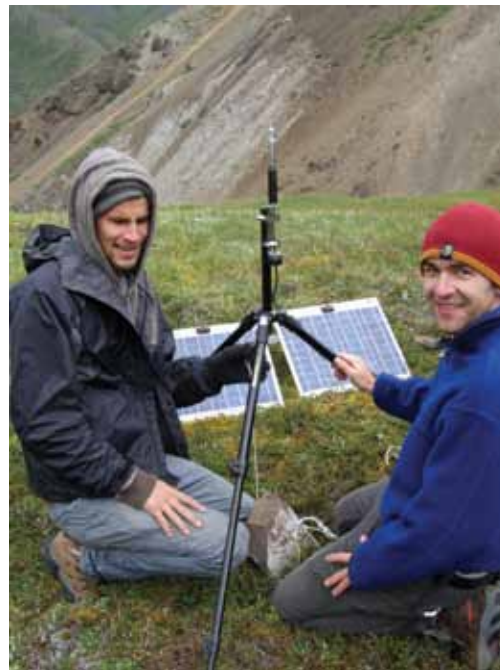
Alaska Geographic photograph

Figure 5. Wildlife biologist Bridget Borg shares stories with seminar participants.



Alaska Geographic photograph

Figure 6. (Left) Seminar participants explore wolf habitat with wildlife biologist Bridget Borg.



Alaska Geographic photograph

Figure 7. (Middle) Seminar participants help deploy a sound monitoring station in Denali.



Alaska Geographic photograph

Figure 8. (Right) Seminar participant Doris Ivory collects paleontological data in Denali.



Photograph courtesy of Ron Karpilo

Figure 9. Seminar participant and school teacher Nicole Flynn finds the location of a 1962 photograph of the Teklanika River valley.



Alaska Geographic photograph

Figure 10. A science seminar participant takes measurements of a large dinosaur track.



Alaska Geographic photograph

Figure 11. The Murie Science and Learning Center facility in Denali.



Photograph courtesy of Ron Karpilo

Figure 12. Seminar participant Paula Davis (left) looks for landmarks with Lacy Karpilo at a repeat image site in Denali.

Capps' Denali explorations. In these, Karpilo gleaned some fascinating first-person accounts from the early travelers. Combining those accounts with his own experiences in the park gave Karpilo a compelling story to tell.

Because of the ties between research and education at the center, Karpilo's project easily adapted into a multi-day course the following summer. Using the Capps story as the theme, a group of teachers and park enthusiasts explored the changes taking place in ancient lake beds, alpine vistas, and cultural sites throughout Denali. This course connected the public directly with a researcher and offered them a place in this unique story of change and history.

Research and Outreach in Kobuk Valley National Park

The fellowship program has made contributions to Alaska's northern parks as well. The 2010 fellow, Shelby Anderson, set out to locate natural clay sources in Kobuk Valley National Park. By comparing these source locations with pottery remains at known archeology sites, Anderson examined the movement of ancient pottery throughout the region as an indicator of early social networks.

In addition to giving presentations in Kotzebue and producing fact sheets about her work, Anderson made valuable connections with local residents in the park. Through interviews with long-time residents along the Kobuk River, Anderson helped strengthen an appreciation for past and present subsistence in the park, as well as an appreciation for the study of our ancient cultures.

A Facility of Support

Acting as a springboard into Denali, the Murie Science and Learning Center was designed to assist visiting researchers by providing much needed office space, internet access, and bed space. Having visiting researchers working in proximity to science educators has excellent benefits. When guest researchers overlap with an education group at the field camp, there is often excellent synergy—even a landscape painting

course will benefit from an evening with a group of ornithologists. Multidisciplinary groups such as this help build bridges between scientific and artistic thinking.

Closing the Gap

Visitors are attracted to our parks for a variety of reasons. They may be hoping to encounter wildlife, experience wilderness, or simply check-off another item on their bucket list. Science educators honor the visitor's desires yet also strive to build lasting connections with the land and an understanding of the science behind the scenery. The Murie Science and Learning Center, through Alaska Geographic's programs, is seeing success in the combined use of current science, hands-on education, and personal narrative. Using the important lessons of Freeman Tilden and Marshall Ganz, they build compelling educational experiences. Having these education programs financially support research efforts further expands their effectiveness, and it is acknowledged in the praise received from past participants. This praise tells Alaska Geographic that they are on the right path. Through the development of park stewardship, they are closing the scientific gap and bringing the head a little closer to the heart.



Figure 13. Seminar participants Alex Lee (left) and Kevin Clement connecting with the mosses of Denali.

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Ecological Land Classification, Soil Landscape Mapping, and Near Infrared (NIR) Spectroscopy of Soils in Lake Clark National Park and Preserve

By Aaron Wells, Matt Macander, Torre Jorgenson, Tracy Christopherson, Becky Baird, Ellen Trainor, and Parker Martyn

Introduction

The jagged peaks, massive ice caps and glaciers, steaming volcanoes, broad glacial valleys, brilliant turquoise lakes, expansive spruce forests, emerald tidal meadows, and sinuous glacial rivers of Lake Clark National Park and Preserve (Lake Clark NPP) form an awe-inspiring landscape and lend to a diverse array of climate patterns, geologic features, soils, and ecosystems. Located in the northern Alaska Peninsula, Lake Clark NPP is situated where the Alaska Range meets the Aleutian Range. At 6.7 million acres (27,000 sq. km) it is the seventh largest park in the National Park Service (NPS) system.

To establish baseline information and to provide information on long-term trends in the conditions of these natural resources, the NPS has developed inventory and monitoring programs for vegetation, terrestrial

wildlife, fish, weather, and coastal and glacial processes. These programs help the NPS to detect changes in ecosystem and determine how human activities (e.g., invasive species, land disturbances) or large-scale phenomena (fire, climate change, earthquakes) have played a part in observed changes. The inventory and monitoring programs also help the NPS focus their efforts to manage and protect park resources for the future. Soils provide fundamental controls on landscape and vegetation dynamics by greatly influencing plant community composition, successional processes, foodweb dynamics, and a host of other ecosystem functions, and are therefore a key component of the NPS Inventory Program. In support of these objectives, ABR, Inc.-Environmental Research & Services worked with the NPS to 1) design and implement an ecological land survey (ELS) to map the ecosystems and soils in Lake Clark NPP, and 2) initiate a near infrared soil spectroscopy study for parks in southwestern Alaska.

An ELS land classification, in conjunction with a landcover map, enables resource managers to more effectively evaluate land resources and develop appropriate management strategies. An ELS is an integrated approach of inventorying and classifying ecological characteristics while using environmental and GIS modeling to better differentiate the distribution of ecosystems across space. An ELS can be used to efficiently allocate inventory and monitoring efforts, to partition information for analysis of ecological

relationships, to develop predictive models, and to improve techniques for assessing and mitigating impacts.

Near infrared (NIR) spectroscopy has been used across multiple disciplines to assess a variety of materials, including soils. In NIR spectroscopy, the spectral signature of a material is defined by the ratio of the amount of energy reflected to the amount of energy absorbed by a substance, as a function of wavelength in the electromagnetic spectrum (*Shepherd and Walsh 2002*). Recent research has demonstrated the ability of NIR spectroscopy to provide rapid and inexpensive prediction of soil chemical and physical properties (*Awiti et al. 2008*). Samples from 18 different soils from Lake Clark NPP were sampled for spectral, chemical, and physical analyses to be used 1) in a pilot study designed to assess the feasibility of using NIR data for predicting soil chemical and physical properties and linking those properties to soil taxonomy, and 2) in the future with additional soil samples to develop an NIR spectrographic library for soils from the parks in southwestern Alaska.

Methods

Ecological Land Classification and Soil Landscape Mapping

To implement the ecological land classification portion of the overall effort, we used a simplified integrated terrain unit approach similar to Jorgenson et al. (2009). The initial steps involved the analysis of

Figure 1. (A) Field surveys teams were comprised of a botanist and soil scientist. They collected data on vegetation species composition and structure, soil physical and chemical characteristics, soil stratigraphy, geomorphology, and hydrology. Each plot team approximately one hour for completion and each team completed 5 to 10 plots per day. (Figure 1. (B) next page.)

Photograph courtesy of Aaron Wells



Photograph courtesy of Aaron Wells

field data to identify hierarchical landscape-ecological relationships, including 1) conducting an integrated ELS to characterize vegetation, soils, and other ecological characteristics, 2) classifying and coding individual ecological components (physiography, geomorphic unit, vegetation structure) using standard classification systems developed for Alaska, 3) laboratory analysis of a subset of soil samples to characterize soil chemical and physical properties, and 4) classification of plant communities and soils (*Soil Survey Staff 2010*). Multivariate analyses were used to identify landscape-ecological relationships between ecological components and classify ecotypes that integrate co-varying ecological properties.

The landscape-ecological relationships identified in steps 1-3 above were then applied in a Geographic Information System (GIS) model to map ecosystems and soils across Lake Clark NPP. Remote sensing and GIS data were compiled for a range of ecological components, including land cover (vegetation), elevation, ecological subsections, coastal habitats, hydrography, topography, climate, surficial and bedrock geology, wetlands, snow regime, and glaciers. These data layers were analyzed and processed spatially to characterize the major components that partition the landscape and soils. In addition, the data were used to develop a set of base maps for ecotype and soil modeling, including ecoregion, physiography, generalized soil texture, soil temperature, permafrost (*Figure 4*), and vegetation. The above map layers were overlaid in a GIS to create a combined layer in which unique combinations of landscape elements were considered “strata.” The strata were then aggregated into ecotypes using the landscape-ecological relationships and soil analytical results identified in the above analysis. This aggregation served as the basis for mapping the distribution of ecotypes and soil landscapes across Lake Clark NPP.

We conducted field work over two sampling periods in 2011. Transect locations were stratified across the landscape using a gradient-directed sampling scheme (*Austin and Heyligers 1989*) to sample the range of ecological conditions and to provide the spatially-related data needed to

Figure 1. (B)

interpret ecosystem development. Intensive sampling was conducted along the transects, and data collected at 266 plots along 44 transects. Along each transect, five to ten plots were sampled, each in a distinct vegetation type or spectral signature identifiable on satellite imagery. At each

plot (~33 ft, or 10 m radius), descriptions or measurements were made of GPS location, geology, surface form (micro- and macro-topography), hydrology, soil stratigraphy, and vegetation cover and structure (*Figures 1-3*). Soil samples were collected at a subset of sites for use in NIR analysis.

Soils Near Infrared Library

Soil samples collected from 18 plots were air-dried and sieved through a 2mm sieve and sent for spectral analysis (350-2,500 nm range) to the VisNIR Diffuse Reflectance Spectroscopy Service Center (Washington



Photograph courtesy of Aaron Wells

Figure 2. Scientists visually estimated the percent foliage coverage of all vascular species and dominant mosses and lichens at each plot.



Photograph courtesy of Aaron Wells

Figure 3. Shallow soil pits (40-50 cm) were excavated at each plot. At each pit soil physical (dominant texture, depth to >15% rock fragments, surface organic thickness, water table depth) and chemical (pH, electrical conductivity) characteristics were described and measured. Soil samples were collected for laboratory analysis.

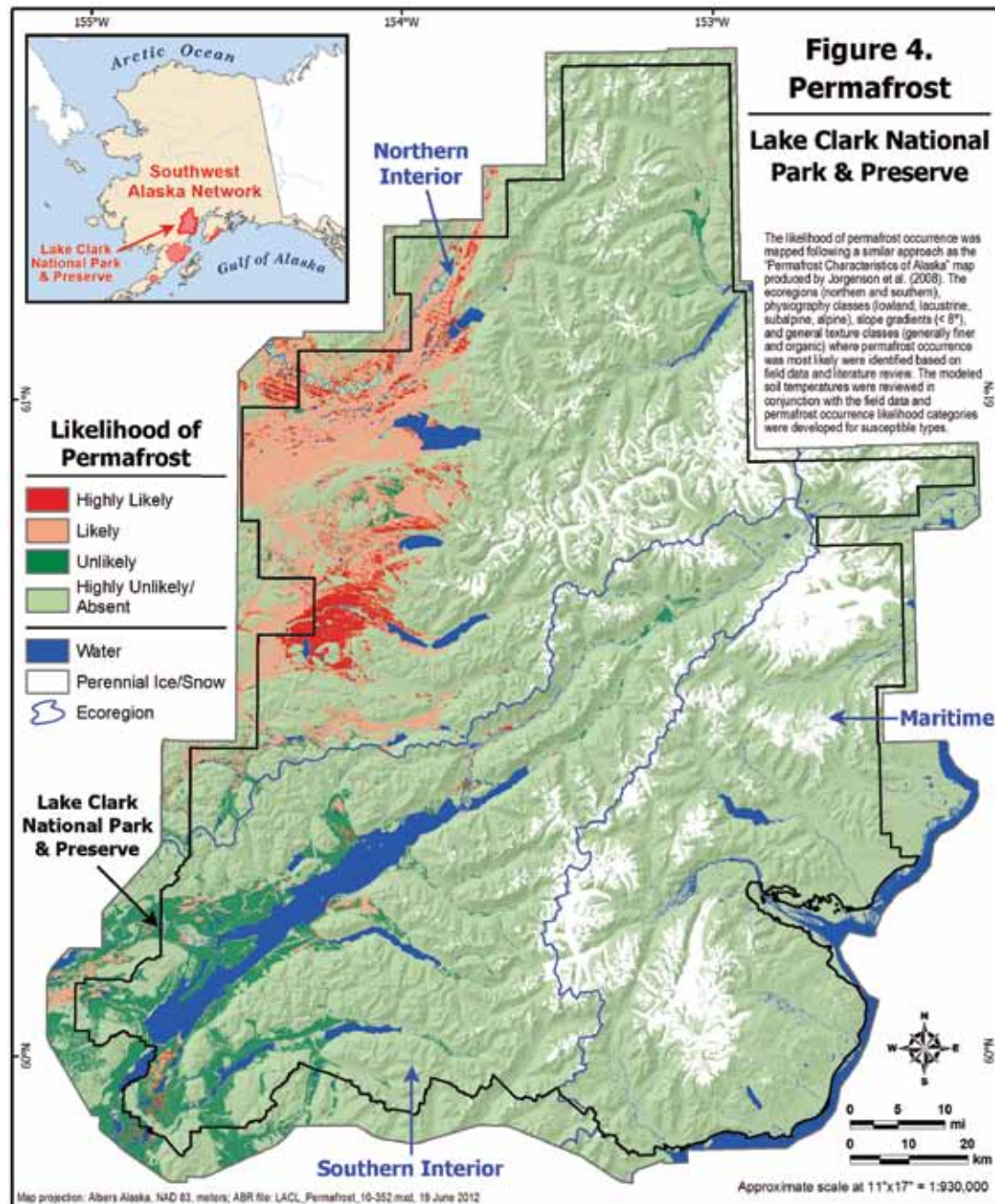


Figure 4. Permafrost map with likelihood of occurrence, Lake Clark National Park and Preserve. The likelihood of permafrost occurrence was mapped following a similar approach as Jorgenson et al. (2008) in conjunction with field data, rule-based modeling, and a soil temperature model (not shown).

State University). Samples were also sent for select chemical and physical analyses, including: total carbon and nitrogen; organic carbon; percent phosphate retention; percent sand, silt, clay (University of Alaska Palmer Research Center); and percent volcanic glass (Alaska Beget Consulting). Multivariate statistical analyses were used to identify soil spectral groups based on similar absorbance spectra. Physical and chemical laboratory data were then summarized by soil spectral groups.

Results and Discussion

We identified 71 plant associations using multivariate classification techniques. Soils from eight soil orders and 95 soil subgroups of soil taxonomy (*Soil Survey Staff 2010*) were encountered during field sampling (*Figure 5*). Soil orders included Alfisols, Andisols, Entisols, Gelisols, Histosols, Inceptisols, Mollisols, and Spodosols. We classified 93 ecotypes that best categorize the variation in ecological characteristics across a broad range of aquatic and terrestrial environments (*Figure 6*). The 93 ecotypes were combined for mapping purposes into a reduced set of 55 ecotype classes (termed map ecotypes). The strata layer was then re-classified to develop a map of ecotypes in Lake Clark NPP (not shown).

Soil-landscape associations, or soil landscapes, were developed to characterize and map broader relationships among soil type, physiography, and vegetation. The most common soil landscape classes included alpine rocky barrens and shrublands (16%); alpine gelic rocky barrens and shrublands (16%); glaciers and permanent snow fields (11%); interior subalpine rocky barrens, shrublands, and forests (7%); and interior subalpine ashy-rocky-organic forests and shrublands (7%). The strata layer was then reclassified to develop a map of soil landscapes (*Figure 7*).

Multivariate analysis of soil NIR spectra identified three groups of soils with similar absorbance spectra (*Figure 8*). Soils in Group 1 had the lowest average percent organic carbon, volcanic glass, silt, and phosphate retention, and the highest average percent sand (*Figure 9*). Soils in this group corresponded to volcanic ash-poor

Figure 5. Two characteristic soil subgroups in Lake Clark National Park and Preserve: Turbic Vitrigelands (A) and Andic Humicryods (B).



Photograph courtesy of Aaron Wells



Photograph courtesy of Aaron Wells

Figure 6. (Bottom) Two characteristic ecosystem types in Lake Clark National Park and Preserve: Interior Upland Ashy-Loamy Birch-Ericaceous Low Shrub (A) and Alpine Rocky Dwarf Shrub-Lichen Tundra (B).



Photograph courtesy of Ron Karpilo



Photograph courtesy of Ron Karpilo

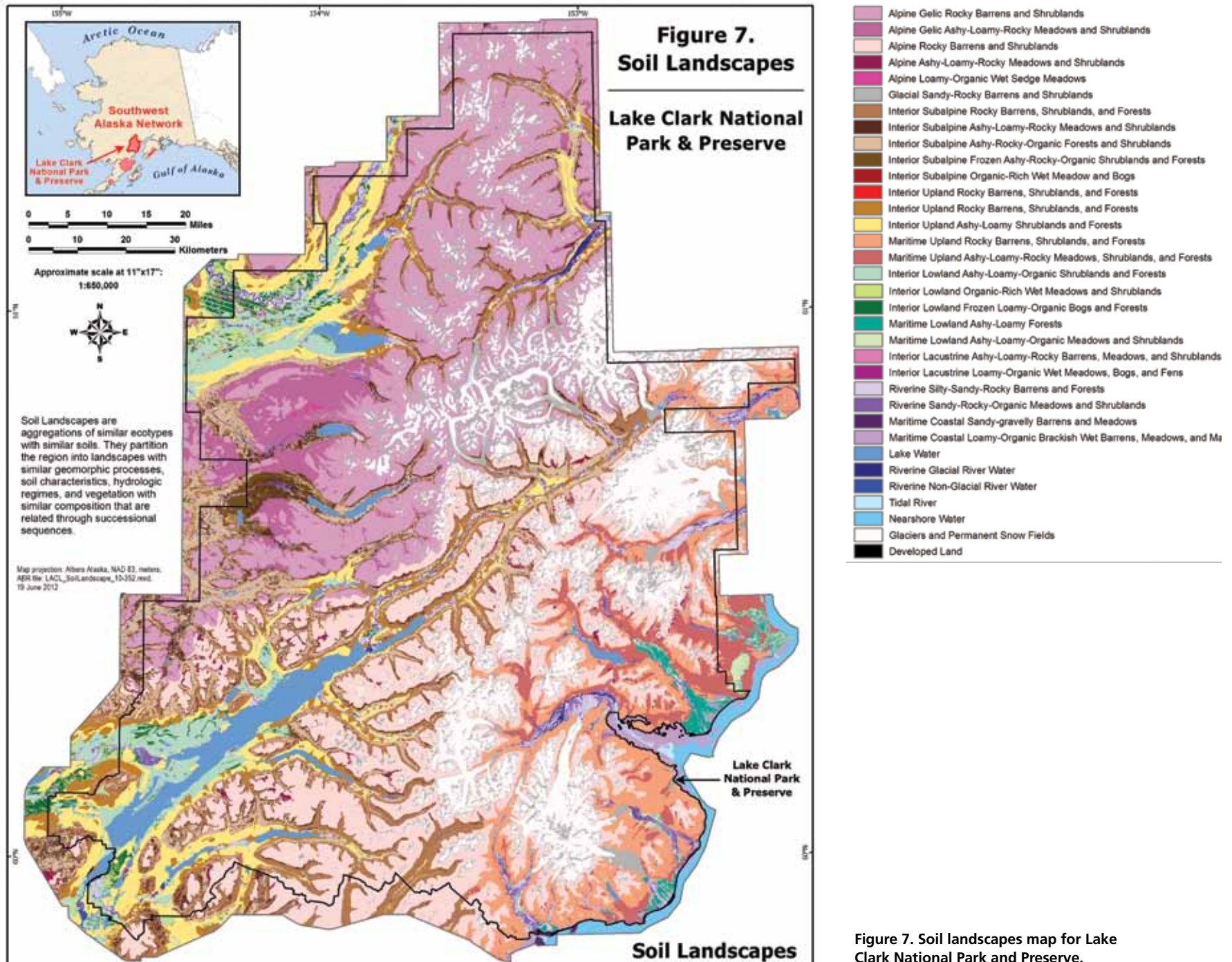
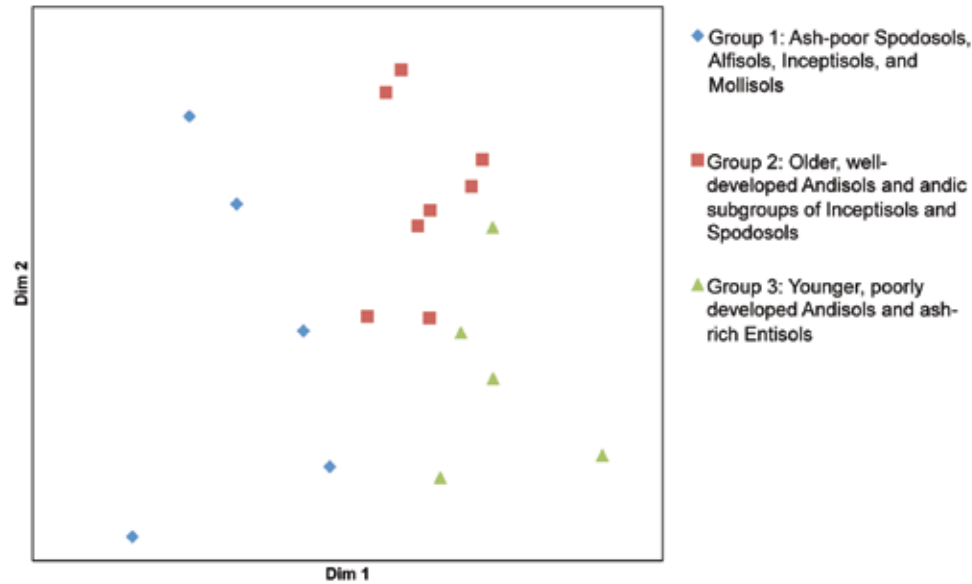


Figure 7. Soil landscapes map for Lake Clark National Park and Preserve.

Figure 8. Non-metric multidimensional scaling of NIR soil absorbance spectra for soil groups in Lake Clark National Park and Preserve.



Plot	Dim1	Dim2	Dim3	nir_pam_clus	NIR_Soil_Class
T01-LACL-01	-0.034903043	-0.039673589	-0.011160233	1	Group 1: Ash-poor Spodosols, Alfisols, Inceptisols, and Mollisols
T10-LACL-05	-0.086626601	0.017241992	0.00438206	1	Group 1: Ash-poor Spodosols, Alfisols, Inceptisols, and Mollisols
T17-LACL-01	-0.04957439	-0.010240363	0.004770279	1	Group 1: Ash-poor Spodosols, Alfisols, Inceptisols, and Mollisols
T30-LACL-01	-0.11289457	0.036257492	-0.011592486	1	Group 1: Ash-poor Spodosols, Alfisols, Inceptisols, and Mollisols
T31-LACL-03	-0.144595577	-0.05484097	0.022201322	1	Group 1: Ash-poor Spodosols, Alfisols, Inceptisols, and Mollisols
T17-LACL-03	0.020908118	0.015905176	0.001681277	2	Group 2: Older, well-developed Andisols and andic subgroups of Inceptisols and Spodosols
T23-LACL-09	0.043856582	0.021065782	0.023550653	2	Group 2: Older, well-developed Andisols and andic subgroups of Inceptisols and Spodosols
T33-LACL-08	0.004700014	0.046310018	-0.00537087	2	Group 2: Older, well-developed Andisols and andic subgroups of Inceptisols and Spodosols
T35-LACL-05	-0.013957107	-0.007098318	0.008171726	2	Group 2: Older, well-developed Andisols and andic subgroups of Inceptisols and Spodosols
T48-LACL-01	-0.003760922	0.041404932	-0.020281357	2	Group 2: Older, well-developed Andisols and andic subgroups of Inceptisols and Spodosols
T48-LACL-03	0.020545434	-0.007464341	-0.010961377	2	Group 2: Older, well-developed Andisols and andic subgroups of Inceptisols and Spodosols
T60-LACL-01	0.014032075	0.012530338	-0.001457056	2	Group 2: Older, well-developed Andisols and andic subgroups of Inceptisols and Spodosols
T68-LACL-07	0.04984423	0.026865455	0.023822677	2	Group 2: Older, well-developed Andisols and andic subgroups of Inceptisols and Spodosols
T23-LACL-02	0.037973992	-0.010629482	-0.016082443	3	Group 3: Younger, poorly developed Andisols and ash-rich Entisols
T23-LACL-03	0.055622723	0.012170486	0.010660707	3	Group 3: Younger, poorly developed Andisols and ash-rich Entisols
T31-LACL-01	0.055847662	-0.020553749	-0.010494566	3	Group 3: Younger, poorly developed Andisols and ash-rich Entisols
T67-LACL-01	0.026482742	-0.042046811	-0.024137964	3	Group 3: Younger, poorly developed Andisols and ash-rich Entisols
T72-LACL-01	0.116498639	-0.037204049	0.012297651	3	Group 3: Younger, poorly developed Andisols and ash-rich Entisols

	Group 1: Ash-poor Spodosols, Alfisols, Inceptisols, and Mollisols	Group 2: Older, well-developed Andisols and Andic subgroups of Inceptisols and Spodosols	Group 3: Younger, poorly developed Andisols and ash-rich Entisols
Analysis	Mean (SD)	Mean (SD)	Mean (SD)
Mean % Organic Carbon	2.90% (1.30%)	7.60% (3.50%)	4.10% (1.70%)
Mean Total Nitrogen	0.2 (0.1)	0.4 (0.2)	0.2 (0.1)
Mean % Sand	71.20% (5.00%)	57.90% (10.20%)	56.40% (10.30%)
Mean % Silt	23.60% (5.30%)	37.90% (11.70%)	39.20% (10.50%)
Mean % Clay	5.20% (3.00%)	4.30% (2.00%)	4.40% (0.90%)
Mean % Phosphate Retention	57.20% (19.50%)	88.50% (8.10%)	84.20% (20.90%)
Mean % volcanic glass	9.00% (9.60%)	36.30% (16.40%)	63.00% (31.90%)
Soil Subgroups ^a	Humic Vitrigelands, Typic Humigelepts, Andic Haplocryalfs, Typic Haplocryolls, Folistic Haplocryods	Alic Haplocryands, Spodic Haplocryands [2], Typic Vitrigelands [2], Andic Humicryepts, Andic Humigelepts, Andic Humicryods	Thaptic Haplocryands, Typic Haplocryands, Spodic Haplocryands, Typic Vitricryands, Vitrandic Cryorthents

^a Sample size of one for soil subgroups unless otherwise noted in brackets.

Figure 9. Chemical and physical laboratory data for soil samples from 18 plots collected in Lake Clark National Park and Preserve, 2011.

Spodosols, Alfisols, Mollisols, and Inceptisols. Soils in Group 2 had the highest average percent organic carbon and phosphate retention, and moderate percent sand and volcanic glass. Soils in this cluster corresponded to older, well-developed Andisols and andic (volcanic ash-rich) subgroups of Inceptisols and Spodosols. Soils in Group 3 had low average percent organic carbon and moderate percent sand, high average percent phosphate retention, and the highest average volcanic glass content. They corresponded to younger, poorly developed Andisols and ash-rich Entisols. Multivariate analysis of the NIR spectra grouped soils with similar physical and chemical properties, which corresponded well with soil classifications. For instance, older, well-developed Andisols and other volcanic ashsoils (Group 2) tend to have large accumulations of soil organic carbon and extremely high phosphorus retention capacity (*Ugolini and Dahlgren 2002*). These older soils are more weathered, and a larger proportion of volcanic glass is broken down into constituent elements. Younger Andisols and Entisols (Group 3) with recent volcanic ash deposition have lower accumulations of organic carbon, and the highest volcanic glass content, as insufficient time has passed for weathering and transformation.

Conclusions

The ecological land survey approach to understanding landscape processes and their influence on ecosystem functions provides two main benefits. First, landscapes are analyzed as ecological systems with functionally related parts, recognizing the importance of geomorphic and hydrologic processes to disturbance regimes, the flow of energy and material, and ecosystem development. This hierarchical approach, which incorporates numerous ecological components into ecotypes with co-varying properties, allows users to partition the variability of a wide range of ecological characteristics. The ELS approach when combined with GIS modeling and the landscape relationships developed from ecotype analysis, allowed for the development of an enhanced set of ecosystem types from existing landcover mapping that

essentially differentiates ecosystems at the site level of ecological land classification. For instance, superimposing a delineation of areas that are influenced by tidal waters and storm surges (i.e., coastal physiography) over the existing landcover map allowed for the delineation of coastal salt marshes in Lake Clark NPP where they were not mapped in the stand-alone landcover map. Secondly, the linkage of landcover maps to climatic, physiographic, and topographic variables improves our ability to predict the response of ecosystems to human impacts and facilitates the production of thematic maps for resource management applications and analyses.

The results of the NIR soil spectroscopy pilot study suggests that this technique may be effective at predicting soil chemical and physical properties and linking those properties to soil taxonomy. However, the full benefits of soil NIR spectroscopy will be realized through the development of a soil NIR spectral library (*Shepherd and Walsh 2002*), of which this study component represents the early stages. We foresee two potential applications for a spectral library. First, the spectra could be linked to landscape-scale variables in a GIS to develop maps of soil spectral properties in the study area, similar to Viscarra Rossel and Chen (*2011*). Secondly, the spectral library could serve as a baseline for assessing and monitoring soil conditions in southwestern Alaska parks into the future. For instance, NIR spectroscopy has been used as a rapid, inexpensive method for measuring soil carbon (*McCarty et al. 2002*) and NIR soil spectral properties have recently been mapped at broad spatial scales. Hence, the potential exists for the soil spectral library to serve as a baseline for mapping and monitoring soil carbon at the landscape scale.

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New Insights on Beringian Plant Distribution Patterns

By Stefanie Ickert-Bond, Falk Huettmann, Israel Loera, Lisa Strecker, Nadya Sekretareva, and Yulia Mikhailova

Abstract

The history and geography of the arctic flora in Beringia has been complex—influenced by glacial retreats during the Quaternary, exchange via the Bering Land Bridge, *in situ* survival in refugia, and differing climatic regimes. Much of the details of these diversifications in Beringia are still lacking and to begin to address this issue we provide results from stochastic character mapping reconstruction to recover historical signals from occurrence data at the Herbarium, University of Alaska Fairbanks. A taxon matrix of 13 selected ecoregions in Beringia and 1549 extant vascular plant species was constructed and analyzed with RAxML and Mesquite software. The flora of Western Beringia appears younger than that of Eastern Beringia, with the ecoregions in Western Beringia derived from within those of Eastern Beringia. The Seward Peninsula ecoregion shares the most taxa with the ecoregions from Chukotka that form a clade. The Seward Peninsula is also the richest ecoregion, with 777 taxa recorded, a sharp contrast to the impoverished Bering Sea Islands ecoregions, where only 276 taxa are recorded. Overall, when examining stochastic mapping reconstructions, current species distributions in Beringia have been independently shaped by dispersal, extinction, and in some cases vicariance events due to ecological or physical barriers (e.g., Bering Strait). Mid-July temperature and precipitation differ across Beringia

Figure 1. View of Lavrentiya Bay with tundra in foreground showing numerous patches of *Dryas anjavensis* subsp. *beringensis* (white), *Eritrichium villosum* (blue) and *Acomasytis rossii* (yellow). Chukotka Peninsula, Russia.

Photograph courtesy of Nadya Sekretareva

and at same latitudes, presenting a driver or “climatic barrier” for the overall ecosystem setup. Our study shows that distributional museum data can be informative in generating testable hypotheses on the history and evolution of the flora in an area such as Beringia.

Introduction

It should be stressed that the flora on both sides of the Bering Strait is identical with few exceptions. This is what can be expected as the present northern Bering Sea more than once during its Pleistocene history has been dry permitting dispersal of plants from one continent to the other. (Eric Hultén 1937).

Alaska and the Yukon immediately present the picture of a floristic appendage to Asia... However, a closer scrutiny of the flora... demonstrates that even in the arctic parts of this territory there are a significant number of purely American taxa. Asian and American portions of the Beringian sector must be referred to different provinces. (Boris Yurtsev 1972).

It is interesting to note that authorities such as Eric Hultén and Boris Yurtsev had very differing views about the history of the Beringian Flora that continue to spur investigations into the origin and evolution of this flora. While Hultén has emphasized taxonomic similarities between eastern and western Beringia, Yurtsev emphasizes more of their differences. A major contribution to today’s flora arrived in Alaska via the Bering Land Bridge as it was exposed during successive intervals of continental glaciation (Ice Ages) and retreat (Hultén 1937). The Arctic portion of this flora is of relatively recent origin (Murray 1995). Traditionally, investigations of the Arctic have emphasized Beringia’s role in the intercontinental exchange of fauna and flora (Ickert-Bond et al. 2009). Exchange was characterized as

asymmetric (Hopkins 1967) with most taxa originating in Northeastern Asia and moving to North America (Flerow 1967). In contrast, eastern Beringia (Alaska) was effectively isolated from the rest of North America by the Laurentide Ice Sheet (Pielou 1991) and therefore was then the easternmost extent of an Asian biome.

Eastern Chukotka along with Wrangel Island are hotspots of biodiversity in the Russian Arctic (Kholod 2007), harboring six [*Carex norvegica* ssp. *cornicorostrata*, *Puccinellia beringensis*, *X Puccinhippsia czukczorum*, *Oxytropis beringensis*, *O. middendorffii* ssp. *submiddendorffii*, *Cardamine sphenophylla*] and ten unique arctic endemic species [*Poa hartzii* ssp. *wrangolica*, *Puccinellia wrightii* ssp. *colpodoides*, *Papaver multiradiatum*, *Papaver chionophilum*, *Oxytropis uschakovii*, *Oxytropis uniflora*, *Potentilla wrangelii*, *Packera hyperborealis* ssp. *wrangolica*, *Silene sorensensis*, *Potentilla uschakovii*] respectively, as compared to four in Western Alaska [*Ranunculus glacialis* ssp. *alaskensis*, *Parrya nauruaq*, *Primula anvilensis*, *Douglasia beringensis*] and seven [*Symphytotrichum pygmaeum*, *Mertensia drummondii*, *Puccinellia banksiensis*, *Poa ammophila*, *Puccinellia vahliana*, *Papaver “murrayi”*, *Poa hartzii* ssp. *alaskana*] in Northern Alaska, based on a total of 28 Arctic endemic species known only to occur in one of the six Beringian floristic provinces (Daniëls et al. 2013).

While Chukotka has a particular meaning for understanding the floristic affinities of the Alaskan flora (Yurtsev et al. 2010), and vice versa, there has not been a formal comparison of these areas to understand how dispersal, vicariance, and climate have shaped the assemblage of these floras. Clearly, plant distributions are heavily driven by climate (typically expressed as temperature and precipitation). In the absence of detailed on-the-ground measurements, ecoregions have historically been defined to summarize ecological climate regimes relevant for plant occurrence and

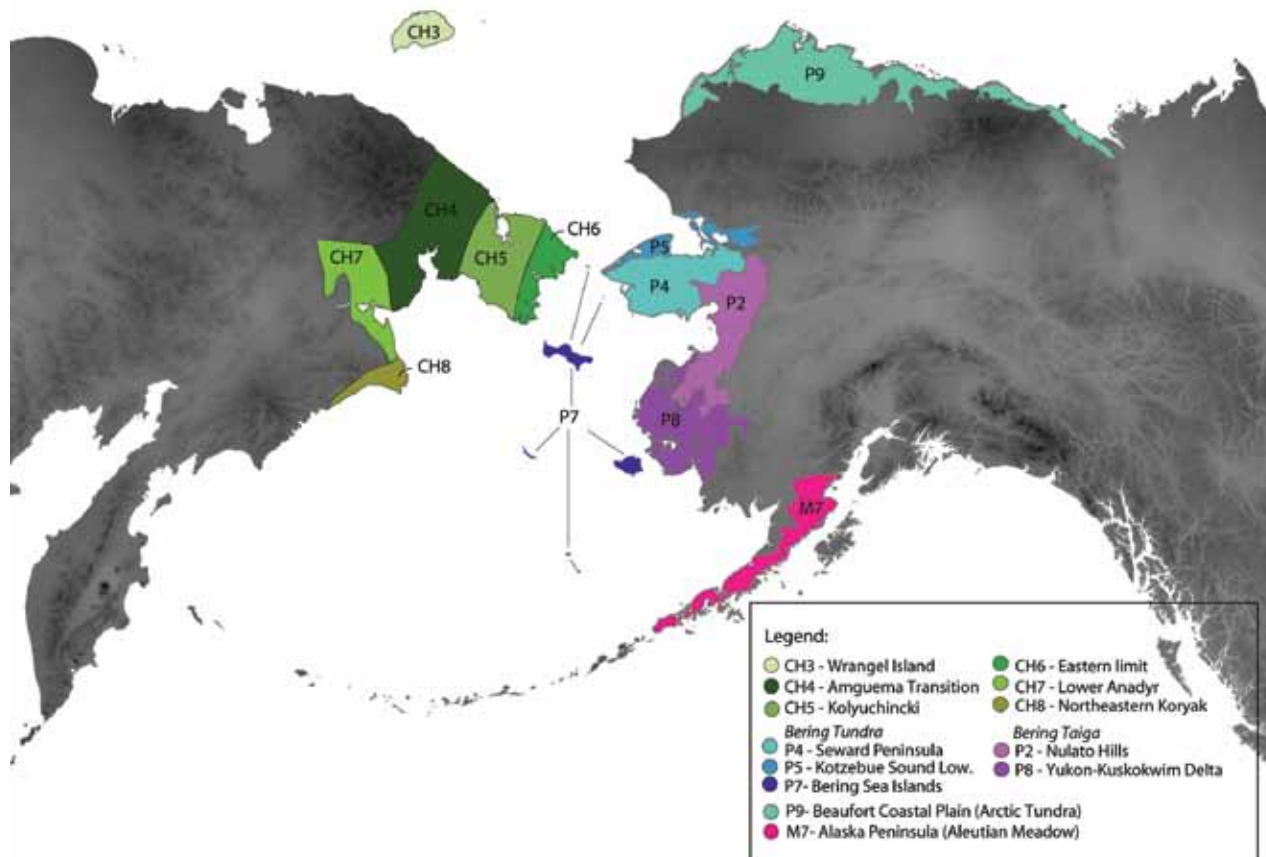


Figure 2. Mapping of selected Alaska ecoregions (after Nowacki et al. 2001) and those from Chukotka (Yurtsev et al. 2010) used in this study.

growth (Holdridge 1947, 1966) and latitudinal biodiversity gradients have been discussed widely (Ricklefs 2004; Wiens and Donoghue, 2004; Roy and Goldberg, 2007).

For Beringia, we currently find no consistent ecoregional classification scheme, and here we confront the best available ecoregion polygons for Alaska (Nowacki et al. 2001) and Chukotka (Yurtsev et al. 2010) with georeferenced specimen data (Arctos, <http://arctos.database.museum/>) as well as with climate data layers (temperature and precipitation) for an assessment and new insights of the climate niche for plants and their

ancestors. Species have climatic preferences that can be correlated with their presence or absence in different areas and will be influenced by changing climate in the future (Young 1971; Edlund and Alt 1989, Daniëls et al. 2000; Loarie et al. 2008; Ackerly et al. 2010; Hof et al. 2012). Thus, the comparison of quantified climatic envelopes between regions can shed some light on the underlying processes affecting species composition in a particular region.

Here we use information of species diversity based on occurrence records and climatic data of the different ecoregions of Beringia (Figure 2) to explain

the differences or similarity of these areas and infer hypotheses of historical biogeography. These regions are not congruent with the floristic zones and subzones as employed by the CAVM Team 2003 (Walker et al. 2005), rather the floristic zones used here reflect extensive field data assembled by Boris Yurtsev (1978) for the Russian Far East as well as those from Nowacki et al. (2001) for Alaska. While not consistent across Beringia, we chose those classifications because they are considered to be accurate, summarize ecoregions, are suitable for the sub- and arctic regions, and are the best we have available. This study will help to understand the history and the possible underlying causes of species diversification in Beringia in general, and the Arctic in particular, using ecoregions and climate data as a measure of diversity between Eastern and Western Beringia.

Materials and Methods

1. Fieldwork in Alaska (long-term) and in Chukotka (2010)

In the early 1990s the Herbarium (ALA) at the University of Alaska Museum secured many arctic specimens with support from the National Science Foundation's (NSF) International Program, the National Park Service's (NPS) Beringia Program, and from collaboration with Russian scientists. Critically important to recent work on the Panarctic Flora are collections from the Russian Far East and central Siberia acquired mostly from the Komarov Botanical Institute in St. Petersburg and the Central Siberian Botanical Garden in Novosibirsk, but also from our own collecting in the Altai and Sayan Mountains of south-central Siberia (by David Murray) and Chukotka (by Carolyn Parker). Recently, with support from the National Science Foundation and the NPS's Shared Beringia Program, we carried out a detailed collecting program of Beringian plants to the Chegitun River, eastern Chukotka, in the summer of 2010 in collaboration with the Komarov Botanical Institute, St. Petersburg. This was done to compare with taxa from long-term collecting efforts on the Seward Peninsula in Alaska.

2. Ecoregion classification for Alaska

(a) and for Chukotka (b)

a) Mapping ecosystems in Alaska has a long history. Initial attempts were trying to interpret terrain and vegetation using black and white aerial photography (Spetzman 1963). In the 1980s, remotely sensed data and a better understanding of ecosystem processes lead to global efforts of mapping ecosystems, resulting in two different maps for the state of Alaska (Gallant et al. 1995, Nowacki and Brock 1995). In an effort to unify ecoregion boundaries for Alaska, an interdisciplinary, interagency, and international team came together and produced the Unified Ecoregions of Alaska map (Nowacki et al. 2001; <http://agdcftp1.wr.usgs.gov/pub/projects/fhm/akecoregions.htm>). A total of 32 ecoregions were delineated within the state of Alaska based on criteria such as climate, physiography, vegetation, geology/surficial deposits, and glaciation. These were then integrated in a digital GIS (Geographic Information Systems, ArcGIS vers. 10) approach.

b) For the floristic division of Chukotka we are following a map that was compiled by Boris Yurtsev and his colleagues at the Komarov Botanical Institute of the Russian Academy of Sciences in St. Petersburg. There are numerous Russian publications that reflect the intense and long-standing scientific effort in the floristic description and subdivision of the Arctic; few of these works have been translated into English (Razzhivin 1999). Yurtsev's work is based on a solid and extensive body of primary field data (Yurtsev et al. 1978). Using these data, Yurtsev developed an elaborated analytical approach with a range of criteria that have to be well balanced with each other in order to define the borders between the provinces or sub-provinces. The map presented here is therefore a map based on a qualitative approach (Yurtsev 1974, Yurtsev et al. 1978, Yurtsev 1994). While the output is not directly repeatable, similar to Viereck's Alaska Vegetation Classification (Viereck et al. 1992), and not based on modern methods either like a Geographic Information System (GIS) geo-databases or underlying

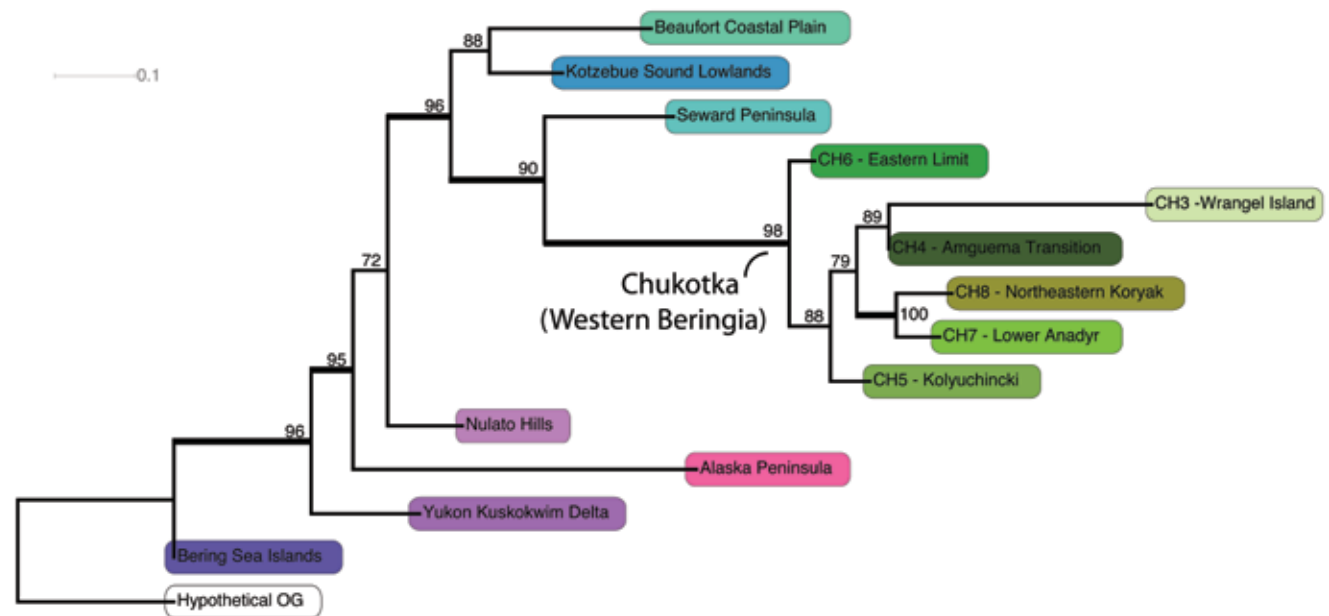


Figure 3. Area cladogram of ecoregions based on Maximum likelihood analysis in RAxML vers. 7.28. Support values (ML BS) are indicated above branches based on 1000 replicates. Color of regions matches those in Figure 2.

online databases and latest non-linear statistics, it represents the authoritative and robust classification scheme used in Chukotka and parts of the Russian Arctic.

3. Taxon-area analysis

We extracted geo-referenced records (103,074) from the UA Museum herbarium database <http://arctos.database.museum/SpecimenSearch.cfm> for ecoregions in Alaska (Nowacki et al. 2001), from the checklist of Flora of the Chukotkan Tundra (Yurtsev et al. 2010) as well as the Checklist of Wrangell Island (Petrovsky 1988) and constructed a presence-absence taxon matrix for selected Beringian ecoregions (Figure 2). Taxonomy follows the Panarctic Flora <http://nhm2.uio.no/paf/>. The dataset was examined in a Maximum likelihood framework using a Markov k model and Gamma distribution rates of heterogeneity in RAxML (Cipres Portal, www.phylo.org/sub_sections/portal/). All analyses included an all-zero

hypothetical artificial outgroup for rooting purpose (Hypothetical OG; Rosen 1988; Cracraft 1991; Morrone 1994). Using the resulting taxon-area cladogram as the basis for stochastic key species reconstruction in the program Mesquite <http://mesquiteproject.org/mesquite/mesquite.html> we generate testable hypotheses about the history of plant populations in Beringia that can be explored with molecular sequencing data in the future.

4. Climate data assessment

For consistency, we used the publicly available data from the WorldClim data set (www.worldclim.org). For the months of July and January we used long-term means of temperature and precipitation to indicate 'climate'. These data were re-projected in ArcGIS in a Mercator projection for the study area (Herrick et al. 2013), and we overlaid them with hand-traced shapefiles for the Ecoregions for Chukotka (Yurtsev et al. 2010) and Alaska (Nowacki et al. 2001). We used the

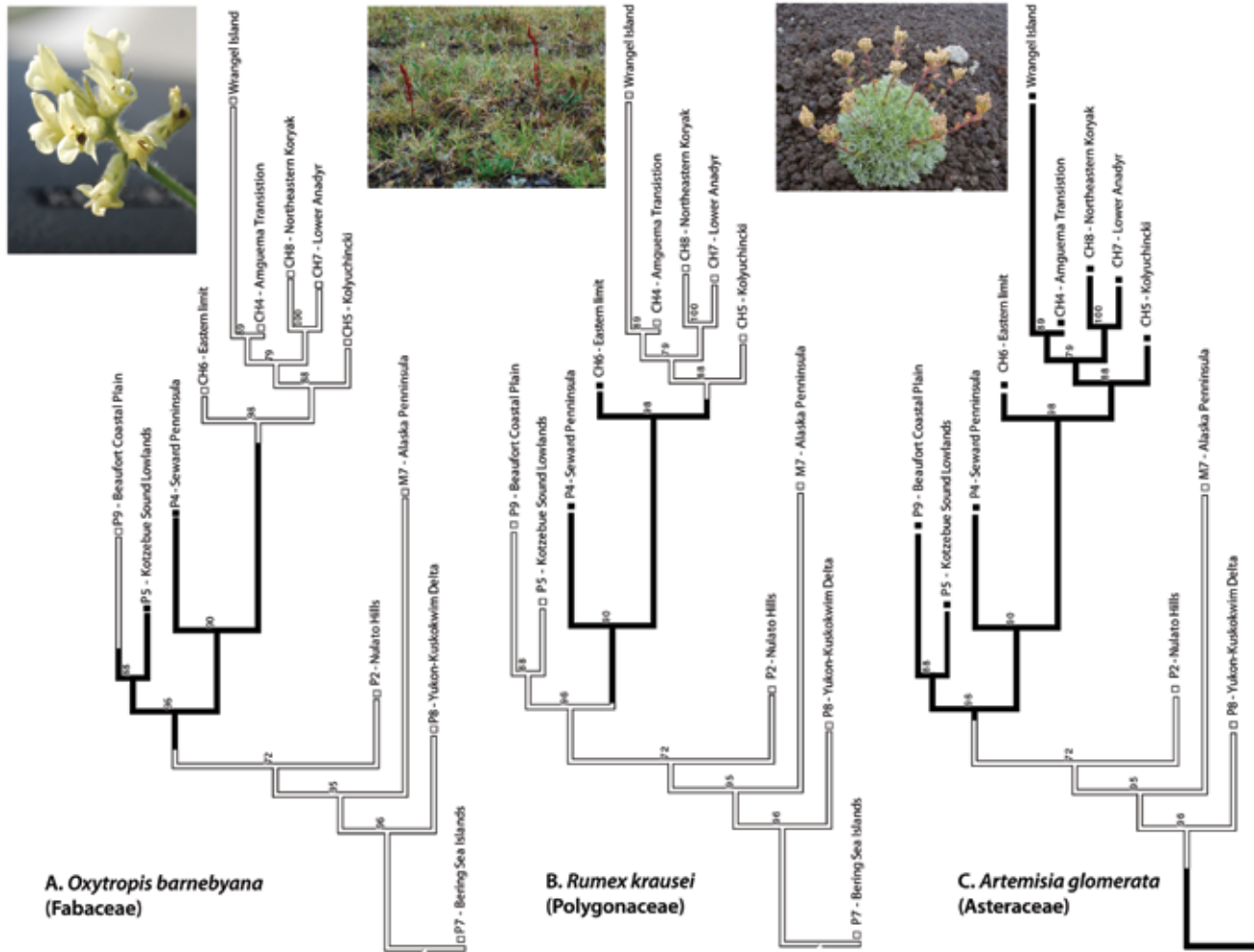


Figure 4. Stochastic character mapping of Eastern Beringian endemic *Oxytropis barnebyana* (at left), a narrowly amphiberian rare *Rumex krausei* (in center) and wide-spread amphiberian *Artemisia glomerata* (at right). Inset photographs of *O. barnebyana*, Alaska: Seward Peninsula; *R. krausei*, Chukotka Autonomous Region; *A. glomerata*, Wrangel Island. Node support (ML Bootstrap) is indicated next to each node. Character states indicated by boxes at the terminals (black = presence, white = absence). Visualization of character changes along branches and not just at the nodes is indicated by colored branches (inferred under maximum likelihood in Mesquite).

Maximum likelihood (ML) analysis in RAxML unambiguously groups the Chukotkan ecoregions together (ML bootstrap support 100%), which are derived from within the AK ecoregions (Figure 2). Support values (ML bootstrap support – ML BS) for all clades are strong across the topology (Figure 3). The Seward Peninsula ecoregion shares the most taxa with the ecoregions from Chukotka that form a clade (ML BS 98%) and forms a well-supported sister group to the Chukotkan ecoregions (ML BS 90%, Figure 3). The ecoregions of Northeastern Koryak (CH8) and Anadyr (CH7) are among the most recently formed in Western Beringia (ML BS 100%, Figure 3), and are characterized by the presence of many common species. They are both members of Yurtsev’s Southern Chukotka subprovince (1978).

Similarly, Wrangel Island (CH3) and the Anguema Transition (CH4) are of recent origin and form a clade (ML BS 89 %, Figure 3). The floristic composition of the Anguema Transition is very closely related to that of the clade (ML BS 100 %) composed of Northeastern Koryak (CH8) and Anadyr (CH7), which can be deduced from the short branch lengths leading to the Anguema Transition in Figure 2. In contrast, Wrangel Island is characterized by numerous endemic species as evidenced by a very long branch leading to Wrangel Island representing numerous taxa unique to the flora of Wrangel Island (Figure 3-4).

We have selected a few interesting species maps to demonstrate patterns of diversification in Beringia (Figure 4A-C). Each map represents one of a large number of

Geospatial Modeling Environment (GME; Hawth’s tools) to extract data, and R and SPLUS for creating boxplots to show medians and 95% confidence intervals for each of the ecoregion polygons (subsampled).

Results

The matrix contained 1,549 unique taxon names for the regions examined. Many are shared across both Alaska and Chukotka, while there are a number of unique taxa found only within one ecoregion (Table

1). The richest communities are the Seward Peninsula (777 taxa), the Alaska Peninsula (685 taxa, albeit not in the Arctic) and the Chukotkan 6 – Eastern Limit region with 611 taxa recorded (Table 1). The regions with the least number of taxa found are the Bering Sea Islands in Alaska with 276 taxa and the Yukon-Kuskokwim Delta with 341 taxa each and Wrangel Island with 352 taxa recorded (Table 1). Only twenty taxa have such broad ecological requirements that they are able to persist in all 13 ecoregions examined (Table 2).

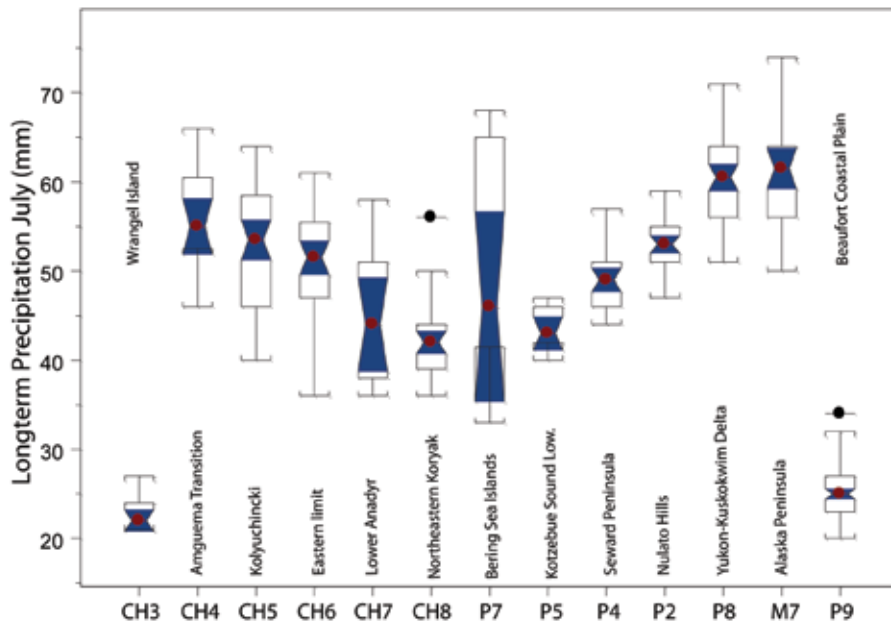
Table 1. Comparison of taxonomic composition between selected Alaska ecoregions and Chukotka regions based on Arctos occurrence data, and the Checklist of Wrangell Island (Petrovsky 1988) and the Chukotkan Tundra (Yurtsev et al. 2010).

	Total # taxa found	%	Total # of unique taxa found	%
Alaska Peninsula	685	44.22	167	10.78
Kotzebue Sound Lowlands	445	28.73	11	0.71
Bering Sea Islands	276	17.82	10	0.65
Nulato Hills	425	27.44	12	0.77
Seward Peninsula	777	50.16	75	4.84
Yukon-Kuskokwim Delta	341	22.01	12	0.77
Beaufort Coastal Plain	420	27.11	22	1.42
Chutkoka 4 – Amguema Transition	487	31.44	1	0.06
Chutkoka 5 – Kolyuchincki	485	31.31	3	0.19
Chutkoka 6 – Eastern limit	611	39.44	16	1.03
Chutkoka 7 – Lower Anadyr	596	38.48	21	1.36
Chutkoka 8 – Northeastern Koryak	481	31.05	5	0.32
Chukotka 3 – Wrangel Island	352	22.72	27	1.74

Anemone richardsonii, *Arctagrostis arundinacea*, *Artemisia tilesii* subsp. *tilesii*, *Cerastium beeringianum* var. *beeringianum*, *Equisetum arvense*, *Festuca rubra* subsp. *rubra*, *Hierochloë alpina*, *Luzula kjellmaniana*, *Pedicularis capitata*, *Pedicularis verticillata*, *Poa arctica* subsp. *arctica*, *Poa pratensis* subsp. *alpigena*, *Pyrola grandiflora*, *Ranunculus hyperboreus* subsp. *hyperboreus*, *Ranunculus nivalis*, *Salix arctica*, *Salix reticulata*, *Saxifraga hirculus*, *Tofieldia coccinea*, and *Valeriana capitata*

Table 2. Taxa found in all fourteen ecoregions examined.

A



B

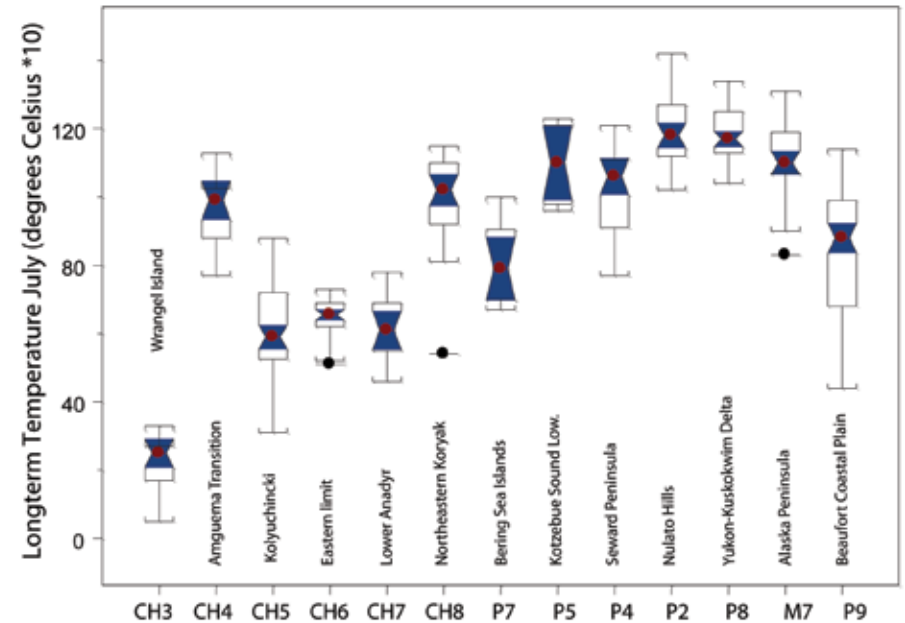


Figure 5. Climate data assessment of (A) mean annual temperature in July and (B) mean precipitation in July. Boxplots showing medians and 95% confidence intervals for each of the ecoregions.



Photograph courtesy of Richard Bond

Figure 6. Pressing specimen in field camp near Lorino village, Chukotka Peninsula, Russia

possible species histories. Figure 4A shows stochastic mapping reconstruction of *Oxytropis barnebyana*, an Eastern Beringian endemic and suggests that the species may have been present in the entire ancestral area of the Beaufort Coastal Plain (P9), the Kotzebue lowlands (P5), the Seward Peninsula (P4), and its derived clade of Western Beringia. It may have subsequently become extinct in the Beaufort Coastal Plain and Western Beringia. Alternatively, *O. barnebyana* might have been present in the ancestral area of the Beaufort Coastal Plain (P9), the Kotzebue lowlands (P5), the Seward Peninsula (P4), and dispersed from the Seward Peninsula into the

adjacent Kotzebue lowlands (P5) only, but the Bering Strait posed a strong barrier to dispersal for these plants into Western Beringia where they are absent today. Figure 4B shows the stochastic mapping reconstruction for the narrowly amphiberian *Rumex krausei*, currently restricted to wet calcareous tundra on the Seward Peninsula (P4) and the Chukotkan Eastern Limit (CH6). The reconstruction shows that it was present in the ancestral area of the remaining five Chukotkan ecoregions of Western Beringia, but perhaps failed to establish there. Extinction might explain the absence in these Western Beringia ecoregions. Stochastic mapping reconstruction of the widespread amphiberian *Artemisia glomerata* shows species occurrence in more nested ancestral areas (Figure 4C). The species diverged in the ancestral areas of the Western Alaska ecoregions (Beaufort Coastal Plain, Kotzebue lowlands, Seward Peninsula) and the derived clade of Western Beringia (CH6 – Eastern limit, CH3 – Wrangel Island, CH4 – Amguema Transition, CH8 – Northeastern Koryak, CH7 – Lower Anadyr, CH5 – Kolyuchinki). The presence in the Bering Sea Islands is possibly due to dispersal into that region.

Noticeable are the climate differences in July across Beringia, e.g. for same latitudes (CH5 Kolyuchincki and CH6 Eastern limit vs. Kotzebue lowlands (P5) and Seward Peninsula (P4) (Figure 5A, B). Chukotka appears cooler and somewhat drier. Whether this presents another barrier for plants, climatic differences in addition to the physical barrier, remains to be tested. But the separations based on climate are already quite distinct and beyond 95% confidence intervals (Figure 5A, B).

Discussion

Measuring species diversity at fine scales through regional inventories and museum records is a first step in prioritizing targeted conservation management efforts. Moreover, a comparison of species assemblages between geographic regions can be used to understand the origins and history of biodiversity (Mavrodiev et al. 2012), when more detailed phylogenetic

data are incomplete or lacking for a specific region.

The history of many taxa occurring in different ecoregions or areas cannot be explained by a single process of vicariance. Instead, many populations must be the result of dispersal into the area. Overall, dispersal across ecological niches is the most likely process for many endemic eastern and western Beringian disjunct distributions. In the absence of phylogenetic data, species occurrence records from herbarium specimens allowed us to generate testable hypotheses about the history of populations in a given area that can be explored using genetic data. Due to the poor comparability schemes for ecoregions within Beringia, we propose to assess and redesign them based on latest scientific data and methods.

Overall, when examining stochastic mapping reconstructions, current species distributions in Beringia have been independently shaped by dispersal, extinction, and in some cases vicariance events due to ecological or physical barriers (e.g., Bering Strait). In time, these processes have led to the independent formation of the same plant community in two disjunct areas (Western and Eastern Beringia).

As an arctic biodiversity hotspot, Wrangel Island is characterized by numerous endemic species (Petrovsky 1997). From our analysis it appears that the flora of Wrangel Island was formed mostly as the result of multiple dispersal events from the mainland; vicariance is also likely. Wrangel Island is part of the large continental shelf and was connected to mainland Beringia until about 10,000 years ago. The island was not glaciated during at least the whole Pleistocene glaciation (Stauch and Gualtieri 2008) and was also not flooded during the late Pleistocene ocean transgressions (Bauch et al. 2001). It supports a great diversity of habitats, with numerous mountains reaching up to 1,096 m, covering over 70% of the surface of the island, and many valleys with favorable microclimate. This diversity of habitats on Wrangel Island may have contributed to the high level of endemism of the island. This increased diversity of endemic species is also reflected in an increased number of polyploids on

the island and Petrovsky (1997) places it in its own floristic area “Wrangelia” (Petrovsky 1997, his Figure 1), distinct from the floristic areas of “Sewardia” that comprises most of the Chukotka Peninsula, St. Lawrence Island and the Seward Peninsula (comprising ecoregions CH5, CH6, P7 [St. Lawrence Island only], P4, P5, and P2, see Figure 1 for details) and “Mackenzia” (which extends from the Beaufort Sea [P9] to the Brooks Range and the Richardson mountains and from the Amundsen Bay in the east to the Gerald Shoal in the west).

The climate summaries for each ecoregion show some distinct patterns, differences and overlaps. Some have not been described for terrestrial parts of Beringia. For instance, we see that during July eastern Chukotka is on average 4 degrees cooler than western Alaska (Figure 5B), but while the precipitation is almost the same (there appears no relevant difference in winter climate though; results are therefore not shown here, see also Figure 5A). Young (1971) had already summarized similar findings in his often-overlooked article on the Floristic Zonation of the Arctic. When examining the northern limit of plant distribution in the Arctic, Young (1971) found that there is a close correlation between those limits and the total amount of summer warmth found in those areas. Using this information he constructed floristic zones for the Arctic that explain well, for instance, why the flora of St. Lawrence Island is so different from the Seward Peninsula despite their similar latitude and geographic proximity (Daniëls et al. 2000).

A detailed comparison of the Bering Sea islands with those of the Western Aleutian, albeit not arctic, provides another assessment of the patterns of floristic assemblage of two distinct oceanic island groups in Beringia (Garrouette and Ickert-Bond, this volume). To our knowledge, the terrestrial climate difference during the summer has not been described before when considering the ecological niche for plants within Beringia, other than the assessment made by Young (1971), with modification used by Elvebakk et al. (1999) and Daniëls et al. (2000). Likely, the influence of summer warmth on plant

distribution in the Arctic are related to ocean regimes and currents and cloud cover (Ritchie and Hare 1971). These factors warrant more attention and study, and in regards to a ‘climate barrier’. Secondly, this finding has bigger implications for what specific regions actually can be compared within Beringia based on plant distributional data and beyond. The validity of the currently known ecoregions, and for Beringia overall requires adjustment and now that good plant distributional, genetic and climatic data are available, it allows us to more accurately describe ecoregions within Beringia.



Photograph courtesy of Richard Bond

Figure 7. “Arctic tundra mobile”, a Russian All-Terrain-vehicle also known as “Vezdehod ” near Chetigun River area, Chukotka Peninsula, Russia.

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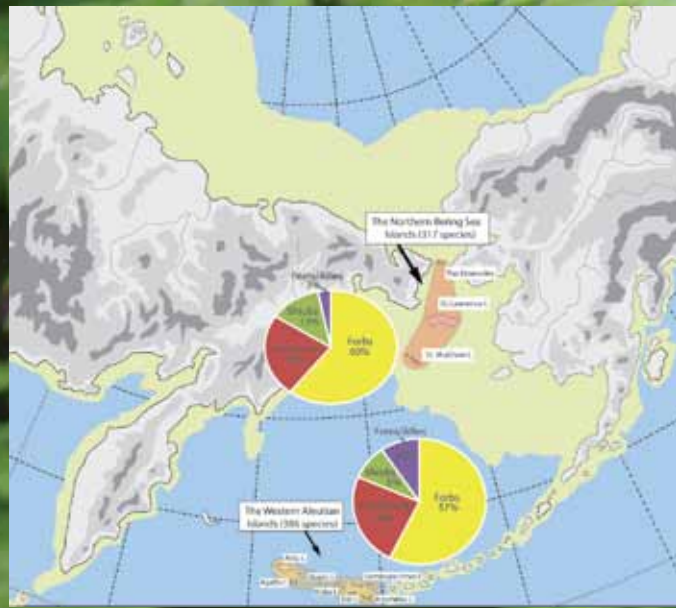
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Origins of Varied Floristic Compositions in the Western Aleutian and Northern Bering Sea Islands

By Monte D. Garroutte and Stefanie M. Ickert-Bond

Abstract

The Aleutian Islands and the Northern Bering Sea Islands have primarily upheld their status as distinct floristic subregions of the Arctic/Subarctic in published treatments, although multiple studies have also suggested a floristic similarity between the two island groups because of their oceanic influences and relative proximity. Using a combination of digitized occurrence data, review of pertinent literature, and recent floristic surveys across both island groups, we examined the influence of Asia on the island groups as well as their oceanic character. We restricted our comparison to the Western Aleutian Islands and the Northern Bering Sea Islands. Species composition was coarsely compared between the island groups by the number of overlapping species, distinctive species presence, and by the species' growth habit. We also used Sørensen's similarity coefficient as a statistical

Figure 1. (Map) The Western Aleutian Islands and the Northern Bering Sea Islands are highlighted. The larger islands in each group, and those mentioned in the text, are labeled. Proportion of the flora by growth form is illustrated for each island group.

Figure 2. *Conioselinum pacificum* (Eastern hemlock-parsley). A characteristic ocean-associated species found in both the Western Aleutian Islands and the Northern Bering Sea Islands.

measure of difference between the island groups. The Western Aleutians (386 species, 0.47 species/square mile) were found to be separated from the Northern Bering Sea Islands (317 species, 0.16 species/square mile) by more than half of their floristic composition, with only 136 shared species between the two island groups, and were considerably more diverse in the number of species/area. The Western Aleutian Islands and the Northern Bering Sea Islands have similar proportions of forbs, graminoids, and shrubs/subshrubs in their flora, although the Western Aleutian Islands show ferns/fern allies in larger proportion than shrubs/subshrubs. Ferns are largely absent in the Northern Bering Sea Islands. The colder midsummer temperatures and Beringian biogeographical history of the Northern Bering Sea Islands may help explain the disparate floristic composition of these two island groups.

Introduction

While most published treatments involving the Aleutian Islands and the Northern Bering Sea Islands have upheld their status as distinct floristic subregions of the Arctic/Subarctic, these studies have also suggested a floristic similarity between the two island groups because of their oceanic influences and relative proximity (Figure 1, Hultén 1937, Hultén 1960, Yurtsev 1972, Yurtsev 1994, Elvebakk et al. 1999, Pan-Arctic Flora 2011). Yurtsev (1972, 1994) has discussed the floral similarity between the two island groups several times, emphasizing that they share characteristic oceanic species such as

Conioselinum pacificum (Eastern hemlockparsley, Figure 2), although he suggests that they are very different as a whole floristically, owing to a historically warmer and more persistent oceanic climate in the Aleutians Islands as compared to the Northern Bering Sea Islands.

However, both the Aleutian Islands and the Northern Bering Sea Islands share persistent high winds and precipitation, and are similarly treeless (Figure 3, Young 1971, Talbot and Meades 2011). Hultén (1937) on the other hand identified an area containing the Northern Bering Sea and the Aleutian Islands as the “center of an equiformal, progressive group of plant species”, with populations spreading west into eastern Asia and east into western North America and the Rocky Mountains. Using the Bailey and Omernik approach to define ecosystems, Nowacki et al. (2001) placed the Aleutian Islands in a distinct ecoregion as part of the “Maritime-Aleutian Meadows” bioclimatic gradient, while the Bering Sea Islands are also classified as a unique ecoregion, which is part of the “Polar-Bering Tundra” bioclimatic gradient. Using average summer temperatures Young (1971) partitioned the arctic and subarctic into four floristic zones (zones 1-4), placing the Aleutian Islands in the same zone as two of the Northern Bering Sea Islands (St. Matthew and Hall Islands, zone 4), while St. Lawrence Island and the Diomedes were segregated into a colder floristic zone (zone 3 of Young). Most other publications have excluded the Aleutian Islands from the Arctic, following Yurtsev (1994), and have treated the Northern Bering Sea



Figure 3. St. Matthew Island, August 2, 2012. Treeless landscapes similar to that pictured can be found in both the Northern Bering Sea Islands and the Western Aleutian Islands.



Figure 4. Buldir Island East Cape, August 19, 2011. Vascular plant surveys were conducted on this Western Aleutian island in 2010 and 2011.

Islands as a single unit (*Elvebakk et al. 1999, Daniels et al. 2000*). The Panarctic Flora project (2011) suggested that an Aleutian-Bering Sea insular region could be justified floristically, although it would be difficult to ignore the even greater similarities between the Bering Sea Islands and the closer mainland floras, and the number of species in the Aleutian Islands, which do not extend into the Arctic.

The repeated mention of similarity between these Western Aleutian Islands and the Northern Bering Sea Islands merits a direct comparison of their floral assemblages. To this end, recent digitization efforts of herbarium collections at the University of Alaska Fairbanks available in ARCTOS (<http://arctos.database.museum>) with associated metadata as well as increased digitization and review of historical literature records can be used to make syntheses of the collection history across large geographic areas for comparison and analysis. In addition we have

been involved in recent survey activities on the Aleutian Islands, including vascular plant surveys on Buldir Island (2010-2011; *Figure 4*), Rat Island (2010), Attu Island (2011), Kiska Island (2011), St. Matthew Island (2012; *Figure 5*) and Hall Island (2012). We provide details of the island groups below, created species lists of the vascular plants, and then compared the species composition statistically to find a measure of beta diversity between the islands groups.

The Aleutian Islands are a long chain of mostly volcanic islands which run west of the Alaska Peninsula towards the Russian Kamchatka Peninsula, arcing between 51° and 56° N latitude (*Figure 1*). This treeless island chain has often been placed in the Arctic floristic zone (*Hultén 1960, Young 1971*), although more recent definitions of the Arctic floristic zone have alternatively placed the Aleutian Islands in the hypoarctic or “treeless boreal” floristic zone, due to the lack of permafrost and relatively

high average temperatures (*Tatewaki and Kobayashi 1934, Yurtsev 1994, Elvebakk et al. 1999*). The numerous active volcanoes in the chain contribute to a rugged topography; the highest point in the chain is the volcanic Mount Shishaldin (9,373 ft., 2,857 m) on Unimak Island.

The Northern Bering Sea islands, in contrast, lie on the continental shelf off the western coast of Alaska, sparsely arranged North-South from 60° N latitude towards the Bering Strait at 66° N latitude (*Figure 1*). Even though these islands lie several hundred miles south of the Arctic Circle, the environment in the Bering Sea Islands is truly arctic, with a polar maritime climate and a persistent pack ice in the winter and spring (*Young 1971*). Permafrost can be found on these islands as well, often up to several feet thick (*Young 1971*). While the Northern Bering Sea islands cover a large area, they also have a relative flat relief, with the highest

point in the group, Atuk Mountain on St. Lawrence Island, reaching 2,070 ft. (631 m) (*USDA NRCS 2006*).

The greatest difference between the two island groups may, however, be their recent geologic history. The Northern Bering Sea Islands were connected as part of the Bering Land Bridge which stretched between Alaska and Russia when sea levels were lower during

the last glacial maximum (60-25,000 years ago, *Hopkins 1967, Hoffecker et al. 1993*). The Bering Land Bridge was a major crossroad for plants from Northeast Asia into North America, though for some plant species the land bridge acted as a filter or complete barrier for plant dispersal between continents (*Hultén 1968, Weber 2003, DeChaine 2008, Ickert-Bond et al. 2009*). During

these periods, the Northern Bering Sea Islands would have been mountain ranges or isolated highlands, and may have served as refugia when sea levels rose between glacial advances (*Hultén 1968, Young 1971*).

In contrast, the Aleutian Islands were not connected by land to Asia via the Russian Kamchatka Peninsula or to North America during the last glacial maximum



Figure 5. St. Matthew Island Field Camp, August 1, 2012. This field camp, set up on the northeast end of St. Matthew Island, in the Northern Bering Sea Islands, was the base for a vascular plant survey in 2012.



Figure 6. *Saxifraga aleutica* (Aleutian saxifrage). This saxifrage species is endemic to the Aleutian Islands.

Figure 7. *Cirsium kamtschaticum* (Kamchatka thistle). Over most of its range, this thistle species grows in eastern Asia. However, large stands of the species can be found in the Western Aleutian Islands. It does not reach the North American mainland.



(Hopkins 1967, Hultén 1968). However, lowered sea levels would have connected all of the smaller Aleutian Island groups by land, shortening the gap between the Aleutian Islands and mainland North America, and facilitating the distribution of North American and Asian species across the islands (Lindroth 1961). Researchers have concluded that the islands have been an area of floral exchange between Asia and North America (Hultén 1960, Tatewaki 1963, Talbot et al. 2010), nevertheless some species have restricted distributions across the Aleutian chain (Talbot et al. 2010). Lindroth (1961) was the first to recognize that Asian endemic species were found in larger numbers in the Western Aleutians, while North American endemic species represented an increasing proportion of the flora with closer proximity to the Alaskan mainland.

To direct our comparison of the Northern Bering Sea Islands and the Aleutian Islands on their similarities of Asian influence and oceanic character, we will base our Aleutian Island assemblage on that of the Western Aleutian Islands, which we here define to include the Rat Island group, Buldir Island, and the Near Island group (Figure 1).

Methods

Acquiring Regional Species Data – The floristic composition of the Aleutian Islands and the Northern Bering Sea Islands were primarily obtained from the University of Alaska Museum database ARCTOS (<http://arctos.database.museum>). Searches in ARCTOS were made using the “Locality” search option with island names specified (accessed October 10, 2012). Vascular plant species names and locality information were downloaded from ARCTOS. Published and unpublished island floras (Hultén 1960, Shacklette et al. 1969, Young 1971, Byrd 1984, Talbot and Talbot 1994, Freeman and Garrouette unpubl., Jones unpubl., Kenney and Kahler unpubl.) which are based on museum voucher specimens were also used as supplementary sources for assembling regional species lists. Furthermore, vouchered and identified collections from the first author’s visits to several Aleutian and



Figure 8. Fern-Overgrown Trail on Buldir Island, August 9, 2011. Many Western Aleutian Islands have large fern populations in seabird-fertilized areas and in the near-shore vegetation. This trail, bordering several large seabird colonies, has been overgrown by *Athyrium filix-femina* subsp. *cyclosorum* (Subarctic ladyfern).

Northern Bering Sea islands were added to the species lists (Buldir Island: August 3-26, 2010, August 5-27, 2011; Rat Island: August 28, 2010; Attu Island: August 2-3, 2011; Kiska Island: August 29, 2011; St. Matthew Island, August 1-6, 2012; Hall Island: August 5, 2012). The USDA Plants Database (*USDA and NRCS 2012*) was used to find information on the growth habit of plant species.

Comparing Floral Assemblages

We made comparisons of the regional floras using several approaches: (1) We compared overlapping and regionally exclusive species numbers, overall species number by area, and the proportion of species by growth

habit. (2) We highlighted the presence of Asian disjuncts and endemic species in each of the island groups using species distribution maps (*ARCTOS, Tatewaki 1963, Hultén 1968*). (3) Sørensen's similarity coefficient (*Sørensen 1948*) was calculated to determine a presence-absence-based statistical value for similarity between the island groups.

Results

Coarse Species Comparison

Based on the data assembled from ARCTOS and individual island floras (*Hultén 1960, Shacklette et al. 1969, Young 1971, Byrd 1984, Talbot and Talbot 1994, Freeman*

and Garrouette unpubl., Jones unpubl., Kenney and Kahler unpubl.) the Western Aleutian Islands are represented by 386 plant species over ~820 square miles of island area (0.47 species/square mile), while the Northern Bering Sea Islands had 317 species in an area of ~1950 square miles (0.16 species/square mile). 136 species are shared between the two island groups, while 250 species are unique to the Western Aleutian Islands (64% of the total species number), but only 181 species are unique elements of the Northern Bering Sea Islands (57% of the total, Table 1). In the Western Aleutian Islands forbs form the largest proportion of the flora, followed by graminoids, ferns/fern allies and then shrubs/subshrubs (*Figure 1*). Similarly,

Table 1. Species metrics by island group.

Regional Species # Comparisons	Taxa	Shared	Unique	Proportion of unique elements	Proportion of shared elements	Total Area (Sq. Mi.)	Species/area
Western Aleutian Islands	386	136	250	0.647668394	0.352331606	820.247	0.470589956
Northern Bering Sea Islands	317	136	181	0.570977918	0.429022082	1956.51	0.162023194
Difference	69	0	69	0.076690476	-0.076690476	-1136.263	0.308566762

This table displays the species number in each region, and numbers and proportion of shared and unique taxa. Also, these numbers are compared with the landmass of the region, calculated as the sum of the island areas (in square miles).

Table 2. Sørensen similarity coefficient calculation.

Sørensen's similarity coefficient	Predicted coefficient	Calculated coefficient
Western Aleutian Islands vs. Northern Bering Sea Islands	<=0.5	0.38

This table displays the prediction and calculation of the Sørensen similarity coefficient, which uses species overlap between the two island groups to determine similarity. Values closer to 1 are more similar, while values close to 0 are more dissimilar.

in the Northern Bering Sea Islands forbs represent the largest proportion of the flora, followed by graminoids, but the ranking of shrubs/subshrubs and ferns/fern allies is reversed in the Northern Bering Sea Islands as compared to the Western Aleutian Islands (Figure 1).

Endemic and Asian Species

There were six endemic species present in the Western Aleutian Islands: *Saxifraga aleutica* (Aleutian saxifrage, Figure 6), *Artemisia aleutica* (Aleutian wormwood), *Cerastium aleuticum* (Aleutian chickweed), *Phyllodoce aleutica* (Aleutian mountainheath), *Campanula chamissonis* (Aleutian bellflower) and *Draba aleutica* (Aleutian draba). In contrast, in the Northern Bering Sea Islands we identified only one endemic species: *Artemisia globularia* var. *lutea* (Purple wormwood).

Several species show a unique disjunct biogeographic distribution between Asia and the Western Aleutian Islands, being present in one or several Aleutian islands and in Asia, but with a large geographical gap between the populations: *Sorbus sambucifolia* (Siberian mountain-ash), *Trollius riederianus* (Kamtschatka globeflower), *Aconitum maximum* ssp. *maximum* (Kamtschatka aconite). In contrast, there are no species in the Northern Bering Sea Islands which are not also well-established on both the Alaskan and Russian mainland.

Sørensen's similarity coefficient

A similarity of 0.38 was calculated between the island groups using the Sørensen's similarity coefficient (Table 2).

Discussion

A comparison of species number between the Western Aleutian Islands and the Bering Sea Islands showed them to differ considerable in their floristic composition. The Western Aleutians were separated from the Northern Bering Sea Islands by more than half of their floristic composition in a coarse comparison of shared and exclusive species (Table 1). In addition, the Northern Bering Sea Islands were found to be less

species-diverse in comparison with the Western Aleutian Islands (Table 1). Young (1971) remarked on the relatively depauperate plant species number on St. Lawrence Island, noting that the approximately 200 species on that island were less than half of the number of species found on adjacent areas of mainland Alaska. The colder midsummer temperatures on St. Lawrence, due to the spring presence of the polar ice pack and the consistently overcast weather, were stated by Young (1971) to explain this pattern of species diversity. Summer warmth during the critical phase of reproductive growth was found to be strongly correlated with species presence across the Arctic (Young 1971). St. Lawrence Island had average summer temperatures several degrees lower than those observed on the Alaska Bering Sea coast, closer to those observed at the Alaska arctic coast (Young 1971). However, these colder summer temperatures are not present to the same extent on all of the Northern Bering Sea Islands. Young's (1971) partition of the arctic and subarctic into four floristic zones (zones 1-4) split the Northern Bering Sea Island group: The Aleutian Islands were placed in the same zone as St. Matthew Island and Hall Island of the Northern Bering Sea Islands (zone 4), while the more northern St. Lawrence Island and the Diomedes were segregated into the next colder floristic zone (zone 3 of Young). However, most authors have not included the Aleutians in their consideration of the Arctic, and so have not made this comparison (Yurtsev 1994, Elvebakk et al. 1999, Daniels et al. 2000, Pan-Arctic Flora 2011).

The two island groups were most similar when the growth habit (shrubs, graminoids, forbs) of the vascular plants is compared (Figure 1), although the Western Aleutian Islands were found to have a slightly larger percentage of ferns and fern allies (Figure 1). This was expected, as ferns are abundant in the Western Aleutian Islands, both in the lower-elevation vegetation complexes on islands fertilized by seabirds (Figure 8, Byrd 1984) and in the coastal vegetation (Talbot and Talbot 1994). Only two fern species are found in the Northern Bering Sea Islands (*Cystopteris fragilis* and *Dryopteris*

fragrans), neither of which are associated with seabird colonies or the coastal vegetation. The other members of this growth habit in the island group are fern allies.

As expected several characteristic oceanic species were found in both island groups. Amphiberingian coastal species made up a portion of the shared taxa in each island group, but several distinctive species, primarily endemic to Asia, were found to extend their range into the Western Aleutian Islands, which helped to distinguish the Western Aleutian Islands from the Northern Bering Sea Islands easily as those lack the Asian disjunct species. The Western Aleutians Islands also had six endemic species, while the Northern Bering Sea Islands only had one endemic species. The abundant Bering Sea Island legume genera, *Oxytropis* and *Astragalus*, are absent from the Western Aleutian Islands, previously cited as an indicator of the large difference between the two island groups in a coarse comparison by Yurtsev (1972).

Calculating the Sørensen similarity coefficient between the Aleutian Islands and the Northern Bering Sea Islands could reveal statistically if any similarity between the entire floral compositions of the island groups exists. A Sørensen coefficient of 1 would indicate that the two island groups had complete species overlap (i.e., their species compositions are the same), while a coefficient of 0 would indicate no species overlap (i.e., their species compositions is completely different). With a calculated value of 0.38, the floras of the two island groups were quite dissimilar statistically, even with similar species groups and very similar proportions of species by growth habit. Although the Sørensen similarity coefficient is known to underperform when rare species are present or species richness is large (Chao et al. 2006), the large area and relatively low diversity in the samples should have overcome these limitations in our current study. Species abundance data would greatly improve this metric.

Both island groups are likely affected by oceanic influence, yet this effect appears to differ by geographic location, as the oceanic icepack, which approaches the Northern Bering Sea Islands and not the Aleutians,

apparently subjects the islands to lower summer temperatures, which results in a particular composition of vascular plants on each of the island groups (*Young 1971*). Furthermore, the lasting effects of differing geological histories between the Western Aleutian Islands and the Northern Bering Sea Islands have shaped their floral assemblages to reflect a greater difference than what is perhaps expected of their relative geographical proximity. Although the Aleutian Islands and the Bering Sea Islands have previously been differentiated by authors examining species ranges and characteristic species presence (*Hultén 1968, Yurtsev 1972, 1994*), our study is the first comparison between the two island groups based on new collecting efforts in the region and distributional metadata available at the University of Alaska Museum online database (ARCTOS) on the entire floral assemblages of these two enigmatic island groups.

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