Sustaining Wild Trout in a Changing World

WILD TROUT SYMPOSIUM

Holiday Inn Resort
West Yellowstone, MT
October 9-12, 2007

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Wild Trout IX

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The organizing committee would like to thank the student volunteers who helped make this symposium a success!

Editor Note:

In this publication we follow Nelson et al. (2004) for common and scientific names of fishes and Behnke (1992) for subspecies of trout.

Nelson. J. S., E. J. Crossman, H. Espinosa-Pérez, L. T. Findley, C. R. Gilbert, R. N. Lea, and J. D. Williams. 2004. Common and Scientific Names of Fishes from the United States, Canada, and Mexico. 6th Edition, Special Publication 29. American Fisheries Society, Bethesda, Maryland.

Behnke, R. J. 1992. Native Trout of Western North America. American Fisheries Society Monograph 6. American Fisheries Society, Bethesda, Maryland.

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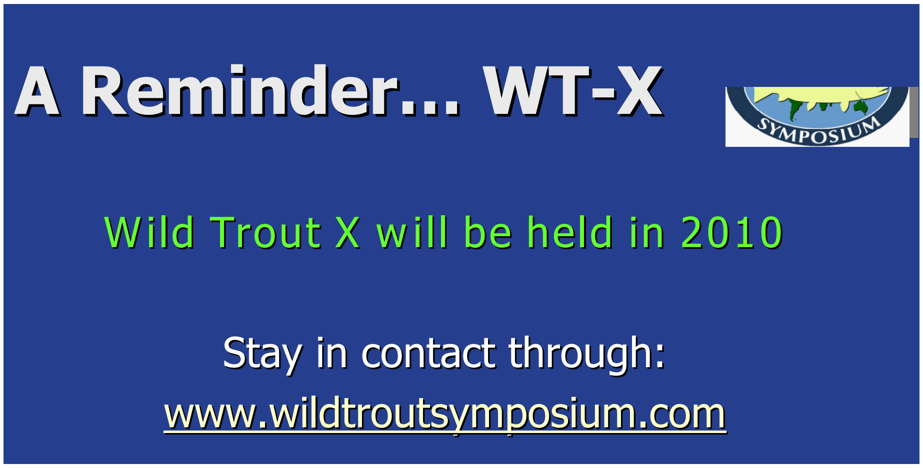

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Sustaining Wild Trout in a Changing World

Steve Moore, Symposium Chair
Supervisory Fishery Biologist, Great Smoky Mountains National Park,
Gatlinburg, Tennessee

As the Steering Committee initiated the planning process for this symposium one of the first tasks was to decide on the theme. After a lot of discussion we decided on "Sustaining Wild Trout in a Changing World". Reflecting on our discussions, I am confident that the sustainability we were thinking about is what Angermeier[1] (2007) described as ecological sustainability - the maintenance of biodiversity and ecological function in the face of anthropogenic disturbances. Our hope is that the information presented during the symposium will provide us with information that can and will be used to sustain wild trout and the places they live in the future.

Wild trout, what are they and why are they so special? I suspect that most of us would say a wild trout is one that has been spawned in a stream or lake and has survived there for one or more generations, even if they are not native to the area. Some managers, conservationists and anglers may argue that native trout are the only true wild trout. Regardless of the definition, wild trout are exceptional creatures that are symbolic of spectacular places. Because wild trout in their natural environment represent a finite resource that is important to us and our society, it fuels our desire to preserve this precious resource from human encroachment.

As biologist, conservationists and anglers we are all painfully aware of the rapid decline of wild trout resources due to population growth and increasing demand for natural resources. The majority of this decline can be tied to population growth and accelerated development in areas that were once considered wild or natural. While our society claims to be environmentally aware and desires to protect the environment from anthropogenic disturbances, we do not hesitate to move farther and farther away from cities and densely populated areas. Development activities in these once wild or natural areas reflect a lack of understanding of the environmental consequences of development and societal values focused on safety and financial security and not on the value of natural environments and the fish and wildlife that depend on them. The folks that live in these beautiful paces just cannot understand why bears or other wildlife invade their yards or why water quality suffers and the stream no longer supports trout.

All of us attending this symposium can relate to this scenario and probably have many similar "war stories". Many of us have attempted to save a special place from development, only to be trumped by politics. When this happens, those of us who manage wild trout resources become frustrated and cannot understand why a large segment of our society does not appreciate natural resources even though the demand for recreation is increasing. The reality is that we must care and must work to preserve not only wild trout resources but all natural resources. If we don't, our children and grandchildren will not have the opportunity to enjoy wild trout and the grandeur of wild places because public lands will be so crowded and over used.

This brings me to my final point. We can no longer continue with business as usual. We who have responsibility for the conservation and management of fish and wildlife resources must foster ownership and understanding of their value through education and outreach programs if we truly wish to have sustainable wild trout resources in the future. Additionally, we must involve the public, decision makers and support groups in our work and planning for the protection and preservation of fish and wildlife resources. If

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[1] *Angermeier, P. L. 2007. The role of fish biologist in helping society build ecological sustainability. Fisheries 32(1): 9 – 20.*

we do not educate this segment of our society, an understanding how fragile and finite natural resources are will never occur in society as a whole. Last but not least, we must make sure our children are directly involved in our wild trout conservation efforts. If we fail to do this, future generations will not have champions who love wild trout and fishing for wild trout.

I realize this is a difficult challenge, but if we do not have a vision of what we expect for wild trout resources for the next 20 to 30 years we will definitely fail to sustain them. As we all know, fishery management now more than ever is a multidisciplinary undertaking. The Eastern Brook Trout Joint Venture and the Western Trout Initiative are currently taking a multidisciplinary approach to educate decision makers and the public on the value of native trout. Trout Unlimited has developed programs for youth education that are great. Now is the time for all of us to combine our efforts for the protection and preservation of wild trout resources. By so doing, we can sustain these fragile resources for future generations.

I look forward to Wild Trout X and to seeing how much progress we have made in fostering public ownership and understanding of the value of wild trout resources.

Steve Moore with granddaughter Stephanie (doing what he preaches and loving every moment of it)!

Challenges for Wild Trout Management: An Eastern United States Perspective

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Salmonids are important components of freshwater fisheries in the Eastern United States. Brook trout *Salvelinus fontinalis* and Atlantic salmon *Salmo salar* are indigenous to the region, and introduced brown trout *Salmo trutta* and rainbow trout *Onchorhynchus mykiss* are now widespread from Georgia to Maine. Generally, the popularity of trout fishing in the Eastern U.S., as indicated by angler participation, increases latitudinally from south to north (Pullis and Laughland 1999).

During the past 40 years, issues associated with the management of wild trout appear to the authors to have evolved from centering primarily on angler-oriented issues, such as the use of hatchery trout, angler gear restrictions, and size and creel limits to more ecologically based issues such as land use, genetic conservation, and habitat restoration. In the future, we suspect this evolution will continue and lead to greater focus on broader landscape issues such as climate change.

In this paper we review the past and present challenges to wild trout management in the Eastern U.S. from the perspective of a state fish and wildlife agency. We conclude with speculation regarding the evolution of future challenges and agency strategies needed for effective wild trout management.

Good Old Days to Present

Cultured Fish

In our opinion, the greatest fish management issue during the past 40 years, and unquestionably the most vitriolic, has been the use of hatchery trout. Beginning in the late 19th century, advancements in rail transportation made the shipment of salmonids feasible on a broad scale, and for the first time made widespread stocking outside native ranges practical. In 1906 alone, more than two

Eastern U.S. Coldwater Fisheries

million rainbow trout were stocked in the U.S. by the U.S. Bureau of Fisheries (Stickney 1994). As the popularity of fishing rose through the 1960s, management agencies responded by stocking ever increasing numbers of catchable-size trout to support angling activity and to provide high returns to anglers (Johnston 1979). By the 1970s, most of the Eastern states had significant trout stocking programs. Nationwide, about 187 million non-migratory salmonids were stocked in 1972 (Swink 1983). During this period the top two management goals identified by fisheries managers were achieving maximum sustainable yield and providing maximum catch for anglers (Bennett et al. 1978). Managers looked to fish hatcheries to help achieve these goals and hatchery staffs were up to the challenge. The Achilles heel that would soon disrupt this blissful strategy was the lack of a conceptual framework for the development of policies to govern the management of stocking programs (Johnston 1979). For many agencies, stocking salmonids was a solution that met angler demands and agency needs for quantifiable measures of success. Engstrom-Heg (1981) offered a philosophy of trout stream management for New York that featured stocking guidelines, but the concepts he proposed were not widely adopted.

In 1985 the American Fisheries Society devoted the plenary session at its annual conference to the role of fish culture in fishery management, which was summarized by Rosen (1985). Hatcheries were identified as essential components of fisheries management, but a national policy was needed to guide the use of cultured fish. Plenary speaker Bob Herbst astutely observed that trout culture and stocking is a management tool (means), not an end.

The reasoned guidance for development of policies and guidelines was not broadly accepted and the debate over the use of cultured fish became more strident. “Hatchery bashing” became fashionable among segments of the fisheries profession and various angling groups with a strong bias toward wild trout fisheries. The position of these groups was bolstered when the geneticists weighed-in with likely genetic impacts of introduced fish, such as outbreeding depression and reduction of genetic diversity (Philipp et al. 1993). These arguments were initially met by hatchery proponents with indifference, then denial of criticisms (often accompanied by colorful attributions of their critics’ motives), and finally some thoughtful introspection (Stickney 1994).

The debate over the use of cultured fish seems to have ameliorated in recent years and it has led to what we believe are better management practices. Jackson et al. (2004) reported several positive trends in the use of propagated fishes. These included requirements for more justification prior to making a decision to stock fish; increased development and use of broodstock management plans; greater use of post-stocking assessments; and greater consideration of genetic and biodiversity issues in stocking decisions. These trends, if continued, bode well for the conservation of wild trout.

Regulations

Regulations governing the harvest of wild trout have received considerable attention in the Eastern U.S. Kemp was reported by Rosen (1985) as saying that naturally reproducing populations are increasingly unable to withstand fishing pressure. This view appeared to be shared by many fisheries managers as Graff (1994) observed that all Eastern fisheries management agencies view harvest regulations as an essential element of wild trout management. Thus, it appears to the authors that most regulations are in place to prevent overharvest. However, in the Southeast, and possibly other areas, regulations seem to have little utility in influencing size distributions of wild trout due to their relatively brief life spans (Habera and Strange 1993) and characteristic infertility of the region’s streams (Cada et al.1987). Likewise, Kulp and Moore (2005) found no changes in rainbow trout population dynamics attributable to a variety of fishing regulations implemented over a 70-year period in Great Smoky Mountains National Park.

Many regulations are angler driven and as such appear to address human issues rather than resource issues. Many states designate waters as fly fishing only, often coupled with restricted harvest regulations. Although such regulations have limited resource conservation value, and may partition the resource among anglers, they do provide fishing opportunities for anglers seeking a less crowded, less consumptive, and what some would say is a higher quality fishing experience. Providing diverse fishing experiences, through social regulation, is now a common management goal of many agencies.

Habitat Improvement

Generally the presence and abundance of wild trout in the East is viewed as a strong indicator of environmental quality (Graff 1994). Most Eastern trout populations inhabit relatively small, 1st–3rd order streams, thus making habitat enhancement a potentially powerful management tool. For many years, the concept was mostly characterized by its potential rather than actual resource benefit and was often used to engage conservation organizations, such as Trout Unlimited, in the enhancement of trout habitats. Early enhancement efforts involved low-tech engineering such as moving rocks around in streams to produce pools or riffles. Such efforts yielded temporary, if any, benefits to the resource and were rarely evaluated.

In recent years, habitat enhancement programs have featured watershed-scale restoration based on geomorphological principles (Rosgen 1996; Williams et al. 1997). This approach relies on determining the natural stream morphology and emplacing structures that reestablish natural stream morphology and riparian conditions. This technique is now widely applied and shows considerable promise of having long-term impacts. Stream restoration projects often involve substantial lengths of stream, which are often on private land; as a result, cost and landowner resistance appear to be major limitations.

Habitat enhancement programs feature watershed-scale restoration based on geomorphological principles

Angler Relations

Relationships between anglers and management agencies have generally emulated a roller coaster. As the hatchery wars grew in intensity, relationships between management agencies and angling groups, such as Trout Unlimited, were strained. Often disagreements were aired acrimoniously in the news media to the discredit of both parties and to the detriment of wild trout conservation. Fortunately for all concerned, relations have improved substantially between agencies and angling/conservation organizations. For example, in 1991 the North Carolina Wildlife Resources Commission established a formalized cooperative agreement (signed MOU) with Trout Unlimited and the U.S. Forest Service that promotes information exchange and a venue to air differences in a non-confrontational setting. These collaborative models are growing in popularity. The Eastern Brook Trout Joint Venture, and other pilot programs under the National Fish Habitat Action Plan, are examples of the current collaborative period. These partnerships are characterized by multiple state and federal agencies, academia, and non-governmental organizations uniting to achieve common resource conservation goals.

Demographics

The demographic profile of the "average" trout angler is changing in many states as populations increase and rural areas become more developed. Historically, many anglers began trout fishing for subsistence reasons, or simply because the resources were in close proximity and trout fishing was part of a cultural heritage. A recent survey of trout anglers in North Carolina found that the demographics of newly-participating trout anglers are changing from rural residents, with minimal education, who prefer to fish locally for stocked trout, to residents of the urban piedmont, who are college educated and travel significant distances to fish, and who practice catch-and-release angling for wild trout or stocked trout managed under catch-and-release regulations (Duda 2007). The opportunity for harvest of trout is becoming less of a motivating factor for the growth segment of trout anglers in North Carolina. We expect this trend applies to other Eastern U.S. states, and requires management agencies to diversify fishing opportunities to meet angler demand and to promote growth in license sales and programmatic support.

Access to Waters

Loss of angler access to waters flowing across private land is a chronic problem that has intensified in recent years. The era in which strangers could readily receive permission from landowners to fish on their properties is near or at its end. Large farms have been subdivided and consequently those stream reaches even of moderate length now have multiple owners. Many of these owners lack a rural heritage, have no experience with angling, and are inclined to post their properties against trespass. Other landowners have discovered that leasing fishing rights to angling clubs supplements their income and relieves them of the burden of enforcing trespass restrictions. In either case, angling opportunities on private lands are lost for the majority of the public.

Consulting the Tea Leaves

We identify three major challenges that we believe management agencies will face in coming years. Our success in addressing these challenges will determine in large part the quality and quantity of wild trout fishing in the 21st century.

Global Climate Change

If model predictions of a 2- to 4-°C increase in average air temperature (IPCC 2007) prove accurate, climate change will be the greatest threat to wild trout we are likely to experience. Elevated average air temperatures will increase stream temperatures, and it is likely that many streams that currently support wild trout will not do so in the future. Wild trout will likely be relegated to waters at higher elevations, which tend to be smaller with less flow. Such waters will likely support lower standing crops of wild trout, with slower growth rates, and smaller ultimate sizes.

In addition to elevated temperatures, climate change will affect the frequency and magnitude of storms. Although regional projections of alterations in precipitation are imprecise, it is probable that Eastern states will have more frequent storms, larger storms, longer periods of drought, or a combination of some or all of these events. Larger or more frequent storms may have as great an effect on wild trout as elevated temperatures, especially on private lands. Maintenance of watershed function and connectivity among trout populations are important factors in trout population responses to catastrophic environmental events (Roghair et al. 2002). Development of private land is already impacting wild trout through removal or reduction of riparian buffers and increased runoff due to increased impervious surfaces. Many of these streams will be incapable of accommodating the increased flows within existing channels and will receive substantially greater sediment input. Both of these changes are likely to degrade or eliminate habitat critical to wild trout survival.

Land Use Changes

Predicted increases in the human population will lead to increased development in the form of new homes, commercial enterprises, and infrastructure. History indicates that such changes will result in direct habitat destruction, habitat fragmentation, pond construction, and introduction of non-indigenous organisms. Protection of existing high-quality coldwater habitats will be difficult, but can serve to buffer range-wide impacts such as climate change (Kinsella and Williams 2005). Coincidentally, changes in patterns of land ownership from locally-owned large tracts to smaller tracts under absentee ownership will likely severely restrict angler access.

On public lands we expect that the demand for diverse recreational activities will increase. Many of these activities, such as off-highway vehicle use, bike riding, and horseback riding can lead to habitat degradation and diminution of wild trout populations. Further, we anticipate that greater demands for developable land coupled with chronic funding deficiencies will lead to increased interest by federal and state governments to raise revenue via the sale of public lands.

Uses of Cultured Fishes

Conceivably, a warmer environment could bring resolution to the controversy about the use of hatchery-reared trout. Many coldwater hatcheries supplied by surface water would become incapable of raising trout and would either be decommissioned or shift production to other species. If our speculation about increased precipitation and the resultant effects on stream habitat are correct, production from hatcheries still capable of raising trout would be needed to maintain seasonal trout fisheries in affected streams. Even in the absence of climate change effects, we anticipate that development of rural land will continue to degrade some streams to the point that sustaining wild trout fisheries is not practical, if not impossible. In particular, hatchery fish will be required to maintain trout fisheries in waters that retain thermal habitat, but lack sufficient spawning substrate due to sediment impacts.

Recent advances in the production of polyploid fishes make their use in management programs more practical. The stocking of polyploids, or trout otherwise rendered sterile, should alleviate most problems associated with genetic interchange between hatchery and wild trout. We agree with Hilborn et al. (2003) that protecting the genetic diversity of wild trout stocks is critical to maintaining their resilience to changing environmental conditions. Several states, including North Carolina, are incorporating sterile trout into their management programs to reduce the potential for negative genetic impacts to wild trout stocks.

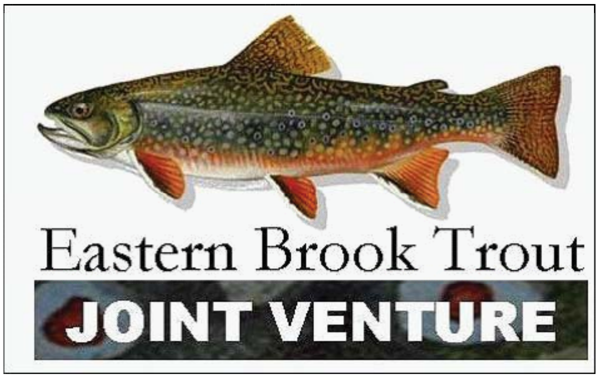
What Do We Do: Fish or Drink?

Since these options are not mutually exclusive we opt for both fishing and drinking, although barring a reenactment of prohibition, the future for drinking may be brighter than that of fishing for wild trout. Legislation and regulation alone are unlikely to maintain wild trout populations anywhere near their present levels. Thus, we will have to develop and employ innovative practices that emphasize incentives and peer pressure instead of or in addition to government coercion.

We are encouraged by the current trend of collaboration among government agencies and nongovernmental organizations to address resource conservation issues. The collaborative negotiation model commonly employed in the relicensing of hydroelectric projects has demonstrated great utility in arriving at negotiated settlements with participation by diverse interest groups.

A promising initiative is the development of “trout-friendly” criteria for residential and commercial development projects. Such criteria emphasize conservation easements, riparian buffers, and natural spaces that benefit terrestrial and aquatic wildlife, as well as appealing to the burgeoning “green” sensibilities of potential buyers and investors. Certification of housing developments as “trout-friendly developments” employs economic forces to protect local area habitats by enhancing the market value of the developments.

We will need to expand development of broad partnerships, such as the Eastern Brook Trout Joint Venture, that offer promise for conservation of wild trout across regional geographic areas. These partnerships can identify and collate commonly experienced local issues and address them with a coordinated range-wide approach. Partnerships also leverage the resources of member organizations to produce outcomes, such



as regional threats assessments, that would not be possible by acting individually. Agency inclusion of nontraditional stakeholders can be an effective means of building support for achieving broad conservation goals (Jacobson et al. 2007).

Finally, we must become better marketers of wild trout and look to acquire diverse funding sources to underwrite wild trout conservation programs. If changes in angler demographics, habitat degradation, loss of access, and other factors result in decreased angler participation, receipts from license sales and excise taxes are likely to decline, or at best remain flat. The growing demands for increased government funding of critical social programs make the appropriation of additional public funds to support fisheries conservation unlikely. Innovative approaches, including corporate sponsorship and support from diverse stakeholders, will be needed to secure adequate funding for successful for wild trout conservation.

In spite of numerous threats to their survival, wild trout are thriving in the Eastern U.S. In coming years, human population growth and the high likelihood of some degree of climate change will present managers with particularly acute challenges to maintain current populations. We are encouraged by the growth of collaborative efforts that unite diverse governmental and nongovernmental entities to achieve conservation goals with an emphasis on voluntary actions rather than strong regulatory prescriptions. In the 19th century Abraham Lincoln observed, “With public sentiment, nothing can fail. Without it, nothing can succeed.” In the 20th century, Aldo Leopold built upon that concept with his advocacy of a societal land ethic. In the 21st century our success in conserving abundant, fishable populations of wild trout will largely be determined by our ability to influence our society’s values and resultant behaviors.

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Future of Wild Trout Management

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Prognosticating the future reminds one of the Farmers Almanac, stock market letters, and the fisheries biologists in Oregon and Washington who made the yearly predictions of future salmon and steelhead returns based only on out-migration of smolts. When asked why they did this, despite a very low historical accuracy, they gave two answers. When they did get it right they were heroes, and two (one that I could never get by my mom) all the other guys are doing it.

So on the second basis, all the other guys are doing it, and the fact that I probably won't be here to own up for my predictions in 20 years, here goes.

In general, I believe Wild Trout Management (WTM) will be fundamentally unchanged 20 years from now. This, despite the fact there will be as many or more of us fishing on less water than today and that the need to properly manage wild trout will have dramatically increased. Three factors could substantially alter this prediction, either plus or minus, if they were to be radically changed:

- Priorities
- Public Access
- Fishing Constituency.

It is fair to say that all the agencies that are charged with WTM are short of funding and have far more on their plate than they can afford to address. Thus, they must establish priorities favorable to WTM. Now the question is, and will continue to be, do they have the intestinal fortitude to do what is best for the fish and their long-term health. Can they say "no" to the tourist agencies that call for stocking truck loads of "catchables" on top of a wild trout population to satisfy the tourism industry? Or "no" to the native trout lobby that wants to restore some native salmonid to all its native water, despite the fact that much of that range is no longer fit for the native, or that introduced species will out compete them if they are reintroduced.

Certainly we want to replicate Bob Behnke's successful greenback cutthroat trout work to preserve and expand our native populations. But at what cost? In Great Smoky Mountain National Park, Steve Moore has a multitude of natural barriers above which the Park Service may be able to clear streams of nonnative species and restock brook trout with a reasonable expectation of long-term success.

But if some group wants to restore brook trout to all of the upper Beaverkill or Battenkill rivers, we must say "no way". Even if it were biologically possible, we can't afford it.

And what of enforcement? It is all well and good to make rules, but who will enforce them? Who will find the "bucket biologists" and prosecute them? We must make the public aware of the cost to our agencies to rectify these apparently "minor wildlife offenses". What is the cost of holding the lake trout infestation at bay in Yellowstone Lake – now and into the future? The public understands economics, but who will get out front and call for stiffer penalties and lobby for funds for enforcement? The Fish and Game Departments? The state commissions? The organized fishing public? They all must do it. It may be sexier to roll rocks, plant trees, or teach fly fishing, but we must dedicate the time and effort to force protections to be established and then to help create the funding required to see that they are followed. We must establish the "right" priorities in support of WTM and then fight to see that they are funded.

There are two other major issues that will affect the face of WTM 20 years down the road: access and new fishing constituents.

- Access – While the U.S. will never suffer the loss of public fishing that Europe has due to our massive public land base, the total availability of access will continue to diminish unless we are able to make its acquisition a high priority. And don't think that your public land access is free from "taking". Even the current administration won't try to sell Yellowstone. But what of those isolated sections on a good river or corridors of public land that provide access to the National Forest? These can be traded or sold by their management agency with little effective notice to the public. We must remain vigilant!

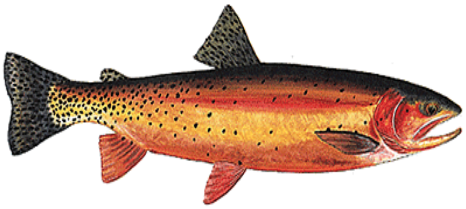
  My organization is opposed to a "taking" of private land for access. Conversely, we strongly support outright purchase or lease of access. Some states already provide funding from property tax, special fees, or lottery proceeds. These programs must be supported and expanded. Access is critical!

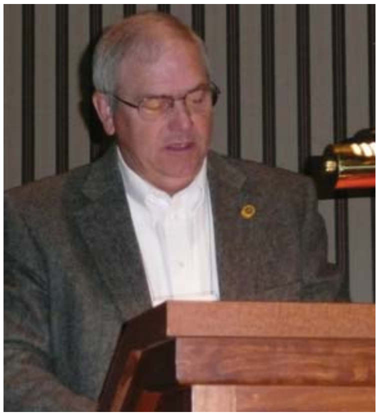
- Education – We are all familiar with the trend that increasingly separates our youth from the outdoors. Many of you may have read "Last Child in the Woods". It emphasizes the trend, provides ample evidence of it, and explores what it means to our youth and our culture in the future. Suffice to say that if this trend continues, we will lose our constituency and, in time, our sport. If no one cares about access, who will vote to fund its acquisition, let alone maintain what we have now or the professionals to manage it? Who will stand up for our Fish and Game Department budgets and for WTM? In almost all of the last 10 years, total fishing license sales have decreased! The average age of serious fisherman is increasing. We must replace our fishers as they pass on. The FFF, AFFE, and others are focusing their energies on teaching youth, BSA in schools, wounded vets, seniors, and any others we can round up. But it will be no good to get people all hot and bothered about fishing, if there is no place for them to apply their newly found skills.

In summary, if we want to continue and expand WTM we must…

- Establish proper priorities
- Fight for every possible piece of access
- Continue to build and educate our constituency.

If we can succeed in these areas, the state of WTM in 20 years may be as good as or better than it is today. If we fail …





Conflict, Confrontation, Court vs. Cooperation, Consensus, Collaboration

Putting What We Have Learned to Work Through the Western Native Trout Initiative and National Fish Habitat Action Plan

Virgil Moore
Deputy Director, Idaho Department of Fish and Game, Boise, Idaho
On behalf of the Western Association of Fish and Wildlife Agencies

Western Native Trout Initiative

Most of the native trout populations across the American West have declined during the last 100 to 150 years, due largely to habitat alteration and the introduction of nonnative species. Currently four native trout species have been petitioned for listing under the Endangered Species Act, six species are listed as threatened, and one species is listed as endangered. Most management actions associated with trout conservation are modest in cost, but even key projects and simple solutions go unimplemented due to a lack of funds. Traditionally, the recovery and conservation of native western trout species has been addressed in a fragmented approach through various recovery plans, conservation agreements, state management plans, or other documents. Furthermore, few state management agencies have sufficient staff to adequately address native trout conservation, despite the mounting losses of what many regard as icons of the American West.

A New Approach

The mission of the Western Native Trout Initiative is to facilitate and bring new emphasis to the development and implementation of science-based actions for the conservation and restoration of western native trout species through collaborative efforts and partnerships.

A new approach is clearly needed to stop and reverse declines of western native trout. Experts agree that the best hope is an approach that pools the strengths of the many agencies and organizations. There are several reasons why well funded, cooperative conservation is needed:

(1) declines are occurring in almost every watershed in which western trout occur;
(2) the threats to this array of species are similar in nature;
(3) cooperative conservation approaches are most cost effective; and
(4) watersheds occupied by western native trout span federal, state, tribal, or other jurisdictions.

Twelve western state fisheries agencies and four federal agencies came together in 2005 and began to collectively address protecting and restoring native western trout. Working in conjunction with the Western Association of Fish and Wildlife Agencies, this group formed a partnership called the Western Native Trout Initiative (WNTI). This new initiative incorporates the best aspects of current joint ventures that are successfully restoring waterfowl, sage grouse, and eastern brook trout. The Western Native Trout Initiative is one of several pilot joint ventures (also known as “fish habitat partnerships”) under the National Fish Habitat Initiative Action Plan (NFHAP).

Achieving Conservation Goals

The WNTI is a non-regulatory, science-based, cooperative conservation effort that will speed the implementation of actions to benefit western native trout. This is a daunting task that will require considerable organization, cooperation, and funding to be successful. To that end, the immediate goals of the WNTI are to

(1) integrate individual species management strategies and the latest science into a regional plan;
(2) develop and improve partnerships using this collaborative conservation strategy; and

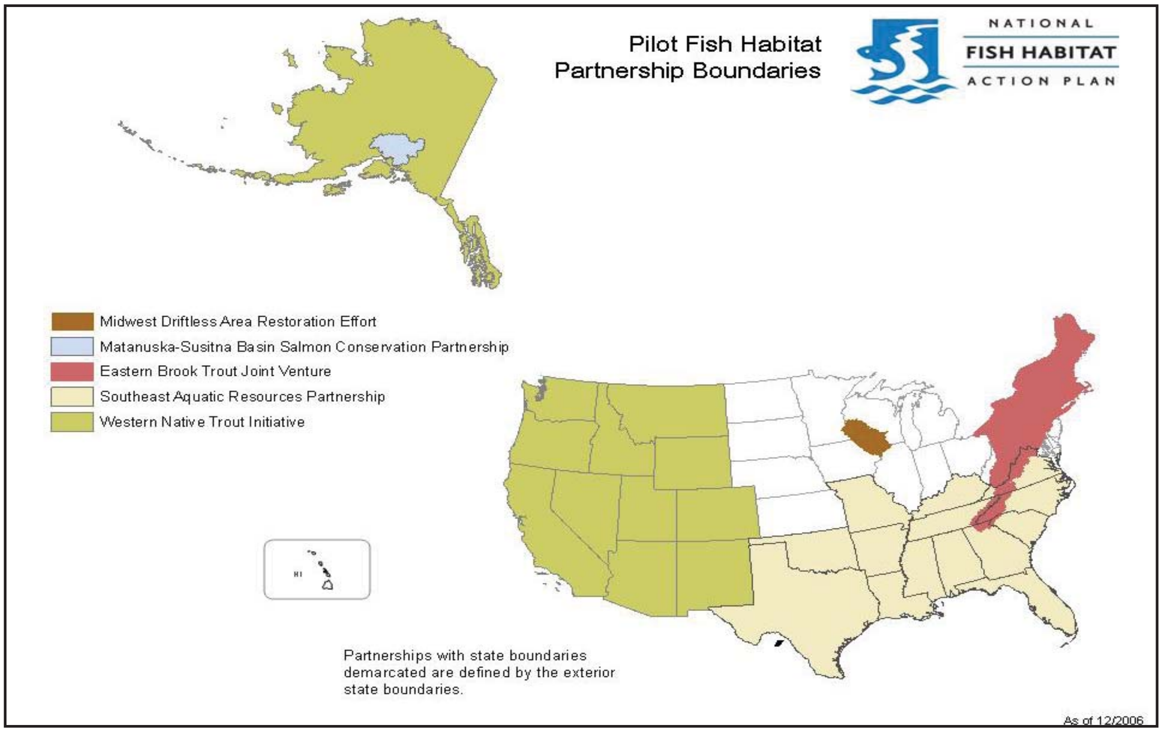
(3) develop cost-share programs for implementation of WNTI priorities.

The scale of both restoring and protecting native trout species, and the need for funding, is large. Two different funding sources were tapped in 2006 to begin WNTI development and implementation.

Funding through the Multistate Grant Program ($188,000) was secured to coordinate and develop the initiative and on-the-ground habitat management projects were started as a result of a Congressional appropriation (US$1 million) for HFHI related projects. The multistate grant funds will be used to develop the WNTI collaborative strategies to begin a wide range of conservation efforts across the west. By establishing secure populations, WNTI will also benefit the American anglers by developing and enhancing recreational fishing opportunities for native trout across the West.

For more information visit **www.fishhabitat.org** or contact: Robin Knox, **WNTI Coordinator:** 303-236-4402

Figure 1. Geographic Scope of States within the Western Native Trout Initiative and other similar efforts.



Status of Inland Native Trout

Species	Federal Status	Plan	State
Gila Trout	Threatened	Recovery Plan	AZ, NM
Apache Trout	Threatened	Recovery Plan	AZ
Greenback Cutthroat	Threatened	Recovery Plan	CO
Lahontan Cutthroat	Threatened	Recovery Plan	NV, CA, OR
Little Kern G Trout	Threatened	State Mgt. Plan	CA
Paiute Cutthroat	Threatened	Recovery Plan	CA
Bull trout	Threatened	Recovery Plan	WA, ID, MT, OR, NV
Bonneville cutthroat	Petitioned	CAS	UT, ID, NV, WY
California Golden trout	Petitioned	CAS	CA
Coastal cutthroat	At Risk	State plans	CA, OR, WA, AK
Colorado River cutthroat	Petitioned	CAS	CO, WY, UT
Redband trout sub-sp	Petitioned	None	WA, OR, MT, ID, CA, NV
Rio Grande cutthroat	Petitioned	CA	NM, CO
Westslope cutthroat	Petitioned	In development	MT, ID
Yellowstone cutthroat	Petitioned	CCA	WY, MT, ID, NV

*All petitioned species have been given not warranted decisions by the USFWS except for California golden trout and Colorado River cutthroat which are still pending. CAS=Conservation agreement and strategy, CA=Conservation agreement, CCA=Candidate conservation agreement. Gila trout was down-listed from endangered on July 18, 2006.

Table 1. ESA Listing Status of the Native Trout in WNTI

The Future of Wild Trout: Protecting, Reconnecting, Restoring, and Sustaining our Wild Trout Legacy

Chris Wood
Trout Unlimited, Chief Operating Officer

Thank you, Steve Moore, for thinking of Trout Unlimited (TU) and inviting us to speak on the panel. And, on behalf of the 170,000 TU members and our 110 professional staff, thank all of you from the various state and federal agencies, tribal interests, and other conservation and industry groups that work with TU to help achieve our mission of protecting and restoring North America's cold water fisheries and the watersheds on which they depend. Without your professionalism, partnership, and collaboration, none of our work would be possible.

Steve Moore asked me to talk about how the future of wild trout would be affected by legal decisions produced by our court system. I have a confession to make. I am not a lawyer. And, I know this is not in vogue, but I am a big fan of lawyers.

In fact, if you look over the past 30 to 40 years, many of the nation's most important environmental laws would not be possible without the work of lawyers representing people and communities disenfranchised by the status quo, and demanding changes that benefit the environment. Litigation, for example, was vital in the creation of federal legislation to better manage National Forests; open up public land grazing to public involvement and environmental review; and regulations to protect endangered species.

The quality and number of environmental lawyers have increased significantly with the growth of the environmental movement. But the playing field has changed since the passage of the landmark environmental laws that we so rely on today. Today's environmental lawyers are no longer the tip of the spear for a broader social and environmental movement as they were 30 and 40 years ago. They are more accurately described today as a last line of defense, a bulwark against well-funded and sustained efforts to weaken or overturn so many of the legal protections for fish and wildlife that we think are so important.

What I'd like to do today is fulfill my charge to this panel and describe some significant legal wins and losses that have profound implications for wild and native fish.

But, then I'd like to talk about a framework that may allow us to broaden the field of play for protection of land and water – so that we are not constantly playing defense of environmental gains made a generation ago.

Wins

TU, and many other conservation groups, have some of the finest lawyers in the country. For example, no other non-profit boasts the wealth of water related legal expertise of our Western Water Project. Over the past 10 years, we have been involved in some critical legal battles. We have won some, and we have lost a few.

In virtually all of our wins, we have worked hard to essentially hold ground already taken in other legal and political arenas. For the six years I have been at TU, for example, we:

1. Won a case before a federal court where we convinced two judges to overturn the Bush Administrations' ill-conceived policy to count hatchery-reared fish as wild fish for the purposes of the Endangered Species Act. If we had lost, the door would have been open to premature and unwise de-listing of many of the 26 salmon species and the habitats they rely on which enjoy the protections of the Endangered Species Act.
2. Conservation interests won a unanimous Supreme Court decision two years ago that upheld the right of the state fisheries and water quality agencies to prescribe fish

passage, and fish-friendly flow measures, for privately-owned, FERC licensed dams under the authority of the Federal Power Act and the Clean Water Act.

3. This year, we convinced a federal judge in Colorado that the Department of the Interior had illegally given away a key water right that sustains the Gunnison River through the Gunnison River National Park. That win is leading the Park Service to work with us and other water rights holders in the watershed to come up with a solution that will restore a key part of the river.
4. Conservation interests recently convinced a federal judge in the Pacific Northwest that NOAA's plans for preventing extinction of listed Snake River salmon and steelhead was insufficient and illegal, compelling NOAA to develop a plan that will not lead to the extinction of the upriver stocks.
5. And perhaps my favorite, which did not directly involve Trout Unlimited, a group of hardy environmental lawyers convinced a federal judge to uphold the Roadless Area Conservation Rule established on Chief Mike Dombeck's watch under the last Administration. The court fight over the protection of 58.5 million acres of National Forest roadless areas has been a see-saw affair, with one federal court knocking out the policy, and another reviving it. For the moment, it is in place, and it protects some of the most important habitats for native trout in the country.

These are all great and important wins. Policy ground was held. Fish resources, in the bulls-eye of one type of development or another, were spared to live for another day.

Losses

But when we lose, the losses are staggering for streams, rivers and fish.

For example, in May of 2006 the Supreme Court handed down what my lawyer colleagues say is one of the most confusing and bad decisions that they have ever seen on the Clean Water Act.

In 1972, Congress passed the Clean Water Act to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." To achieve the goal, Congress recognized the imperative of broadly applying the Act's programs to the "waters of the United States," including headwater streams and remote wetlands.

Two recent split decisions of the U.S. Supreme Court: *Solid Waste Agency of Northern Cook County v. United States Army Corps of Engineers* (*SWANCC*), issued in 2001, and the one I just mentioned, *Rapanos v. United States*, issued in 2006, have narrowed and confused the extent of the Clean Water Act's geographic scope. The plurality in the *Rapanos* decision seemed to be especially hostile to the small headwaters streams that are so vital to healthy watersheds and successful implementation of the Clean Water Act.

As much as 60 percent of sometimes dry headwater streams in some states around the nation may lose Clean Water Act protection because of these two cases – a stunning legal setback. TU, National Wildlife Federation, Ducks Unlimited and others are leading an effort to pass a bill to restore pre-Supreme Court decision level protections under the Act, but it is hard-sledding.

So we have lawyers, and we will defend our laws that defend wild trout. But courts only interpret laws, and you may have noticed that in recent years Congress and most states have not racked up a host of tougher new environmental laws. Look no further than the ones I just mentioned: The Endangered Species Act was last reauthorized in 1988, and the Clean Water Act in 1985.

With the exception, we hope, of a new regulatory program that may come soon to control greenhouse gas emissions to reduce climate change impacts, regulatory environmental laws are not likely to get tougher.

We need to turn to other ways to reach out beyond the floor of environmental regulations we now have to sustain fish and wildlife. TU's vision—the notion that our work will result in fishable populations of wild and native fish in North America's rivers and streams within the next 30 years—forces us to think beyond individual court battles. And though this may be TU's organizational vision, I'd wager it's the very reason every person in this room goes to work every day.

The implication of this vision is that we won't simply hold ground, but rather broaden the context of our work. Consider these facts:

- Every single one of our Western native trout is listed under the Endangered Species Act or has been proposed for protection under the Act.
- More than 106 unique stocks of Pacific salmon have become extinct, and hundreds more are imperiled.
- Even the eastern brook trout, a species most anglers would consider productive and reasonably healthy, is extirpated or greatly reduced in nearly half its historic range.

Layer over the top of the already grim situation the fact that climate change could raise mean global surface water temperature by 3-5 degrees Celsius. Without corrective action, the additional stress of a warming climate on already compromised trout and salmon habitat could lead to local extinctions and broad-scale declines of many species. Fisheries biologists from the Forest Service, for example, predict up to a 95 percent decline in brook trout in the southern Appalachian Mountains without corrective action.

Alone, we cannot undo the effects of decades of roading, dredging, ditching, damming and irrigating on our rivers and streams – even if we were to triple the size of the TU membership. So long as our focus remains on fish and fisheries management, we are talking to ourselves.

Broadening the Base

In 1998, I worked for Mike Dombeck. Mike was the first person to ever lead both the Bureau of Land Management and the Forest Service. He was also the first fisheries scientist to assume either position. One of my responsibilities at that time was to help Mike with Forest Service speeches. That year, he gave the keynote to an American Fisheries Society meeting, delivering a red meat speech to an appreciative audience entitled, From Combat Biologists to Restoration Practitioners.

It was a whiz-bang moment for a closet fish-head speechwriter. You can imagine my surprise when we left the meeting, and Mike turned to me and said, “We need to stop talking to these guys. We need to be spending more time with county commissioners and chambers of commerce. Not the already converted.”

I felt like a kid whose Dad told him Santa Claus wasn't real. But Mike was right.

Similarly, in 1992, when then Democratic-nominee Bill Clinton was running for President on a mantra of “It's the Economy Stupid,” and committing to develop a plan to sustain old growth forests in the Pacific Northwest while providing local jobs, TU came up with the slogan, “It's the Fish, Stupid.” It was a wonderful way to draw attention to the plight of salmon when all of the media focus had been on Northern Spotted Owls.

In spite of the effectiveness of the TU slogan for its time, so long as we keep talking about fish issues to fish advocates we relegate ourselves to a very narrow audience.

Mindful of that, we in TU began to ask a series of questions:

- How can we make the recovery of trout and salmon a driving force of the agendas of state and federal agencies–not just the fish programs but of entire agencies?
- What would happen if local planning boards, county commissioners, and chambers of commerce saw social and economic benefits in our vision for sustaining wild and native trout and salmon?
- How would the political dynamic change if home builders saw the economic benefit of trout and salmon friendly development, and

agricultural interests the benefit of leaving water instream?

- What if we were able to engage the land trust community in aligning their land protection priorities with our fish protection priorities?

Protect-Reconnect-Restore-Sustain

So, I'd like to share with you one framework for broadening the playing field for sustaining wild trout and salmon. TU is using this approach to drive our own organization's conservation agenda, and we want to know what you think and how we can improve on it.

Our approach has four basic elements. **First, identify and protect the best remaining habitat for trout and salmon**, whether it is on public, state or private land. This means advocating for continued protections for undeveloped backcountry. It requires collaborating with oil and gas companies to retire development leases, opposing ill-advised mining projects, and piloting responsible drilling methods on public lands. It means forming partnerships with local, regional and national land trusts, and identifying shared land protection priorities. It means continuing to defend environmental laws which protect wild trout and salmon.

In addition to protecting habitat, we must also recognize the imperative of maintaining the genetic diversity of trout and salmon. Diversity begets resiliency, and in a warming climate, we cannot afford to lose, for example, the genetics that allow brook trout to thrive in the southern Appalachian Mountains, or steelhead in Southern California.

Second, ***reconnect*** **high quality habitats to upstream and downstream areas** by increasing river flows and removing barriers to migration. Increased levels of drought, flooding and fire are expected in a warming climate. Providing opportunities for isolated populations of native and wild fish to migrate during these disturbances will help them to survive.

North America's waterways are riddled with old dams that block passage for migratory fish and serve little social or economic purpose. Removing obsolete dams and diversions can provide quality, family-wage jobs while improving watershed health. And if we want to recover those upriver stocks of salmon and steelhead in Idaho, we will have to remove those four lower Snake River dams. But so long as it remains us fish advocates making the biological, scientific, and legal case for dam removal, we will likely keep winning court cases but lose the fish. We must work with the affected communities that depend on those dams and figure out a way to make them whole if we are to see the upriver stocks recover.

Looking east, water delivery systems in the Eastern United States were designed to supply large urban areas, but much of the population growth in the East is occurring outside of traditional metropolitan areas, placing water demands on small streams that provide important brook trout habitat. In the West, as a result of century-old state water laws designed to encourage settlement and development, irrigation accounts for 80 percent of water use in the fastest growing region in the country. More rational state water laws and policies that encourage conservation will be essential if we are to meet the needs of people and still recover the connectivity of trout and salmon habitats.

The final biological imperative of our vision is to ***restore*** **degraded areas.** A healthy watershed should do three things—collect, store and slowly release water over time. Development and disturbance around watersheds creates flashy systems that are prone to drought and flooding, with none of the benefits of filtration or a slow water recharge to the system.

TU's grassroots volunteers are an incredible asset in this area, willing to roll up their sleeves and work to improve the rivers and streams in their backyards. But achieving our vision will also require that we dramatically expand the nation's capacity for restoration.

For example, only a fraction of the billions of dollars spent on Farm Bill conservation programs directly benefit fisheries. In the Western United States, abandoned hard rock mines affect 40 percent of headwater streams, and there is no single federal, state or private funding source dedicated to abandoned mine clean up. Creating new state, federal and private sources of funding for restoration is perhaps the most daunting challenge to achieving our vision.

Finally, in order to ensure the durability of our efforts to protect, reconnect and restore lands and waters, **we must *sustain* our work through succeeding generations**. In the span of a single generation, America has evolved from a majority rural population to one where 80 percent of today's kids grow up in urban and suburban areas. Not surprisingly, more and more children are spending less and less time outdoors. As numbers of anglers decline, we need to promote programs such as youth camps and Trout in the Classroom to help educate the next generation about the importance of clean water and land health. If future generations are unaware of, or disinterested in, the legacy of our work, it won't endure.

Protect. Reconnect. Restore. Sustain. Taken together, we think these are the keystone elements of wild trout sustainability. The fisheries benefits of this framework are obvious. But so are the social and economic benefits to communities of people.

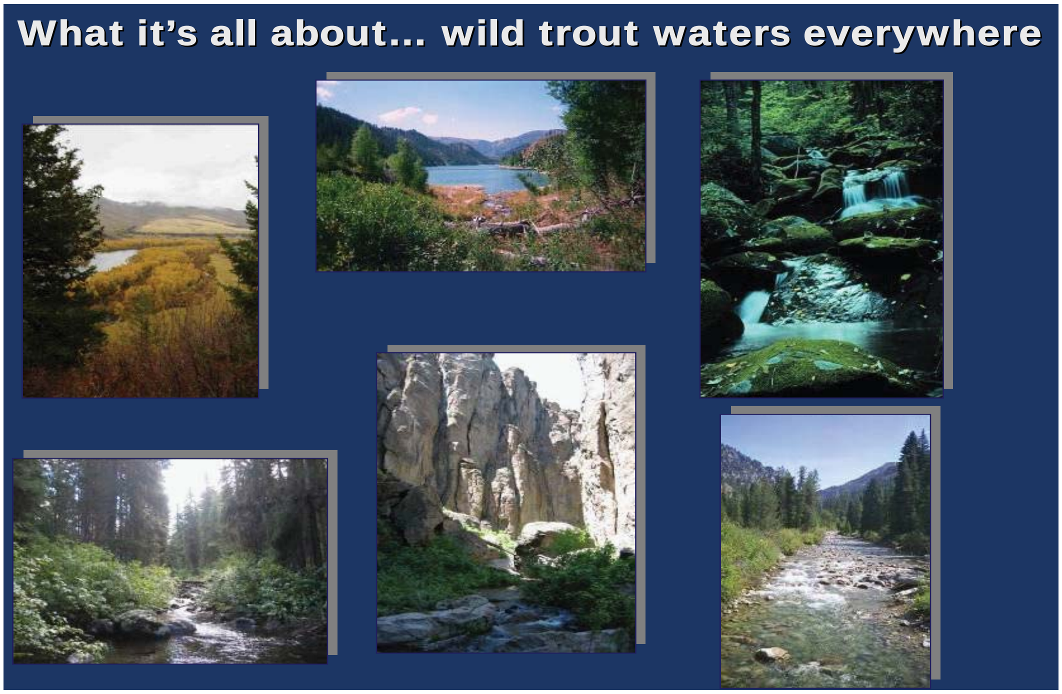
- Higher quality drinking water;
- Reduced flooding;
- Managing sprawl and growth;
- Providing high-quality family wage jobs through restoration on a landscape scale;
- Restoring forest health;
- Controlling invasive species that diminish land productivity;
- Maintaining the quality of life in less-urban communities;
- Protecting children; and
- Preventing catastrophic fires.

This work may involve more partnerships at broader scales, but it's the same protection, reconnection, restoration, and sustaining work we've always done. It's how we talk about it, and who we talk to that is different.

Our challenge is to build a framework, a context, a logic-model–whatever term you prefer–that allows us to turn recovery of trout and salmon from a defensive, reactive, and reactionary game to the forward-looking, positive, and solution-oriented outlook that local communities can rally behind and that can recover wild trout and salmon. In short, it entails reconnecting people to the lands and waters that sustain them.

Legal actions by Trout Unlimited and our conservation allies will always have a clear role in this work. But, far more is needed. We believe this approach represents our best hope for ensuring that native and wild coldwater fish once again thrive within their North American range, so that our children can enjoy healthy fisheries in their home waters.

Location of Wild Trout IX Symposium, 2007.



What it's all about… wild trout waters everywhere

Wild Trout IX—Closing Summary

Paul Schullery
Former Director of the American Museum of Fly Fishing,
Manchester, VT

It's always a treat, personally and professionally, to attend a Wild Trout Symposium, and it is an honor to get to speak at one.

It is, however, intimidating to try to summarize one, especially one as exciting and stimulating as this one. Besides all of the presenters who have shared important insights and discoveries with us, I counted at least five papers that would each by itself serve as an eloquent statement of the spirit of the whole conference. But here goes.

I'm a historian, so I tend to seek the context of the longer view, and the longer view of wild trout is very long indeed. One hundred years ago, the great fisheries biologists David Starr Jordan and Barton Warren Evermann introduced their scientific description of the American brook trout with this statement:

> The trout are rapidly disappearing from our streams through the agency of the lumberman, manufacturer, and summer boarder. In the words of the late Rev. Myron W. Reed, a noble man, and an excellent angler,—"This is the last generation of trout-fishers. The children will not be able to find any. Already there are well-trodden paths by every stream in Maine, New York, and in Michigan. I know of but one river in North America by the side of which you will find no paper collar or other evidence of civilization. It is the Nameless River.
> Not that trout will cease to be. They will be hatched by machinery and raised in ponds, and fattened on chopped liver, and grow flabby and lose their spots. The trout of the restaurant will not cease to be, but he is no more like the trout of the wild river than the fat and songless reed-bird is like the bobolink. Gross feeding and easy pond-life enervate and deprave him. The trout that the children will know only by legend is the gold-sprinkled living arrow of the white water; able to zig-zag up the cataract; able to loiter in the rapids; whose dainty meat is the glancing butterfly."

I offer that lovely and gloriously over-wrought quotation to suggest that we who care about wild trout have worried about the future for a long time. Among many other things, the future has always been an unparalleled rhetorical opportunity for eloquent disquisitions upon what is wrong with the present.

With very few exceptions, Reverend Reed nailed the big-picture problems wild trout and their friends still face. He did not anticipate newer challenges like climate change, of course, but for the most part, his list was very good: loss of living space; too many humans with too many demands on the fish; habitat destruction by an industrial society; compromise of genetic integrity; our sporting society's apparently irresistible temptation to pander to the cheapest, laziest aesthetic standards; and loss of respect for what wild trout can and should mean in our world. We may have added to the list of problems, but we could not express our alarm with greater urgency than Jordan, Evermann, and Reed did 100 years ago.

That Reverend Reed was wrong about the timing of the coming disaster—that wild trout are still out there and their friends are still putting up a fight on their behalf—in no way diminishes the urgency of his message, or the responsibilities we now face. Wild Trout IX clarifies that urgency, and will help focus the responsibilities for all of us.

As several speakers have pointed out, the Wild Trout conferences themselves now provide us with a long view. Much has changed since that first meeting at Mammoth Hot Springs in Yellowstone National Park 33 years ago.

When Wild Trout I convened, I lived right across the street, but I confess that I missed the meeting because I was in Oregon trying to catch a steelhead. I'm sure it served me right that I got skunked. But thanks to some notes kept for me by a friend, and thanks even more to the splendid proceedings that Frank Richardson and his pals put together, I can offer a few impressions on where we started and where we've arrived.

Let me start by invoking a couple particularly telling remarks made at Wild Trout I. As Marty Seldon told us yesterday, A. Starker Leopold, a powerful presence in federal wildlife management for many years, forcefully questioned the presumed appropriateness of multiple-use policies, even on public lands whose managers were legislatively obliged to honor multiple-use mandates. It seems strange to us today to think that such a comment could be either novel or revolutionary, but that is what it was when Starker advocated scientific research to test and quantify what multiple-use policies, especially those relating to livestock grazing, meant to wild trout and their habitat.

I can still remember the happy expression on Starker's face not long after that, when he told me that he'd just tossed that idea out there with no idea if it would fly, and was delighted to be approached by a young researcher who was involved in just such a project. The Wild Trout conferences have fostered a long, productive dialogue among professionals, a dialogue whose worth has been immeasurable.

Here's another equally revealing statement from that first conference. Gardner Grant, one of the authentic citizen-heroes of modern wild-trout conservation, articulated a prevailing truth of the time when he said, "The trout angler must come first in our deliberations." Gardner accurately perceived anglers as the only significant wild-trout constituency, but I think his statement reveals another momentous change in only three decades. This week's sessions suggest to me that the trout can't make it if only anglers care about them. Many of this week's speakers have provided creative ways to ensure that more non-anglers do care. The future of wild trout seems to be all about collaboration and partnerships, often in complex mixes of interest groups that our Wild-Trout-I counterparts would have had a very hard time imagining

This is a fascinating sign of how we change, and how our sense of proportion develops to suit the times. I think it was Virgil Moore, during the opening plenary session this week, who pointed out that when Wild Trout I was convened, the National Environmental Protection Act (NEPA), the Endangered Species Act (ESA), and other important environmental legislation were so new that we were still trying to figure out what they might mean.

What happened when all that new legislation took hold was probably predictable. If you hand a bunch of determined and often desperate advocates a batch of powerful weapons like NEPA and the ESA, it's a pretty sure bet that they're going to turn those weapons on their adversaries, and that though this may help, it also will ensure that the adversarial relationships will just harden.

I wouldn't for a moment suggest that some of those adversaries didn't deserve it, nor would I suggest that we shouldn't still make every necessary use of those laws. But what we have heard from several presenters this week, about some remarkably effective and unorthodox collaborations on behalf of wild trout, reminds me of what I've similarly heard from some Canadian friends who have for many years been involved in grizzly bear conservation. What they say to me is, "We don't have an endangered species act. Our only hope is to get everyone together and talk with them."

Maybe there's an unspoken message in that thought for us in this new collaborative climate. Maybe breaking the reflexive habit of suing the perceived bad guys might be further facilitated if, each time we face one of these crisis issues, we approached it as if we had no choice but to talk to everyone instead.

At Wild Trout I, the topic of special regulations, especially but not exclusively catch-and-release, was a nervously cutting-edge conversation. Today, catch-and-release and its many variant themes have become almost venerable topics. The contention over catch-and-release has itself gone on long enough to become an almost ritualized exercise in our angling society. And, as the catch-and-release session here at Wild Trout IX has shown us, the continuation of catch-and-release research not only enriches our grasp of this momentous management tool but further informs us of its cultural complications.

In 1974, restoration of habitats and native fish populations was a discussion based on a few shining examples. Here in 2007, an overwhelming majority of the papers dealt with those topics. In fact, of all the things discussed here this week, I imagine that modern genetics analysis and climate change represent the two most dramatic changes in our conversations since Wild Trout I. Those topics would probably sound almost like science fiction to our Wild-Trout-I counterparts.

To further emphasize the dynamic nature of wild-trout management over time, I'd like to turn to the Yellowstone Lake crisis for a cautionary case study, one whose scientific story was so well presented by my Yellowstone colleagues at this meeting.

About 30 years ago, the great angling theorist Lee Wulff came to Yellowstone National Park to learn more about the extraordinary overhaul of trout management launched by the host of Wild Trout I, Superintendent Jack Anderson, along with biologists Jack Dean and John Varley. Lee looked around, fished for a few days, talked to the right people, and announced that the future of wild trout had in fact arrived.

Many of us in Yellowstone felt the same way right then. We were pretty proud of ourselves for what the grand old park had contributed to reshaping the political, social, and scientific landscapes of wild trout. Even grunt rangers like me, whose only role in wild trout management was to try to explain catch-and-release fishing to bewildered crappie fishermen from Indiana, felt like we were a part of that achievement.

It is still shocking to recall how quickly that glowing future fell apart. Lake trout and whirling disease made that great old future of the 1970s into a deeply lamented artifact of memory.

But it still mattered hugely. For a little while there, we could happily agree with Lee Wulff that the bright future of wild trout was no longer a forlorn and remote abstraction. It was real, we made it happen, and the memory of it will keep us going for a long time. Yellowstone was just one of the places where we proved that we could take on the problems of wild-trout management and actually solve them. It also proved that there will always be new problems, and now we are trying to prove that there are new solutions, too.

As with the previous eight conferences, we conclude this one with our eyes open and the alarms still ringing. In his opening remarks, Steve Moore challenged us to champion wild trout. We know the urgency and the stakes. We know there are more surprises to come. We've heard about declining fishing license sales and the crisis of nature-deficit disorder. We have vivid GIS-quality maps in our heads that show this or that cherished native species retreating up into smaller and smaller tributaries, with nonnative hybridizers hot on their tails. We know that more American children could accurately draw a velociraptor than could accurately draw a trout.

And we've all heard the solutions. More fishermen. More youth education. More public education. More political engagement. More collaboration.

Certainly those needs become more important all the time. But another message I heard here this week is that those things aren't enough.

My favorite moment in that great old TV show, "Hee Haw," was when several hillbilly girls were talking, and one of them said, "My boyfriend don't know nothin!" In response, one of the other girls said, "Know nothin'? Honey, he don't even suspect nothin'!"

When it comes to the future, historians don't know nothin' either. But we often do suspect something. Here is what I suspect.

I suspect that even if we can halt the decline in sport fishing, and even if we can recruit more and more anglers, this alone will not turn the tide that now seems to be running so strongly against wild trout and their needs.

That is why I am inclined to believe that we're going to have change the demographics of wild trout appreciation even beyond what has been suggested here. If wild trout are to become the universally respected aesthetic symbols and environmental indicators we know they deserve to be, somehow we're going to have to unhitch those trout from their narrow public image as only a fisherman's animal. Until the wild trout constituency broadens, the trouts' fate is our fate, and our fate may not be good enough for them.

I likewise suspect that we sportsmen are going to have to unhitch ourselves from who and what we have become. We've done this before. As the historian Daniel Herman wrote in his book *Hunting and the American Imagination* (2001), between 1850 and 1900 the American sportsman reinvented himself. In those years, we transformed ourselves from a socially marginal and politically meaningless mob of self-centered game hogs into a politically influential force whose members had successfully equated good sportsmanship with good citizenship.

No matter how highly we anglers think of ourselves as conscientious conservationists and enlightened citizens, the rest of the world is no longer impressed. We must impress them again, for our own sake and for the sake of the trout.

Do I know what we should become instead of what we are? Not really. But I do have some ideas of how the world of wild trout might look if we succeed.

What we're after, I suspect, is a world in which a typical calendar or coffee-table book about the so-called great American wildlife species would routinely include, right along with the charismatic grizzly bears and bald eagles, not only the golden trout but the desert pupfish or the mottled sculpin. It is a world in which good sportsmanship would again be—especially in the minds of the urban non-angling public—synonymous with good citizenship. It is a world in which wild-trout anglers would purchase their memberships in Trout Unlimited, Fly Fishers Federation, the Nature Conservancy, and many other organizations as reflexively as they purchase their fishing licenses. It is a world in which schools would routinely come to us, rather than have to be approached by us, for our help with their educational programs, because everyone would know how important it is to understand the lives and ways of wild trout.

More specific to the past few days, I suspect that in this new world a wild trout conference, while it would be just as scientifically rigorous as today, would attract a different mix of participants. Not only would there be the managers and researchers, there would be more of the traditional adversaries with whom we are now learning to collaborate. There would also be social scientists, non-angling environmental activists, general-interest journalists, educators, congressional staffers, and even those passionate and politically savvy folks from the animal welfare movement. And a much higher percentage of all these people, from all these groups, would be female.

Last, there's something I don't have to suspect, because I know it's true. If there is ever to be such a brave new world of wild trout, some of us veterans of the older world are going to have the hardest time living in it.

But that's a price worth paying if it means we get to keep the trout.

Marty Seldon

2007 Awards Luncheon and the Aldo Starker Leopold Wild Trout Medal

Marty Seldon, Jim Daley

Awards Committee Chochairmen

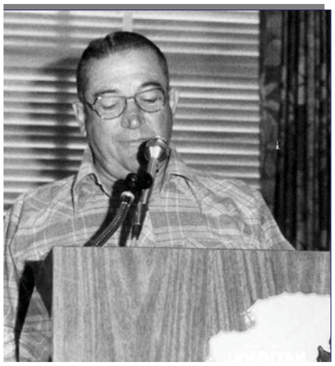
Jim Daley

Starker Leopold, world-renowned scientist, dedicated teacher, distinguished author, outstanding naturalist, beloved angling companion to many, and an influential speaker and participant at both Wild Trout I and II died on August 23, 1983. His death occurred a year before Wild Trout III at his home near the University of California Berkeley campus where he taught and was the retired head of the Zoology Department. Many of us still miss him and his counsel.

At the suggestion of Nathaniel P. Reed, former Assistant Secretary of the Interior, the federal official that first approved these Symposiums, the Sponsoring Committee established The Aldo Starker Leopold Wild Trout Award as a memorial to Starker in 1984.

A. Starker Leopold was born in Burlington, Iowa and was the eldest son of Aldo Leopold. Following in his father's footsteps, he became one of the worlds most influential and honored authorities on wildlife ecology and management. He attended the University of Wisconsin, Yale Forestry School, received his Ph.D. from the University of California at Berkeley in 1944 and retired there as Emeritus Professor of Biology in 1978.

Starker Leopold was heavily involved in public policy at the highest levels. In 1968 he chaired the Special Advisory Board on Wildlife Management of the Department of the Interior which led to significantly new national park and refuge policies. He was a member of the Advisory Committee on Predator Control and an international consultant on wildlife conservation policy. He served as a Director and President of the California Academy of Sciences, as a Director and Vice President of the Sierra Club and engaged in a broad range of public service activities.



Aldo Starker Leopold

Leopold addressed the negative impacts of multiple use at Wild Trout I. At Wild Trout II he spoke about degraded wild trout populations and the need to give higher priority to land use patterns and the physical condition of our lakes and streams. The following year Starker told the Federation of Fly Fishers annual convention, "For my part, I believe that the limited budget available for trout management is largely misspent on trivial activities, of no present value, such as the catchable trout program. Unless we bite the bullet and attack the habitat problem with vigor, the future of quality trout fishing in America is unpromising."

Starker's main goal was a world suited to wildlife and therefore fit for people. His personality was characterized by eminent academic and scientific achievements, love of the outdoors, positive personal warmth, and sensitivity. A. Starker Leopold was a friend to fish and wildlife, and to all of us.

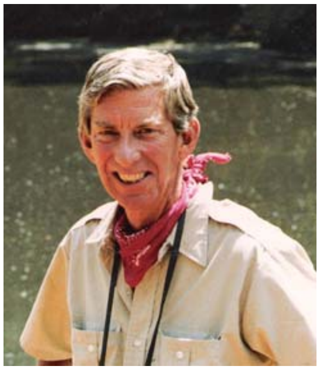
As a continuing memorial the Aldo Starker Leopold Medals are given at each Symposium to a professional and a nonprofessional who over time have made significant individual contributions to the enhancement, protection, and preservation of wild trout in North America. Prior to each symposium, nominations are solicited from the sponsoring organizations, biologists, administrators, and conservationists that attend these wild trout symposiums and the wild trout community.

The first Aldo Starker Leopold Wild Trout Medal Awards were made at Wild Trout III in September, 1984 to Martin M. Seldon of Sunnyvale, California, a long-time fisherman-conservationist; and to Dr. Robert J. Behnke, Colorado State University, Fort Collins, Colorado, the noted trout biologist. Table 1 provides a summary of the other Medal recipients. Table 2 lists the members of the WT-IX Symposium Awards Committee

During the nomination and selection process for WT-VIII, the symposium's 30th anniversary, the Awards Committee set an objective of designing and striking an appropriate physical medal as the award. Success of the project was made possible though a very generous $3,800 grant from WT-VIII exhibitors Richard and Laura Reichle and Advanced Telemetry Systems. Inc. (www.atstrack.com). As seen on the photos below, a profile of Starker, drawn by the late Ernie Schwiebert, is on one side of the medal and Awardee information on the other. The medal is three inches in diameter, made of solid brass with an antique bronze finish, and appropriate lettering.

After completion of the nomination process and by vote of the committee, the 2007 WT-IX Aldo Starker Leopold Wild Trout Medals have been conferred on:

Nathaniel P. Reed Professional Level Medal



Nathaniel Pryor Reed was born in New York City, July 22, 1933 and grew up in Florida, and Greenwich, Connecticut. As he matured, he fished and discovered the mysteries of sweet water streams, estuaries, sand lakes, and in the north, trout and salmon.

Mr. Reed received a B.A. from Trinity College, Connecticut in 1955 and served as an officer in the U.S. Air Force military intelligence service, retiring in 1959 with the rank of captain. He returned to Florida and began a career as manager of the family real estate business in Hobe Sound. He is an avid trout and Atlantic salmon fly fisher.

Reed's experience and active concern with environmental matters steered him into public life. He became involved with the problems of Everglades National Park, and was invited by Governor Kirk to become Florida's first governor's environmental advisor. Reed held a number of State positions and was a major factor in the purchase of 22 new Florida parks and wilderness areas.

Nathaniel P. Reed served as Assistant Secretary of the Interior for Fish, Wildlife and Parks in the

The Medal(Sponsored by ATS)

Nixon and Ford administrations (1971-1977) with responsibility for the Bureau of Outdoor Recreation, the Fish and Wildlife Service, and the National Park Service. He was very concerned with fish and wildlife protection, public lands management, endangered species, and the establishment new parks and refuges. His opposition to dams, drainage ditches, and other pork barrel projects became three "60-Minutes" television segments.

Mr. Reed used his position in the Department of Interior to educate the administration and the general public on the centrality of conservation to American life. When Frank Richardson, Peter Van Gytenbeek, and John Peters first presented the concept of a Wild Trout Symposium, Nathaniel Reed enthusiastically supported the idea, provided the funding and directed Frank Richardson to coordinate and manage the event. Nathaniel was also an active participant sharing the podium with Starker Leopold.

Reed returned to Florida following President Ford's leaving office and continued to serve seven governors. Described by Bruce Babbitt, "Nat Reed is a lean, ruddy aristocratic sportsman..... a Republican in the spirit of Theodore Roosevelt, passionately committed to environmental causes." He became one of Babbitt's most trusted advisers in the 1990s.

Reed's friendship with Starker Leopold led to many trout fishing excursions throughout the west, both men preaching 'wise land management and the value of clean water not only for trout but for all forces of life, including man'.

Nathaniel P. Reed has been vice chairman of the National Audubon and of The Nature Conservancy Boards; member of the Natural Resources Defense Council; and on the boards of the National Geographic Society, the Everglades Foundation, Hope Rural School, American Rivers, the first chairman and founder of 1000 Friends of Florida, and advisor to many other environmental organizations. He has always been one of Wild Trout's greatest advocates and well deserving of the Aldo Starker Leopold Wild Trout Medal.

Nathaniel P. Reed Medal Acceptance Remarks

Frank Richardson and Van VanGytenbeek

Symposium Founders Van VanGytenbeek and Frank Richardson accepted the Aldo Starker Leopold Wild Trout Medal awarded to Nathaniel P. Reed, who could not attend. Before retirement, Frank was the US Fish and Wildlife Service point man funding and managing the Symposia and Van was the TU Executive Director. Both recalled the early days when Nat's participation and support made it all possible.

Van recalled several examples where Nat stepped up and confronted controversial conservation issues head on, such as instituting catch-and-release only regulations in Yellowstone National Park and banning fishing from Fishing Bridge. As Van put it, "no individual in this world is more deserving of the Starker Leopold award."

Frank recalled how Nat knew Starker Leopold intimately, and considered Starker to be his mentor. Whenever confronted with a scientific problem, Starker was on of Nat's most relied upon sources of accurate information. Frank then read a quote from Nat given during a recent interview. Nat was responding to the question posed by the interviewer "What is your legacy?" Here is Nat's response:

…I do not know anybody on the face of the earth that has been luckier than I have. I hope I have tried to confront the important issues, not dodge them. That does not mean we won all of those, but we confronted them, we brought them forward to decision makers who did not agree with us. We based our confrontations with existing policies on good science, as well as common sense. I will go to my grave proud it was not just hugging the tree kind of conservation. It was based on study. It was based on good science. It based on commitment. It was based on ethics and responsibility.

Frank noted that he would be seeing Nat in Florida this winter, and will personally deliver the Wild Trout Medal to Nat at that time.

Nick Lyons Nonprofessional Level Medal

Nick Lyons is a trout fisher's trout fisher. His books and regular magazine articles have made his life an open story that we all have enjoyed. Nick gained fame not only as a wild trout author but as the owner of Lyons Press and the excellence of its published works. Lyons Press was sold to Globe Pequot in Guilford, CT (www.globe-pequot.com) in recent years and Nick is now enjoying life between his homes in New York City and Woodstock, New York.

Nick Lyons received a B.S., University of Pennsylvania, 1953; M.A. 1959, PhD in American Literature, 1963, University of Michigan, where the AuSable River was close enough to sandwich in between Milton and Keats. He held positions as Professor of American Literature and Writing, Hunter College, 1962-1988; Crown Publishers, Inc., 1965-1979--Executive Editor, developed the "Sportsman's Classics" series.

Mr. Lyons was founder and Publisher, The Lyons Press (for a time called Lyons & Burford), edited and published more than 150 books on fly fishing, conservation, and natural history. His writings included the "Seasonable Angler" column for Fly Fisherman, 1977-1998, articles in Field and Stream, Outdoor Life, Sports Afield, Harper's, The New York Times, National Geographic, Outside, and elsewhere -about 400.

He is the author or editor of more than twenty books, including In Praise of Wild Trout, The Seasonable Angler, Bright Rivers, Hemingway on Fishing, Spring Creek, and Full Creel. In Fish Tales, Nick said, "In the best stories about Fly Fishing....the words have the warm colors of earth and water, not the jargon of the specialist; we meet real people, with warts and wit and maverick gestures; big fish are caught or lost; people say wild and spontaneous words; event becomes memory and sometimes, in the hands of a master, bleeds into art." Ed Zern said of Nick that if he fishes as skillfully as he writes about it, I'd pay to watch him.

Several years ago, Lyons Press sent me a flyer of their current releases that added to my appreciation of the contributions made by Nick Lyons. A partial list of authors he helped develop at the time was substantial: American Fly Fishing, Paul Schullery; Caddisflies, Gary LaFontaine; Brook Trout and Early Love, James Prosek; Fly Fisher's Guide to Crimes of Passion, Seth Norman; Green River Virgins, Mallory Burton; Selective Trout, Swisher and Richards; Steelhead Country, Steve Raymond; Stillwater Trout, John Merwin; The Orvis Streamside Guide to Trout Foods, Tom Rosenbauer; The Seasons of a Fisherman, Roderick L. Haig-Brown; To Know a River, A Haig-Brown Reader, Editor Valerie Haig-Brown; Trout Madness; Robert Traver; Trout Magic, Robert Traver; Streamside Guide, Art Flick; and A Modern Dry Fly Code, Vince Marino.

Nick is married to Mari Lyons, an accomplished painter who has illustrated four of Nick's Books. They have four grown children.

Nick Lyons Medal Acceptance Remarks

Craig Mathews

Craig Mathews accepted the Aldo Starker Leopold Wild Trout Medal awarded to Nick Lyons, who could not attend. Craig is a noted author and conservationist in his own right. He has owned and operated Blue Ribbon Flies in West Yellowstone for 25 years, has authored a number of books and award-winning DVDs on fly-fishing in the western United States and Yellowstone National Park. What is truly special about Craig is his commitment to give something back to help preserve, protect, and enhance western trout waters for future generations. Blue Ribbon Flies has won several conservation and environmental awards, and donates over 1% of their sales to conservation and environmental causes. Craig's remarks follow.

The adjectives that describe the finest of humankind apply to my friend Nick Lyons: Courage, honesty, tenacity, dignity, grace and generosity. In all Nick's writings he has the gift of sight beyond ordinary vision, and yet he is so humble.

In much of his recent writing he teaches us to strive to protect, preserve and enhance wild trout and wild places.

Nick has encouraged, coaxed and inspired our 1% for the Planet business alliance from its early beginnings in 2001. 1% for the Planet is an alliance of nearly 800 businesses which donate at least 1% of their GROSS sales to conservation causes. This year we expect to break $18 million with some of the donations going to wild trout programs and projects in and around Yellowstone National Park.

Nick is to me like father, like mentor, like friend.

It is truly an honor to accept the Aldo Starker Leopold Wild Trout Medal from the Wild Trout Symposium for my friend, your friend, and one of wild trout's greatest supporters: Nick Lyons…

Craig then read the following letter submitted by Nick Lyons:

One of the saddest moments in angling literature occurs in Where the Bright Waters Meet, when the author, Harry Plunket Green, fully realizes the loss of the River Bourne's native brown trout. They were, in his words, "broad shouldered" trout – "happy" fish that rarely forgot themselves "so far as to pursue a nymph." Bulging they considered "bad form."

With indiscriminate stocking, the smaller hatchery fish dominated the river, winning the chase for food, and he watches on of his "great silver trout" grow weaker and weaker until it is "enervated, inert, blue, and blind."

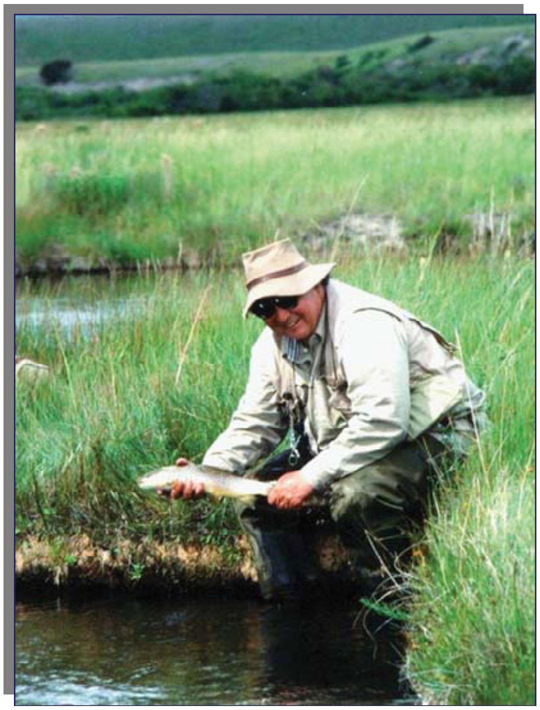
With the demise of the wild stock, the author's emotional connection to the Bourne fades until we are forced to think what wild trout may well be why we fish at all, and without them won't.

My contributions to the presence of wild trout in our rivers is modest:

Merely a few essays that address this issue directly, though many do so slyly, since I catch so few trout:

The spirit of my old Lyons Press and the many books we published on trout biology and fly fishing for trout;

And my little anthology, done with love, In Praise of Wild Trout. But I am hugely grateful to the Wild Trout Symposium for thinking that some of what I've managed to do has helped a vision to which I have been deeply committed.—Thank You.



Recognition of Liz Mamer's Contributions to Wild Trout Symposia

In 1998, Liz Mamer, Idaho Department of Fish and Game, agreed to assist Steve Moore and Dan Schill with the program for Wild Trout VII. Throughout the preparation for this symposium, she worked diligently to keep track of conference call minutes, assisting with the organization of the meeting schedule and providing the organizing committee with timely reminders of important due dates. Liz continued this valuable assistance during Wild Trout VIII and IX as Symposium Secretary.

During all phases of theses two conferences, Liz assisted the chairman and all committees with schedules and assignments. She kept diligent meeting and conference call notes, managed the web site, sent timely reminders for important due dates and cheerfully assisted with the hundreds of details necessary to make these events successful. Additionally, she recruited and organized students to help with photos, registration and audio visual needs for the conference as well as assist staff from MSU with registration.

At the WT-IX Awards Luncheon, Symposium Chairman Steve Moore, gave special recognition to Liz Mamer for her exceptional services to Wild Trout VII, VIII and IX. He presented her with a 5wt Sage fly rod for her outstanding efforts. Symposium attendees added to the recognition by giving her a standing ovation. The rod was donated by the Federation of Fly Fishers.

Montana American Fisheries Society Outstanding Landowner Award

The Wild Trout-IX Awards Luncheon included a special presentation during which the Gallatin National Forest and the Montana Department of Fish, Wildlife, and Parks presented a posthumous Montana Chapter of the American Fisheries Society's 2007 Outstanding Landowner Award in recognition of Dale Koelzer for allowing access to and encouraging fisheries research and education on his private land in the West Yellowstone area. Because of Dale Koelzer's civic-minded generosity, the Hebgen Basin Interagency Fisheries Working Group was able to install fish traps, operate gill nets, and collect data on the important Duck Creek tributary of Hebgen Lake fishery and conduct an annual kids fishing day on the ranch.

Establishment of the Wild Trout Stewardship Award

A new Wild Trout Stewardship Award was announced during the Wild Trout-IX Awards Luncheon. The new award will be given to a club, group, or organization in recognition of significant wild trout projects. Sponsorship is being solicited from TU and the FFF, possibly with help from private donors, to establish an endowment to be able to provide an honorarium with each award.

The "TU/FFF Wild Trout Stewardship Award" will be conferred by the Wild Trout Symposium for the implementation of an outstanding fishery project or plan that makes a significant contribution to the conservation, protection, restoration, or enhancement of a cold water fishery. This award is made to a club, group, or other organization.

Establishment of New Marty Seldon Student Travel Scholarship

Also announced was the establishment of a new student award category in the name of Marty Seldon. Each year two $500 scholarships will be made to students in support of their travel to attend the wild trout conference.

Martin M. (Marty) Seldon is a retired Electronics Engineer that still consults for the Microwave Tube Company he has been associated with since 1963. Starting in the 1960's Marty wrote fishing columns for San Francisco and Central Valley fishing newspapers and was Angler Magazine Conservation Editor. He has written extensively on Catch-and-Release. Marty was a Trout Unlimited chapter president, a founding director of CalTrout, and has been a Federation of Fly Fishers volunteer since 1972.

He has held positions as Conservation Vice President of the Northern California Council FFF and from 1976-1986 was on the FFF Executive Committee as Senior Vice President Conservation. He has been Chairman of the FFF International Relations and Fish and Wildlife Committees, and managed several FFF fly fishing industry databases. He is presently a FFF Northern California/Northern Nevada Council Director, and a FFF Senior Advisor.

Marty and Rita Seldon, 2007.

Marty joined the Wild Trout Symposium Organizing Committee and presented a paper at Wild Trout-II in 1979. He has been active on the Photography, Awards, and Program Committees. Seldon was Chairman of the Aldo Starker Leopold Wild Trout Medal Awards Committee from WT-VII in 2,000 and Awards Committee co-chairmanship for WT-IX in 2007.

Among many others, he received the Federation of Fly Fishers' highest honor, The Order of the Lapis Lazuli Award. He was also the Symposium's first nonprofessional category Aldo Starker Leopold Wild Trout Medal recipient at Wild Trout-III in 1984.

Marty Seldon served in the U.S. Army of Occupation in Germany just after WW-II, graduated from Columbia University in 1952, and holds one patent. He and his wife Rita live in Sunnyvale, California and have two children and three grandchildren in San Francisco and Eugene, Oregon.

Marty Seldon fishing in West Yellowstone, 2007.

Table 1. Wild Trout-IX Symposium Awards Committee, 20 January 2007

The Wild Trout Symposium's Aldo Starker Leopold Wild Trout Medal Awards Committee is made up of prior recipients and volunteers. Otto Teller and Ernie Schwiebert have passed away, and Roger Barnhart has asked to be deleted. We now have ten (10) Awards Committee members:

Robert Behnke
3429 E. Prospect Rd
Fort Collins, CO 80525-9739
970-482-1078
rjsjbehnke@lpbroadband.net

Jim Daley, Co Chairman
Coldwater Fisheries Unit Leader
Division of Fish, Wildlife, and
Marine Resources
625 Broadway
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(518) 402-8959
jgdaley@gw.dec.state.ny.us

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H 914-946-5784
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(winter)
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bobphylhunt@charter.net

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marionjones@arkansas.net

Bud Lilly
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406-284-9943

Frank Richardson
(summer-May)
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406-586-1371
tworiversides@aol.com
(winter)
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tworiversides@webtv.net

Marty Seldon, Chairman
1146 Pulora Court
Sunnyvale, CA 94087-2331
408-736-5631
mmseldon@sbcglobal.net

R.P. "Van" VanGytenbeek
% FFF
215 East Lewis Street
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406-222-9369
van@fedflyfishers.org

Ray J. White
320 12th Avenue No.
Edmonds, WA 98020-2930
Tel: 425-672-8768
rw@seanet.com

Table 2. Recipients of the A. Starker Leopold Wild Trout Award

The A. Starker Leopold Wild Trout Awards are given at each Symposium to a professional and a nonprofessional who over time have made significant contributions to the enhancement, protection, and preservation of wild trout in North America. Prior recipients include:

Date	Professional	Nonprofessional
1984, WT-III	Robert J. Behnke	Martin M. Seldon
1989, WT-IV	Frank Richardson	Otto H. Teller
1994, WT-V	Ronald D. Jones	Gardner L. Grant
1997, WT-VI	Roger A. Barnhart	Ernest G. Schwiebert
2000, WT-VII	Robert L. Hunt	Walden Francis "Bud" Lilly
2004, WT-VIII	Ray J. White	R. P. Van Gytenbeek

This year's sympsoium activies included:

Bob's 30 inch, 10-Pound Madison River Brown Trout

Flycasting Demo and Hands-on Lessons by Bob Jacklin

Bob Jacklin is the longest standing outfitter in West Yellowstone who has been guiding West Yellowstone fishermen for thirty eight years and fly tying for over 47 years. Bob moved to West Yellowstone and was guiding by 1969, opening his fly shop in 1974. Bob has a degree from the North Western School of Taxidermy and is a licensed taxidermist. A world class fly fisherman, fly caster, and fly tier, Bob has taught thousands of people to fly fish.

You can find out more information by contacting: Bob Jacklin's Fly Shop, P.O. Box 310 / 105 Yellowstone Ave, Corner Canyon Street, West Yellowstone, MT 59758 (406) 646-7336, bjacklin@jacklinsflyshop.com, http://www.jacklinsflyshop.com

Fly casting demo--Bob jacklin and Dave Losapio

Live Entertainment by Greg Keeler

Thursday evening was the Symposium Banquet. After a good meal and the usual welcomes, we were entertained by humorist Greg Keller, a western fold singing, Professor of English at Montana State Univeristy, Bozeman, MT. Gren even wrote a songt, "Wild Trout" for us. You can find more about his unique outlook at 222. troutball.com and listen to four of his off-the-wall tunes at: http://www.flyfisherman.com/downloads/neoprene.

Greg Keeler

“It’s about spawning wild trout”
R. Cutter

The History of the Wild Trout Symposia

Marty Seldon
Federation of Fly Fishers, Sunnyvale, California

Introduction

Frank Richardson (U S Fish and Wildlife Service), Pete Van Gytenbeek (past Executive Director, Trout Unlimited and FFF President), and John Peters (Environmental Protection Agency) conceived the idea for periodic symposiums that focused on wild trout. The mission was to provide a forum where professional wild trout biologists and fishery conservationists could interact and get acquainted. Yellowstone National Park offered a pleasant environment where symposium participants could learn about the current status of wild trout populations (perceived as declining) and fisheries management trends.

Symposium organizers felt that by discussing the wild trout resource, conference participants would learn more about ways to preserve and restore remaining magnificent wild trout resources. Although major national speakers and agency heads participate, these forums focus on the needs of working-level wild trout professionals and fishery conservationists. The originators hoped that each conference would lay a foundation based on insightful research and management for future sessions on wild trout management.

The initial organization of these wild trout symposiums called for conferences held each five years and normally included Sunday Registration, a meeting and reception for speakers and the program committee. Monday began with a plenary session, often featuring top-level agency speakers, such as the Secretary of Interior, followed by two days of sessions on all aspects of wild trout. Each symposium included an awards luncheon and an evening banquet. This format has continued with minor variations.

Wild Trout-I

The first International Wild Trout Symposium held 25-26 September 1974 at Mammoth Hot Springs Hotel, Yellowstone National Park (YNP) was cosponsored by Trout Unlimited and the US Fish and Wildlife Service and received enthusiastic support from N. P. Reed, Assistant Secretary of the Interior for Fish, Wildlife, and Parks. Jack Anderson, Superintendent YNP, hosted the conference and Dr. Willis King edited conference proceedings.

Over 300 anglers, writers, students, and professionals met on common ground to talk about wild trout and establish a new tradition. Symposium panels addressed anadromous species, water quality and quantity, habitat and species, regulations and politics. Presenters included several familiar names such as Roger Barnhart, Gardner Grant, Ray White, and A. Starker Leopold. Dick Vincent presented his well-known paper on the effects of stocking hatchery-reared-catchable-sized trout on wild trout populations. Dr. Wilfred Carter (International Salmon Federation) spoke on management of Atlantic Salmon.

Wild Trout-II

The conference was held 24-25 September 1979 at Mammoth Hot Springs, YNP with Frank Richardson (USFWS), Gardner Grant (FFF), and Mike Owen (TU) co-chairing the Program Committee. Sessions focused on managing fish and anglers and emphasized the importance of genetic adaptations in strains of trout and that locally adapted populations have great ecological advantages. Lee Wulff and others discussed the importance of preserving the quality of the angling experience as opposed to the commodity aspect (full creel) of fisheries management.

Several perplexing reports documented declines in wild trout fisheries. Rupe Andrews (Alaska) and Gerry Taylor (British Columbia) compared similar problems confronting the great Alaska and British Columbia wild trout fisheries. Gratifyingly positive results of studies on catch-and-release (CR) trout fisheries on the Madison River and in YNP were discussed by Ron Marcoux (Montana) and John Varley (YNP). YNP Superintendent Jack Anderson initiated CR regulations in the park by closing angling at Fishing Bridge and establishing no-kill regulations that saved the Yellowstone National Park cutthroat trout fishery.

Starker Leopold asked that all administrators assign high priority to the study of watershed-trout relationships, such as the impact of livestock grazing on wild trout populations. He said that better data to justify the conservation of stream-side riparian zones was the real key to improved wild trout populations.

Wild Trout-III

The third wild trout conference was held at Mammoth Hot Springs, YNP, 24-25 September 1984 with TU, US Fish and Wildlife Service, and the US Department of Agriculture sharing sponsorship. Roger Barnhart was Chairman, assisted by Gardner Grant and Mike Owen. Frank Richardson chaired the Program Committee with Bob Barbee responsible for logistics and Bob Hamre serving as Proceedings Editor.

Keynote addresses by G. Ray Arnett (Assistant Secretary of Interior) and John Crowell (Assistant Secretary of Agriculture) spoke of the stark reality of a troubled fisheries resource, impacted by limited funding, competition among users, and the demanding effort that must be dedicated to successful stewardship of trout and salmon resources. Reverend Dan Abrams (Jackson, WY) offered an inspiring tale about the worth of trout that extends far beyond nostalgia, sentimentalism, and winter dreams. Ben Dysart, National Wildlife Federation President, dramatically illustrated the larger picture and how trout hatchery management solutions have changed to encompass complete watershed management.

A. Starker Leopold, outstanding naturalist, teacher, author, and public policy advisor passed away at his Berkley, CA home. In recognition of his gentle eminence, the A. Starker Leopold Award was established as a continuing memorial, given to people who have contributed significantly to the conservation, management, and preservation of wild trout. Dr. Bob Behnke and Marty Seldon received the inaugural awards.

Bob Behnke, WT-III 1984

Marty Seldon, WT-III 1984

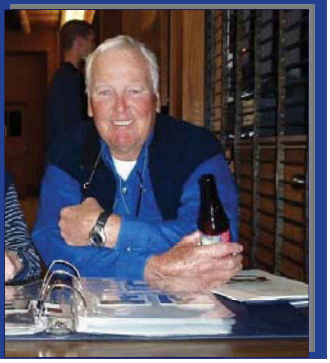
Wild Trout-IV

The 4th Symposium took place at Mammoth Hot Springs, YNP, 18-19 September 1989. Over the 15 years since Wild Trout I, conference proceedings grew from about 100 pages to more than 200, reflecting the content and scope of symposium presentations. The American Fisheries Society and Environmental Protection Agency were added as cosponsors. Frank Richardson and Gardner Grant co-chaired the symposium.

Nathaniel Reed delivered a major keynote talk addressing progress made since Wild Trout I. He spoke of the importance of explaining ecosystem management to the public so that they understand such things as the Yellowstone fires of 1988. He illustrated how the work of Jack Anderson, Starker Leopold, and Durward Allen helped strengthen the cutthroat trout resource in YNP, making possible restoration of grizzly bear populations. Mr. Reed said that people attending wild trout conferences represented the caring vanguard of wild trout resource stewardship, ever seeking to better manage man's rapacious appetites to save planet earth and wild trout that share it with us.

Benjamin Dysart (National Wildlife Federation) again served as a keynoter. He approved of scientific approaches to watershed management but suggested that projects should be conducted with win-win recipes. The real challenge is for development to occur without jeopardize or preclude public environmental quality values. When this happens, everyone wins.

Frank Richardson, WT-IV 1989



WT-IV included panels that addressed wild trout and planted trout, fish management and economics, angling regulations (no-kill included), the overall resource, fishery restoration, wildfire, drought, each with five to seven 20-minute presentations. Several poster papers and exhibits were also included. Well known author Richard Telleur reported on 25 years of no-kill regulations on New York's Beaverkill and Willowemoc rivers and the economic boom in Roscoe, NY that resulted from the special regulations. Results were similar for Atlantic salmon fisheries in Canada's five Atlantic seaboard provinces where no-kill regulations were implemented.

At WT-IV we assessed wild trout management progress over the 20 years since WT-I. Much was learned and much is yet to be learned and implemented. At this fourth conference we learned that state and federal production of hatchery salmonids increased from a total of 169.4 million in 1958 to 256.5 million in 1983, including an increase from 50.2 million to 78 million catchable trout over the same time period. Cost of each "hatchery-reared-catchable" trout varied from $1.06 to $3.62 per fishing license sold, creating an economic imbalance. Bob Behnke said that more angler days at lower cost could be provided by creating more wild trout opportunities and stressed that this area needs more investigation.

The 1989 A. Starker Leopold Award Recipients were Frank Richardson and Otto H. Teller.

Otto Teller, WT-IV 1989

Wild Trout-V

On 26-27 September 1994, we returned to the traditional site, YNP Headquarters at the Mammoth Hot Springs Hotel. Roger Barnhart and Ron Jones were co-chairmen and the theme was Wild Trout in the Twenty First Century. The National Biological Service, Fish and Wildlife Service, and National Park Service joined the ranks of symposium co-sponsors.

Jay Hair, President and CEO of the National Wildlife Federation, presented the message that our society desperately needs to return to a sense of place. He said that exhilarating wild trout fishing is an endangered experience.

Bruce Babbitt, Secretary of the Interior, reflected on his experiences with issues of trout and ecosystems. He spoke about water quality and grazing impacts and how the new Endangered Species Act, Section 404 of the Clean Water Act, and nonpoint pollution standards will protect the nation's fisheries. He believed that the Forest Plan Management Act would help establish buffer zones in timber harvest activities and that mining, urban expansion, water consumption, and road construction need similar attention and planning. He said that we can learn from the tragedies and mistakes of the past and begin to move toward equilibrium upon the landscape.

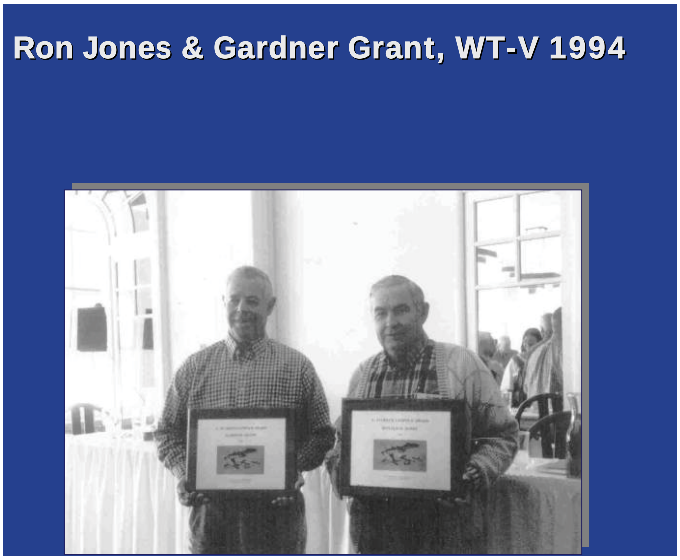
There has been conflict for many years over these issues and it flares up in every generation. Response to the Sagebrush Rebellion, also called the Wise Use Movement, has not been adequate. There are far too many signs of the environmental movement and the classic sportsmen conservation groups drifting apart. Too many sportsmen's groups are being lost and those that remain are not pulling their weight as they should. Wild trout advocates need to bridge the gap between resource conservation and the sportsman tradition of Teddy Roosevelt. Good science is wonderful but in the final analysis it is political clout that can make a difference. We need to find our constituencies and make certain that they understand that everyone's concerns are tied together to get quality ecosystems. That understanding must be translated into political action.

WT-V also considered positive and negative aspects of the animal rights movement, recognizing that their ideals cannot be ignored. Attendees also learned about the use of DNA analysis to track the movement and interactions of 26 populations of cutthroat trout. This work offered better approaches to defining genetic diversity and indicated that we cannot draw valid conclusions from simply observing single, isolated populations. Other presentations discussed New England Atlantic salmon restoration where populations in 28 rivers have declined from 1.1 million returning adults to less than 4,000. Ray White discussed why wild trout matter. Information about wild trout management in British Columbia was also presented and several restoration projects considered.

The greater public, not just wild trout resource advocates, will determine the future of wild trout in the next century. Pedantic discourses about when a wild trout is wild must cease. In an environmentally balanced world, there would be no dispute that wild trout would always be preferred over hatchery-produced trout. Hatcheries represent only the need for temporary mitigation. The clarion them of WT-V was that those involved in wild trout management must convince the greater public of their value if wild trout are to survive. Fishery management agencies must represent and protect the interest of the unorganized groups. Managers and advocates must stop arguing among themselves and share their passion for wild trout with the public.

A three-year frequency of wild trout conferences was recommended to better keep up with the more rapidly changing resource and changing fisheries management programs.

The 1994 A. Starker Leopold Award recipients were Ron Jones and Gardner Grant.



Ron Jones & Gardner Grant, WT-V 1994

Wild Trout-VI

To overcome the challenge of limited capacity and accommodations at Mammoth Hot Springs, WT-VI was held at the excellent convention facilities of Montana State University, Bozeman. Pat Dwyer chaired the symposium. Attendance was limited because of the national American Fisheries Society meeting held the following week on the West Coast. Nonetheless, WT-VI offered one of the better technical sessions that included such panels as; Public Awareness and Education, What is a Wild Trout Worth (economics), Wild Trout Family Trees (genetics), Trout in Trouble (diseases and threats), and Trout on the Rebound (restoration projects). Panels consisted of five to 10 papers, each speaker limited to 20 minutes, followed by 5 minutes for questions. There was a reception Sunday evening, an opening plenary session Monday morning followed by papers on Monday, Tuesday, and a half-day Wednesday.

WT-VI focused on the formation of user group and agency partnerships including those for bull trout in Alberta, Canada, cutthroat trout in Colorado, and a partnership with the University of Moscow to preserve steelhead of the Kamchatka Peninsula. Conference attendees learned about improved management techniques, the latest developments in genetic research, the impacts on fish and wildlife of increasing public use of national parks, and economic value of wild trout resources. Angling generated $9 million following implementation of catch-and-release, barbless hook regulations in New York's Beaverkill and Willowemoc watersheds.

New DNA analysis was used to confirm the discovery of new salmonid species or subspecies of New Mexico Gila trout, cutthroat trout in Colorado and Nevada, as wells as three different groups similar to cutthroat in Kamchatka. WT-VI also focused on the serious cutthroat trout-competition problems caused by introduced lake trout in Yellowstone Lake and the continuing spread of whirling disease and possible threats from global warming. Examples of the loss of more cold water habitat and rainbow-cutthroat trout hybridization in Idaho, Montana, and Ontario, Canada were also discussed.

Examples of successful wild trout restoration projects were highlighted by well-known river keeper Ron Holloway who discussed how Great Britain's Itchen River wild brown trout fishery had been abused, destroyed and then restored over the past three centuries. Consideration of total watershed management rather than just solving site-specific problems was the key to success. While we have the knowledge to put the natives back into wild trout it is the will to get the job done that is needed. WT-VI highlighted that fisheries professionals, guides, and all user groups have much in common and must work together towards restoration, conservation, and preservation of wild trout stocks to continue progress made since the first conference on wild trout.

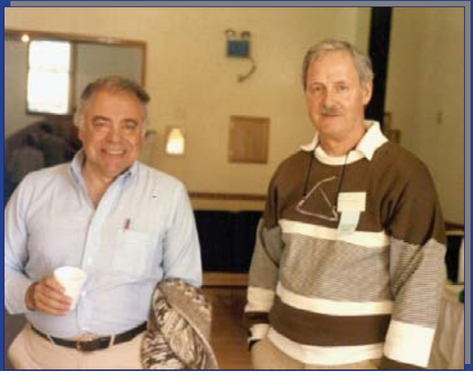
Ernie Schwiebert inspired us when he spoke of his lifelong love for what he called the poetry of wild trout. Everything about wild trout is beautiful; the cold lakes that sustain them, the equipment used, the methods of catching them, and the flies we dress to attract them. Fly fishing is both old and honorable. Its roots lie in medieval chivalry, and we share a literature of sport more than five centuries old. It is filled with bright rivers tumbling swiftly toward the salty, the deft choreography of swifts and shallows working to a hatch of fly, and the quicksilver poetry of the trout themselves. And, in speaking of their beauty, we may still discover that beauty itself is the most endangered thing of all.

The 1997 recipients of the A. Starker Leopold Award were Roger Barnhart and Ernie Schwiebert.

Wild Trout-VII

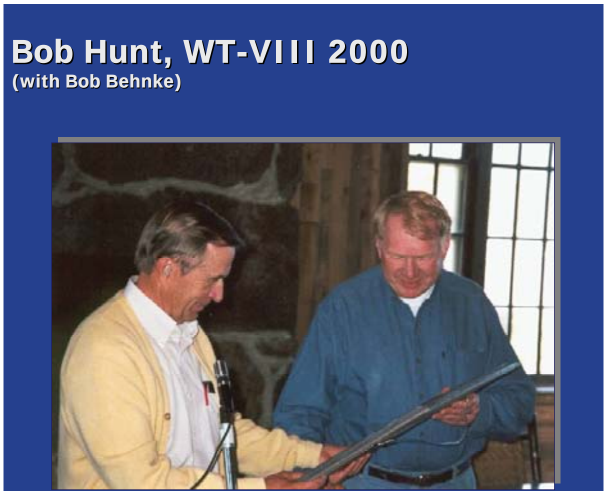
Pat Byorth took over the reins as Symposium Chair for Wild Trout VII, and the meeting returned to Yellowstone National Park, October 1-4, 2000. It was the first meeting held at Old Faithful Lodge, and most found this site, in the shadow of the great geyser, to be an inspiring venue for the meeting. Dan Schill and Steve Moore (Program Committee co-chairs) worked with seven committee members to put together a diverse group of presentations ranging from Wild Trout Regulations to Electrofishing Injury. The symposium theme, “Management in the New Millennium: Are We Ready,” seemed especially apropos in the year 2000. Although presentations concerning native trout had always been prevalent at the Wild Trout symposia, this year marked a substantial shift in program emphasis toward native trout. Three different sessions focused exclusively on native trout and restoration activities, and numerous presentations in other sessions were related to natives. Attendees walked away with a strong sense of urgency concerning management of wild native trout in the 21st century.

Roger Barnhart & Ernie Schwiebert WT-VI 1997



Special invited speakers provide several “big-picture” presentations that set the tone of the meeting. Karen Wade, the Director of the Intermountain Region of the National Park Service, started the meeting with the keynote address emphasizing the need for collaboration among fisheries managers representing state, federal, tribal, public, and private interests. Author Thomas McGuane encouraged banquet attendees to develop new, more easily understood, ways to deliver our scientific knowledge to politicians, decision makers, and resource enthusiasts. At the Awards Luncheon, Bob Hunt urged the group to manage for wild trout first, and he emphasized that fish populations cannot be managed separately from the habitat that they occupy. During the second luncheon, Dr. Jim Rose provided fascinating information concerning the inability of fish to feel pain. He concluded that fish do not feel pain because the cerebellum of a fish is not developed to a point that allows the sensation of pain to be processed. Bob Wiley, symposium summarizer, reminded the audience that this subject, and others topics related to angling, could be controversial in some circles, and it is critical that as fisheries professionals, we must be willing to entertain alternate points of view at our Wild Trout meetings.

Wild Trout VII recipients of the A. Starker Leopold Award were Robert L. Hunt, professional category, and W. F. Bud Lilly, nonprofessional



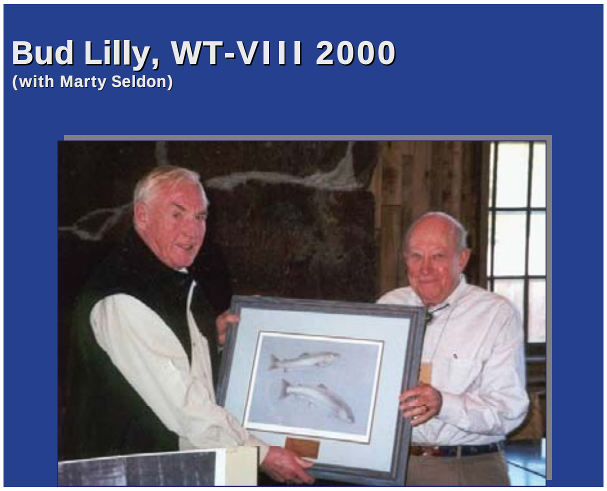
Bob Hunt, WT-VIII 2000
(with Bob Behnke)

category. Both individuals have dedicated much of their lives to the enhancement, protection, and preservation of wild trout in North America.

Wild Trout-VIII

The Thirtieth Anniversary forum was held 19-22 September 2004 at Old Faithful Lodge, YNP. Ensuring the Future of Wild Trout Working Together was chosen as conference theme. A special positive spirit accompanied WT-VIII, perhaps due to the 210 pre-registrants, the four years since WT-VII, or that everything came together so very well. YNP Assistant Superintendent Robert Walker gave the welcoming address and Pete Van Gytenbeek (a symposium founder) reminisced about our beginnings in 1974 and how special the thirtieth anniversary occasion was. Ted Turner admonished us that we needed to actively fight the battles to save humanity and to save our fisheries. He reminded that we are all interdependent and asked that all step up to the plate to make a difference.

Symposium co-founder and organizer Frank Richardson, spoke during the first hosted lunch hour describing the 1972-1973 luncheons in Denver where the idea for Wild Trout Symposia was born. From those informal Denver meetings, the symposium idea went to Washington DC and Assistant Secretary of the Interior Nathanial P. Reed, where it was enthusiastically endorsed. An excellent power-point show illustrated the talk and added substance to the presentation.



Bud Lilly, WT-VIII 2000
(with Marty Seldon)

A series of very significant presentations and poster papers, plus an excellent cross section of professionals and trout conservations in attendance made WT-VIII memorable. Presentations from Australia, Canada, and England highlighted international concerns about trout resources. Excellent participation and technical services provided by the MSU Student Association was much appreciated and should be encouraged at future WT sessions.

Greg Keller, a unique fly-fishing-Montana State University Professor of English and innovative western folk singer provided symposium banquet entertainment. His rousing songs on fish and politics were humorous, yet carried important messages.

Thirtieth anniversary (2004) recipients of the Aldo Starker Leopold Wild Trout Medal were Ray J. White and R. P. Van Gytenbeek. A grant from Advanced Telemetry Systems, Inc. made the design by Ernie Schwiebert and minting of a physical medal possible to formalize these prestigious awards.

Old Faithful Lodge and Inn – 100 years old and counting – provided more than enough room for the conference. The Inn and nearby Old Faithful geyser offered a wonderful environment to meet old and make new friends plus enjoy the excellent state-of-the-art presentations that typify wild trout symposiums.

Wild Trout-IX

On 9-12 October 2007 we selected a new location, the Holiday Inn Resort and Conference Center, West Yellowstone, Montana. Old Faithful Lodge and portions of the Inn were closed for construction. The just under 200 attendees were very well pleased with the modern facilities and excellent friendly services provided by the Holiday Inn. The opening Plenary Session was moderated by Symposium Chairman Steve Moore and Paul Schullery, and emphasized WT-IX's theme, Sustaining Wild Trout in a Changing World. Fred Harris, North Carolina Wild Life Resources Commission; Van Van Gytenbeek, FFF; Virgil Moore Idaho Fish and Game; and TU's Chris Wood tasked us all to do better.

Program Co-Chairmen Bob Carline and Dirk Miller assembled an outstanding group of moderated panels including: Native Species Management; Catch-and-Release Fisheries; Habitat Enhancement and Restoration; Genetic Considerations; and Balancing Native and Introduced Species.

Participants were familiarized with a number of new studies including work on piscivorous ferox brown trout in Loch Rannoch, the unique dolly varden on Hokkaido Island, threats to Atlantic Salmon fisheries, and efforts, to preserve Sakhalin taimen in Japan's Sarukotu River. We learned how modern technology using microsatellite DNA, adaptive management, Google Earth, and bioelectrical impedance analysis were improving our capabilities. We also faced the transport of invasive New Zealand mud snails and Didymosphenia Alga and projected effects from global warming.

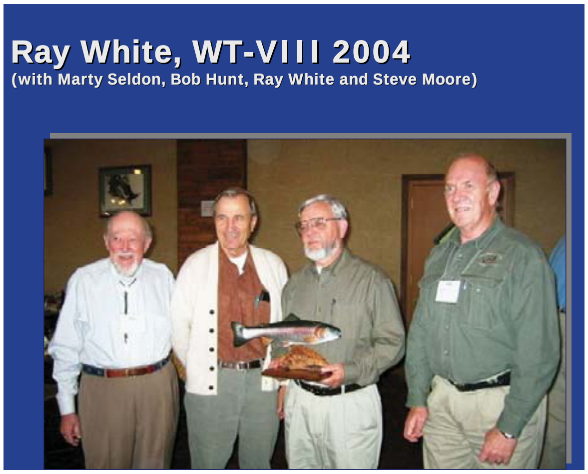
There was also an impressive array of contributed and poster papers and welcomed presentations by professionals from Canada, Japan, Norway, and Scotland. Of particular note was the increase in participation by fishery students, coordinated by Symposium Secretary, Liz Mamer. Student were offered registration at reduced rates, some housing assistance for student volunteers, and at WT-IX the establishment two student travel scholarships.

MSU Bozeman's cowboy English professor folk singer Greg Keeler entertained us once again at the Symposium banquet. This year, Greg wrote a song, Wild Trout, for the symposium that we hope can be included on the Proceedings CD.

The Aldo Starker Leopold Wild Trout Medals at WT-IX, addressed in detail in these proceedings, went to Nathaniel P. Reed in the professional category and to author, publisher, and wild trout advocate, Nick Lyons as the nonprofessional.

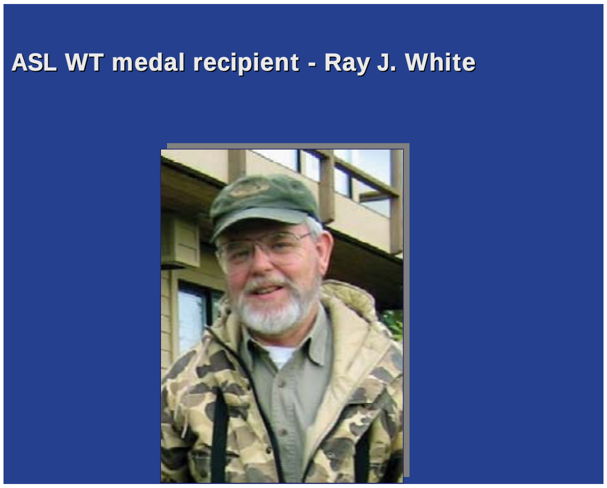
Historian-author Paul Schullery was the symposium summarizer and pointed out that many of this year's presentations gave us a long view of our wild trout resources as well as important insights that captured an evident spirit of the conference. He also sounded a call, that if we are have wild trout in our future, that we must greatly broaden the wild trout constituency.

Wild Trout-IX attendees joined with the organizing and program committees in applauding this symposium. We believe we have provided a forum that embodies not only an important learning experience, but that offers professionals, fishing conservationists, and interested anglers to get to know each other in the kind of informal environment that would not be otherwise possible. Please plan on attending Wild Trout-X in 2010.

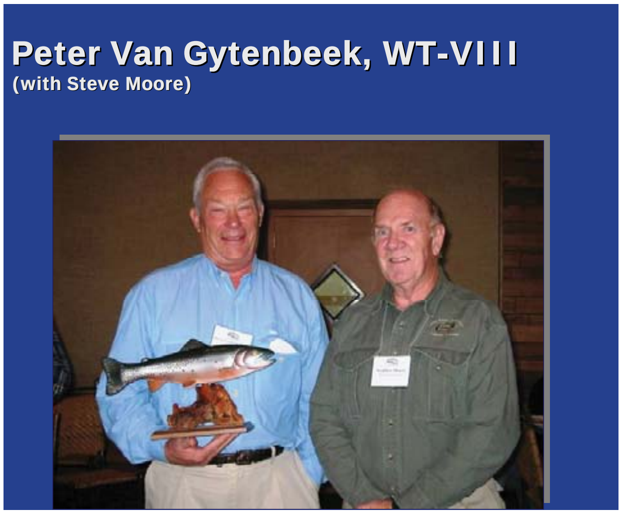


Ray White, WT-VIII 2004

(with Marty Seldon, Bob Hunt, Ray White and Steve Moore)

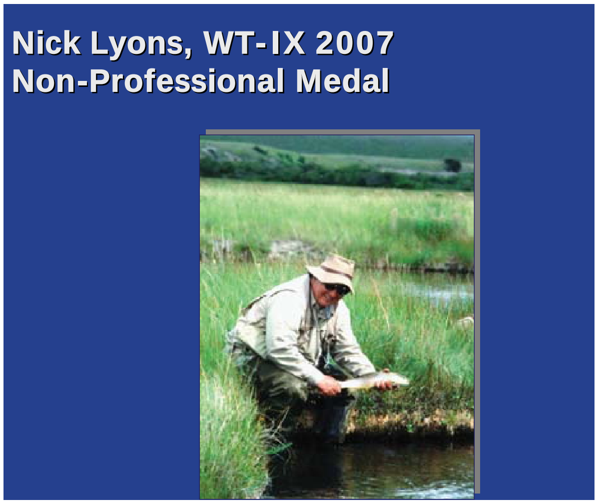


ASL WT medal recipient - Ray J. White

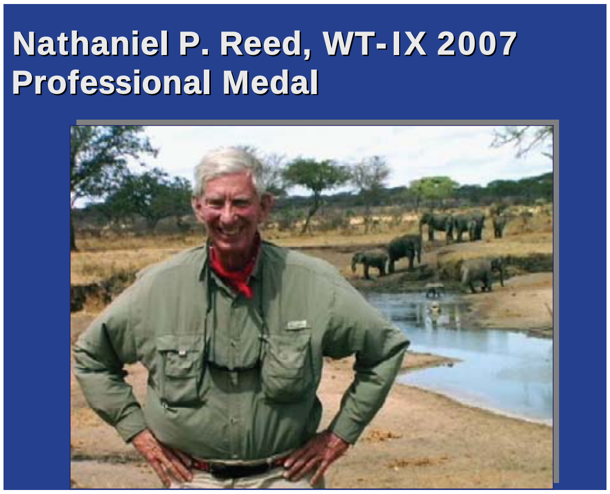


Peter Van Gytenbeek, WT-VIII

(with Steve Moore)



Nick Lyons, WT-IX 2007
Non-Professional Medal



Nathaniel P. Reed, WT-IX 2007
Professional Medal

A Reminder… WT-X

Wild Trout X will be held in 2010

Stay in contact through:

www.wildtroutsymposium.com

And please consider submitting
Aldo Starker Leopold Wild Trout Medal
nominations

In Memory of Ernie Schwiebert

by Marty Seldon (8-9-07)

Ernest Schwiebert passed away on December 10, 2005 at his home in Princeton, New Jersey at age 74 from cancer. He was probably one of most famous and important modern American fly fishing writers. He was an architect, a bon vivant, our original renaissance man, and a fly fishing giant who was loved by all that were privileged to know him. During his last year, Ernie, working closely with Marty Seldon, was the artist who drew and fathered the design, and the striking of the new bronze International Wild Trout Symposium's Aldo Starker Leopold Wild Trout Medal, the award he received in 1997.

Ernest George Schwiebert, Jr. became a serious angler at the age of five when his first cast into a Michigan Creek surrendered a twelve-inch brook trout. Before age thirty, he fished the major rivers of Europe, South America, Canada, and the United States, and had already gained worldwide recognition as an authoritative writer-conservationist, artist, and angler.

Schwiebert received his bachelor's degree in architecture from Ohio State University in 1956. As an Air Force officer, he was a member of the architectural team that planned and built the Air Force Academy in Colorado Springs, CO. He entered graduate school at Princeton University in fine arts and architecture and city planning, where he was the Lowell Palmer Fellow in Architecture from 1958 to 1962. At Princeton, he earned a Master of Fine Arts degree in architecture and dual Ph.D. degrees in fine arts in architecture and planning and then in the history of architecture. He practiced architecture and city planning for 15 years in New York, Puerto Rico, Chile, Pakistan, Tibet, Malaysia, Australia, and Argentina.

His first book, "Matching the Hatch" published in 1955, considered a classic, was followed by many important magazine articles and books including "Nymphs" in 1973 and his monumental two-volume, 1,745-page "Trout", in 1978. Other titles included: Salmon of the World, Death of a Riverkeeper, The Traveling Angler, Remembrances of Rivers Past, A River for Christmas, and more. As further evidence of his outstanding competence and respect, Ernie was acknowledged by more than twelve references in Arnold Gingrich's book "The Fishing in Print" and fourteen references in Paul Schullery's, "American Fly Fishing, A History". Arnold Gingrich considered Schwiebert's position impregnable as the leading angling author of our time and recognized his impressive ability to absorb entomological detail and convert it into pleasing prose for his readers. At the time of his passing, a completely rewritten "Nymphs-Vol. I " was completed and is now available. Ernie's wife Sarah reminded us that Ernie always had a lot to say and that Vol. II of "Nymphs" and other projects are in the works. His family is also collaborating on a book of his original drawings. Ernie Schwiebert still does has a lot more to say.

Ernie made a major contribution to our understanding of the genetics and habitat requirements of wild trout and salmon through his lectures to conservation and fishing groups, and to educational institutions.   Combined with his research into fishing-relevant stream entomology, Ernie has given generations of anglers and fishery professionals new insights into the importance of wild salmonids.

Ernie Schwiebert was a pioneer in the fishery conservation movement and involved in the founding of Trout Unlimited (TU), Theodore Gordon Flyfishers (TGF), and the Federation of Fly Fishers (FFF). He has served as a Director of both Theodore Gordon Flyfishers and the Atlantic Salmon Federation, and was on the scientific advisory boards of TU, FFF, and The Nature Conservancy. In recognition of his contributions, a Trout Unlimited Chapter in New Jersey is named after him.

His, eloquent "Elegies and Epilogues" address as the banquet speaker at Wild Trout IV, September 1989, reported in the Symposium's Proceedings (Proceedings Wild Trout IV, Page 4.) gave special meaning to scientific and management efforts for wild trout. His wonderful address "I Fish Because of Beauty" to the FFF's August 2005 Conclave in Livingston, MT can be found in Flyfisher Magazine, Winter 2006, Page. 21.

Ernie was a founding member of the Federation of Fly Fishers in 1965 and was always an important and integral part of the organization. He attended his last FFF Conclave in Livingston, MT in August 2005. Trying to act as positive as he could over drinks and deep conversation with Mel Krieger at Russ Chatham's Livingston Bar & Grill in Montana, the ravages of cancer were evident and saddened us greatly. Ernie and I were both very excited over how great his design of the Wild Trout Symposium's Aldo Starker Leopold Wild Trout Medal was in bronze. We chatted with others including Russ Chatham, Ted Rogowski, and Joan Wulff for several hours, savoring old times and great adventures. Mel and Ernie where still there when the bar closed. Our friend, author, and artist Russell Chatham took Ernie on his last fishing trip that week. Russ said they had a great time and that Ernie had administered a fishing lesson by catching the largest trout.

Ernie, go with God. You will always be with us.


WILD TROUT
SYMPOSIUM

Distribution and Movements of Yellowstone Cutthroat Trout in the Upper Yellowstone River Drainage

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Abstract

Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri* were historically one of the most widely distributed subspecies of cutthroat trout, but now occupy only a small portion of their historic range. Yellowstone Lake and River above the Upper Falls contains the world's largest concentration of genetically pure cutthroat trout. The Yellowstone River is the largest of 124 tributary streams in this system, draining approximately 42% of the lake basin. While long-term data exist for several tributaries of the lake, no comprehensive fisheries assessment had been conducted in the remote upper Yellowstone River system. To determine movement patterns and distribution of cutthroat trout, we surgically implanted radio transmitters into 151 cutthroat trout in the Yellowstone River drainage and tracked their movements over a 3-year period. Our data showed a minimum of 72% of relocated fish returned to Yellowstone Lake following spawning while only 2% displayed resident behavior. This indicates the majority of fish in this basin are lacustrine-adfluvial. Electrofishing and underwater census of the main-stem Yellowstone River also found few adult fish following the spawning period. Electrofishing tributaries of the Yellowstone River also found few adult fish indicating that resident populations may be relegated to headwater reaches in the river system.

Introduction

Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri* evolved as the only trout species within the Yellowstone and Snake river drainages above Shoshone Falls (Behnke 1992). With the exception of westslope cutthroat trout *Oncorhynchus clarkii lewisi*, the Yellowstone subspecies was the most widely distributed subspecies of inland cutthroat trout. Hybridization and competition with nonnative fishes and anthropogenic influences have reduced the distribution of Yellowstone cutthroat trout by 70-90% since settlement by Europeans (Kruse et al. 1997). Presently, the Yellowstone subspecies has been replaced by nonnative brook trout *Salvelinus fontinalis*, brown trout *Salmo trutta*, and rainbow trout *Oncorhynchus mykiss*, throughout most of its original range in the upper Yellowstone and Snake river drainages (Behkne 2002). Yellowstone Lake and River above the Upper Falls in Yellowstone National Park contains the greatest concentration of genetically pure Yellowstone cutthroat trout (Behkne 2002). This watershed has not been subjected to large-scale environmental degradation because it is located within a national park and national wilderness area (Gresswell et al. 1997). However, the recent discovery of lake trout *Salvelinus namaycush* and whirling disease in Yellowstone Lake threatens the survival of this crucial population.

The cutthroat trout is a key component of the Yellowstone ecosystem and prized catch of anglers. Up to 42 mammal and bird species feed on cutthroat trout (Varley and Schullery 1995). A recent study conducted by the U. S. Geological Survey Interagency Grizzly Bear Study Team and National Park Service showed a minimum of 75 grizzly bears were foraging along spawning streams of Yellowstone Lake (Haroldson et al. 2005). Historically, over one-third of anglers who fished in Yellowstone Park fished in Yellowstone Lake or River (Koel et al. 2005).

A total of 124 tributaries to Yellowstone Lake are flowing during runoff each year (Jones et al. 1987). The largest of these tributaries, the Yellowstone River upstream of Yellowstone Lake, drains an area almost 110,000 ha about 42% of the watershed (Gresswell et al. 1997). Due to the remote location of this portion of the watershed a comprehensive fishery assessment had never been conducted. In 2003, the National Park Service initiated a fisheries assessment study of the upper Yellowstone River drainage. The Wyoming Game and Fish Department was contacted and agreed to join the project. This allowed us to expand the scope of the study beyond Yellowstone National Park boundaries to the headwaters of the Yellowstone River. The project goals were to determine distribution, movements, and life history of adult Yellowstone cutthroat trout in the upper Yellowstone River drainage.

Study Area

The Yellowstone River begins in northwestern Wyoming in the Bridger-Teton Wilderness Area and flows north into Yellowstone National Park to its confluence with Yellowstone Lake. The river exits the lake and continues to flow north, northeast to its confluence with the Missouri River, 1,113 km from its source. The project study area consisted of the upper Yellowstone River and tributary streams from its headwaters on the southeast and northwest slopes of Younts Peak to its mouth at Yellowstone Lake. From the confluence of the North and South forks (9.2 km and 11.4 km, respectively) the Yellowstone River flows 73 river kilometers to its mouth at Yellowstone Lake. The basin contains over 200 km of tributary streams and covers an area about 1,244 km2 (Figure 1). We also included Yellowstone Lake, several tributaries located in the Southeast Arm of the lake, and the Yellowstone River from the Yellowstone Lake outlet to the Upper Falls in radio tracking events.

The upper reaches of the Yellowstone River consist of riffle-pool complexes that flow through steep forested slopes consisting of lodgepole pine *Pinus contorta*, whitebark pine *Pinus albicaulis*, douglas fir *Psuedotsuga menziesi*i, and blue spruce *Picea pungens*. The lower two-thirds of the upper river is made up of long runs, glides, and pools. The overstory is similar in structure to the upper reaches lacking only whitebark pine, but the understory includes fields of willow *Salix spp*. and grasses. Burned patches are located sporadically throughout the watershed.

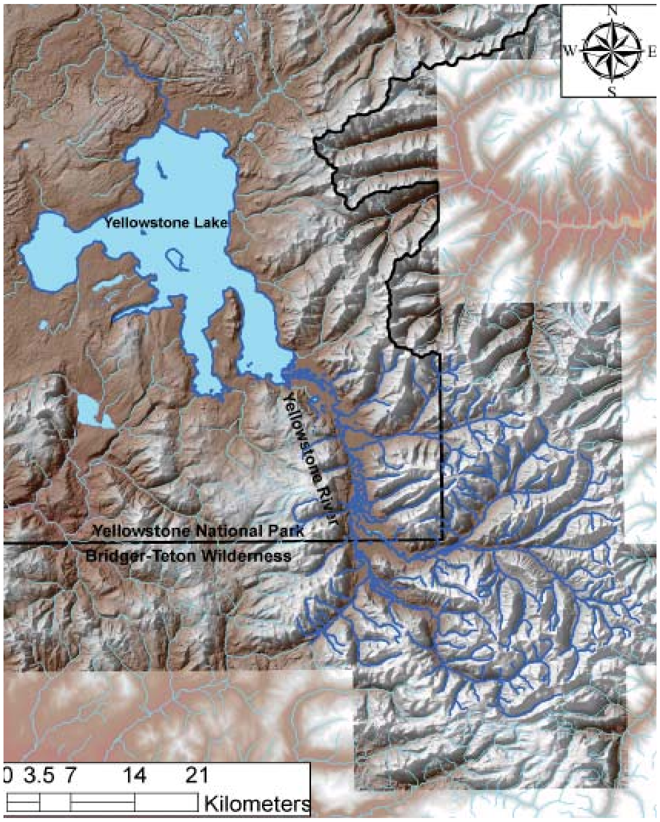

Figure 1. Upper Yellowstone River study area, Yellowstone National Park and Bridger-Teton Wilderness.

Methods

Assessment of Movement Patterns

Our primary method for examining the movements of adult Yellowstone cutthroat trout was radio telemetry. From 2003 through 2005, National Park Service and Wyoming Game and Fish personnel surgically implanted 13-g radio transmitters into cutthroat trout in the Yellowstone River and several tributaries. Tag weight limited implantation to larger adult fish. All tagged cutthroat trout weighed a minimum of 650 g to ensure that transmitters did not exceed 2% of their total body weight (Figure 2). Transmitters were programmed with one of three duty cycles, (6 months on, 12 h on), (12 months on, 12 h on), and (3 months on, 8 h on). The use of varying duty cycles allowed us to assess movement during periods of heavy migration potential over several years as well as movement throughout an entire year. This aided in determining spawning migration movements and winter habitat use. Our tagging design called for equal distribution of implantation sites throughout the main stem of the Yellowstone River, Thorofare Creek and tributaries, if logistically possible. Implantation dates were to be spread from May through September. Data from other spawning tributaries of Yellowstone Lake (i.e. Clear Creek, Pelican Creek, Arnica Creek, and Bridge Creek) indicated that lacustrine-adfluvial cutthroat trout have exited spawning tributaries by mid-July (NPS unpublished data). Therefore, tagging dates after August 1 were more likely to target resident cutthroat trout in the system. Spring run-off, ice cover on Yellowstone Lake, and bear closures all prevented entry at earlier dates.

Angling was our primary method of fish collection; however, fyke, trap, and gill-nets were used in the mouth of the Yellowstone River and approximately 0.4 km upstream. Five tags were placed in Yellowstone Lake at known locations and depths to test the accuracy of flight relocation data.

All fish collected were measured (total length mm), weighed (g), sexed, and had their GPS location noted. Scale samples for aging, and fin clips for genetic testing were collected from a subsample of fish during tagging operations. Fish movements were monitored weekly using a fixed wing aircraft and supplemented with ground truth trips as time permitted from May through August, twice monthly for September and October, and monthly from November through April. Surveys of Yellowstone Lake were conducted using an aircraft outfitted with a directional Yagi antenna and boat using a handheld Yagi antenna as time and funding permitted. All tracking data were collected using an Advanced Telemetry Systems R4500 radio transmitter receiver and data logger. The data logger is capable of recording tag frequency, code number, date, time, signal strength, and GPS. Fish found overwintering in the Yellowstone River basin would be classified as resident fish. Those migrating to the lake or distinctively moving downstream when their last signal was received would be classified as lacustrine-adfluvial.

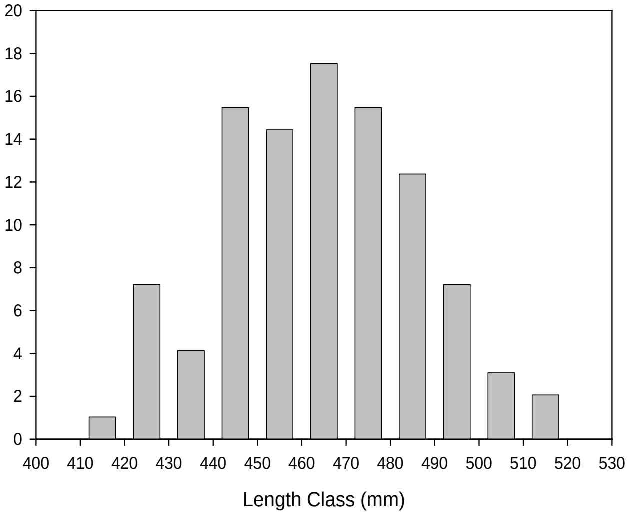

Figure 2. Length class distribution of Yellowstone cutthroat trout implanted with radio transmitters in the upper Yellowstone River basin, Wyoming, 2003 to 2005.

Cutthroat Trout Distribution

To determine cutthroat trout distribution in the main stem of the Yellowstone River within the Yellowstone National Park boundary, we sampled 500-m sections in each river kilometer using both electrofishing and underwater census.

For underwater census surveys, three snorklers drifted downstream through sample sections. Divers were spaced to cover the entire stream width as best possible. Fish were identified to species, counted, and cutthroat trout were placed into one of four categories based on total length (<70 mm, 70 – 150 mm, 150 – 330 mm, and >330 mm). Electrofishing surveys took place in the same sections as snorkel surveys using a 5-m long raft outfitted with electrofishing equipment. The raft followed a minimum of 30 min behind snorklers to allow fish to redistribute if displaced by divers. Each section was sampled on two dates in September approximately 10 d apart to produce mark-and-recapture data for abundance estimates. Fish were marked with one of four clips depending on capture location. Data collected during the electrofishing events will also be used to make comparisons with underwater census data for distribution and abundance. All fish captured were identified to species, measured (total length mm), and weighed (g). Scales for ageing and tissue samples for genetic analysis were taken from a subsample of captured fish.

In tributary streams, distribution surveys were preformed in Trappers, Mountain, Howell, Phlox, Cliff, Escarpment, and Badger creeks and their tributaries. Each creek was divided into 1-km sections, each kilometer was divided into ten 100-m sites and one of the 10 sites was randomly selected to sample. Single-pass electrofishing is an effective method for estimating fish abundance in mountain streams with sparse habitat (Kruse and Hubert 1998). Each site was sampled using one pass with the backpack electrofishing unit. All cutthroat trout captured were sampled in similar fashion to those collected on the main stem river. Wyoming Game and Fish personnel performed similar surveys in waters outside the park boundary in Thorofare, Open, Dell, Atlantic, Elk, Coyote, and Hidden creeks.

Results

During the study, 151 Yellowstone cutthroat trout were surgically implanted with radio transmitters. Cutthroat trout were tagged in the Yellowstone River, Yellowstone Lake, Mountain, Trappers, Thorofare, Atlantic, and Open creeks. Fish were tagged from late-May through mid-August. The paucity of fish in the later part of the season resulted in only six fish being tagged after August 1. Tagging after mid-July in 2003 proved minimally successful; therefore, tagging trips in 2004 and 2005 were conducted prior to that time.

Approximately 72% of adult cutthroat trout identified during tracking events in the upper Yellowstone River and its tributaries migrated back to Yellowstone Lake following the spawning period. An additional 13% showed a distinct downstream migration pattern until their signal was lost. Of the six fish tagged after August 1, four moved downstream and were located in Yellowstone Lake, one showed a distinct downstream progression until the signal was lost, and one moved downstream to Yellowstone Lake and returned to the river 2 years later. Time spent in the river system differed with individual fish. However, fish that returned to Yellowstone Lake generally spent less than 3 months in the river system. The majority of the 76 fish that migrated to Yellowstone Lake did so by the end of July.

Cutthroat trout traveled great distances to spawn. Several fish migrated from Yellowstone Lake upstream over 48 km to Thorofare Creek before returning to the lake. Several male cutthroat trout tagged during the first year of the study returned to spawn the following season indicating male Yellowstone cutthroat trout may spawn in successive seasons. No female fish sampled during the first year returned during the second season, indicating females do not spawn in successive seasons.

There were several known mortalities of tagged fish during the study. Several radio tags were located on or recovered from the Molly Islands in the Southeast Arm of Yellowstone Lake. These fish were most likely consumed by white pelicans Elecanus erythrorhynchos, because the Molly Islands provide a vital nesting and rearing ground for pelicans. Other tags were retrieved below standing dead pines in the lower river and along the Yellowstone Lake shoreline where bald eagles Haliaeetus leucocephalus are frequently seen. Eagles may have predated on the fish or may have scavenged the carcass. One tag was recovered on an island in the Yellowstone River just north of Mountain Creek in bear scat. Numerous grizzly tracks were seen in the area; however, black bears are also found in the area. One angler harvested a tagged fish south of the park boundary. The tag was returned to Wyoming Game and Fish personnel after the fish was consumed. Other tags were recovered throughout the drainage with no way of determining cause of tag loss by the host fish. We were unable to relocate 28% of our tagged fish.

Yellowstone cutthroat trout were intermittently detected during underwater census of the Yellowstone River. A total of 125 cutthroat trout were identified in the 42 survey sections. Juvenile cutthroat trout were identified in the stream substrate, aquatic vegetation, and stream margins, while adults mainly resided in deep water areas with unstable banks. Approximately 60% of all cutthroat trout >330 mm long were detected in four of the 42 sections.

Electrofishing surveys of the main stem of the Yellowstone River produced few fish. During the mark run, 130 cutthroat trout were captured in 39 sites (sites 32, 33, and 34) were omitted due to heavy lightning and unsafe conditions). We sampled 71 cutthroat trout in 40 sites (sites 41 and 42 were omitted due to weather conditions) during our recapture run. Cutthroat trout were captured throughout the river with the exception of the 5 km leading to Yellowstone Lake. Length frequency data indicate that the population consists mainly of juvenile fish with few adults found in the system. No marked fish were captured during our recapture run.

Backpack electrofishing of tributary streams of the Yellowstone River within Yellowstone National Park showed juvenile cutthroat trout were present below migration barriers in all streams. Larger, older cutthroat trout were present only in the headwater reaches of several streams without migration barriers and in one stream above a migration barrier. Cutthroat trout ranged from 26 to 305 mm in total length with the largest fish being captured in an unnamed tributary to Mountain Creek (Figure 3).

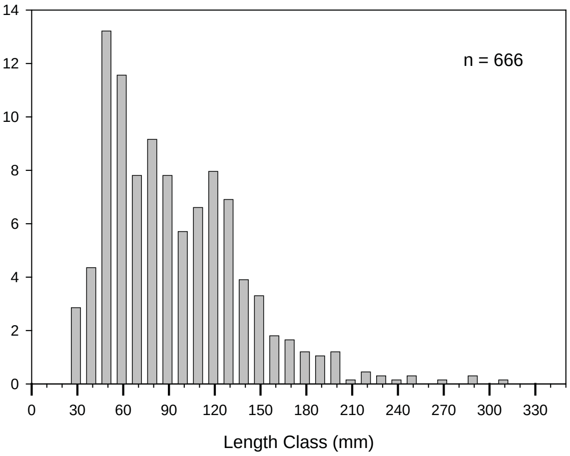

Figure 3. Length frequency distribution of Yellowstone cutthroat trout captured in tributary streams of the upper Yellowstone River, Yellowstone National Park, Wyoming, 2005 to 2007.

Discussion

Efforts to tag fish in even numbers throughout the drainage over a wide range of dates failed due to our inability to locate fish in all areas. Logistical constraints prevented us from sampling reaches of the Yellowstone River above Woodard Canyon during implantation trips and a 4-km section of the Yellowstone River downstream of Cliff Creek was omitted from sampling due to heavy bear activity.

Lack of implantation locations in the headwater reaches of the Yellowstone River and its tributaries may have biased our sampling, causing us to miss possible headwater resident populations or a distinct group of fish around Cliff Creek. This was not viewed as a major setback, because headwater populations are not found in any of the tributary streams historically surveyed on Yellowstone Lake (Pelican, Clear, Arnica, and Bridge creeks National Park Service unpublished data) and possible headwater residents were too small in size to be implanted with our radio transmitters. Tracking data indicate fish that may have been missed in the small portion of the river around Cliff Creek would have been available at other times in other locations for tagging. Also, our inability to locate fish to tag after August 1 may have biased our tagging operations to favor lacustrine-adfluvial fish. This, however, is unlikely and the lack of fish present for tagging late in the season was most likely due to a true lack of resident fish in the main-stem river.

Tracking and electrofishing data collected over the past 3 years indicate that few resident adult Yellowstone cutthroat trout reside in the upper Yellowstone River Basin below migration barriers. The lack of fish found during the post-spawn period (August to October) indicates the majority of fish in the upper Yellowstone River system were lacustrine-adfluvial and returned to Yellowstone Lake prior to August.

Our inability to relocate 28% of our tagged fish after initial implantation was troubling and could be due to several factors. Fish may have quickly moved downstream into the lake and resided at depth greater than our detection range, remained in the river at depths greater than our detection range, been preyed or scavenged upon and tags moved out of the system, or had malfunctioning tags. We will not be able to determine which occurred unless the tags are located in the future.

Data analysis shows that cutthroat trout in the Yellowstone River are very similar to other tributaries of Yellowstone Lake. This being the case, the Yellowstone River most likely makes a large contribution to the Yellowstone Lake population. To show this correlation, distribution and movement of fry and fingerling cutthroat trout in the upper river basin should be examined in the future. To gain a better understanding of distribution and possible resident populations, headwater areas should be sampled if possible. This area could be the last stronghold for Yellowstone cutthroat trout in this Yellowstone Lake system and all possible areas should be sampled.

Acknowledgements

We would like to thank Bob Gresswell and Carter Kruse for their continued support and input throughout this project. Without their insight we would not have been able to complete the daunting task of surveying this remote region. We would also like to thank the National Park Service, Wyoming Game and Fish Department particularly Jason Burckhardt, and the dozens of technicians who have assisted us over the past several years.

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Analyzing Tradeoffs Between the Threat of Invasion by Brook Trout and Effects of Intentional Isolation for Native Westslope Cutthroat Trout

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Abstract

Native fishes often face simultaneous threats from habitat fragmentation and invasion by nonnative trout. Unfortunately, management actions to address one may create or exacerbate the other. A consistent decision process would include a systematic analysis of when and where intentional use or removal of barriers is most appropriate. We developed a Bayesian belief network (BBN) as a tool for such analyses. We focused on native westslope cutthroat trout *Oncorhynchus clarkii lewisi* and nonnative brook trout *Salvelinus fontinalis*. We considered the environmental factors influencing them, their potential interactions, and the effects of isolation on the persistence of local cutthroat trout populations. The tradeoffs between isolation and invasion were strongly influenced by the size and quality of the stream network to be isolated and existing demographic linkages within and among populations. A strength of our approach was that it captured interactions where effects would otherwise difficult to visualize. The model can be used to conduct site-level analysis of barrier management relative to other possible conservation actions, such as habitat improvement or angling restrictions, and to help prioritize actions among streams. By eliciting precise definitions of conservation priorities, the model can also help clarify management objectives and facilitate communication among biologists, managers, and the public.

Introduction

Conservation of inland cutthroat trout *Oncorhynchus clarkii spp.* can involve either the placement or removal of migration barriers to address threats from invading species and habitat fragmentation. There are important tradeoffs, because barriers that may limit invasion can also isolate a native population making it more vulnerable to local extinction through a variety of processes. Projects to install or remove barriers may proceed without a formal analysis that considers potential tradeoffs from addressing these competing threats. Because resources for conservation management are limited, effective prioritization is important. Tradeoffs may be relatively clear to biologists and managers with intimate knowledge of a particular system, and their efforts can be focused effectively. Elsewhere, the tradeoffs may be more ambiguous or the data and experience more limited, and the result may be a decision that is influenced more by personal philosophy or public pressure than by knowledge. When the differences in these choices cannot be clearly supported and articulated, the decision process can appear inconsistent and arbitrary to the public or the administrators who fund these projects. A consistent decision process would include an analysis of the relative risks associated with either action.

Fausch et al. (2006) provided a synthesis of the science and theory relevant to this issue and proposed a framework that could help guide an appropriate analysis. The analysis could be complex, because of the potential interaction of multiple physical and ecological processes. For example, the probability that brook trout *Salvelinus fontinalis* may invade and displace cutthroat trout from any stream may depend on the physical characteristics defining the suitability of stream habitat for either species (e.g. Peterson et al. 2004), the condition of that habitat (e.g. Shepard 2004), the size, connectivity and complexity of the available habitat network (Rieman and Dunham 2000), distance of potential source populations, fishing pressure, and their interactions (Figure 1). Many biologists may inherently understand those processes for systems they have studied in detail, but consistent evaluation of these processes across multiple populations and environments could be improved by a formal assessment tool.

We explored the application of a Bayesian belief network (BBN) as a tool to facilitate such analyses (Cain 2001). We focused on westslope cutthroat trout *Oncorhynchus clarkii lewisi,;* hereafter WCT, and nonnative brook trout and current understanding of environmental factors influencing both species, their potential interactions, and the effects of isolation on the persistence of individual WCT populations.

Methods

We started with a conceptual model that represented the key processes and conditions we believe important to the biology of WCT and their interactions with invading brook trout (Figure 1). The conceptual model was formalized as a belief network by linking a series of conditional probability tables that quantified the key relationships implied by the arrows in the conceptual model (Figure 2). Estimation of the probability distributions for these relationships involved professional opinion, data based on actual species observations, and simulation of demographic characteristics with traditional matrix and diffusion-approximation population models. The resulting BBN predicted the probability of WCT occurrence in a stream segment after 20 years. The details are available in Peterson et al. (In Press).

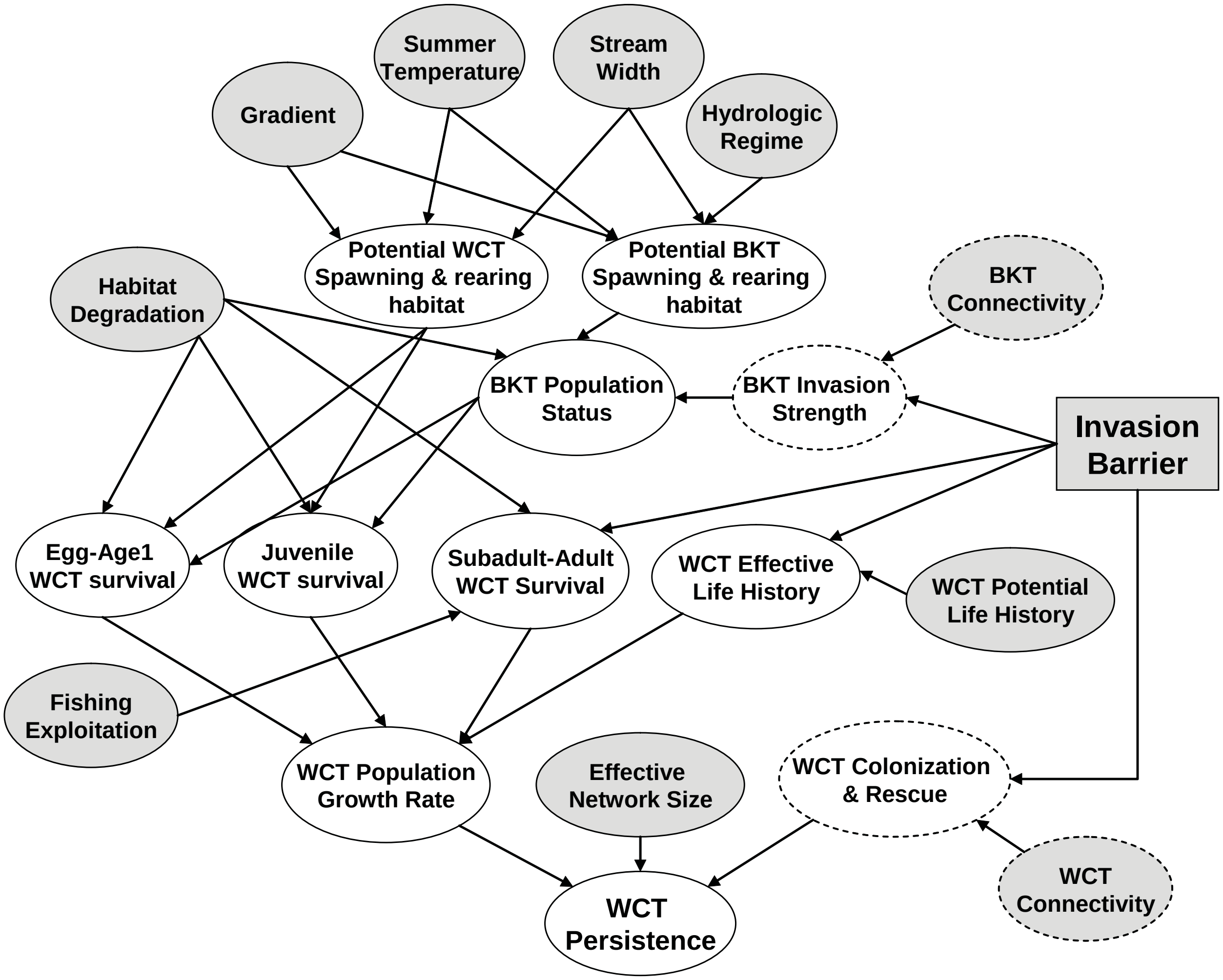

Figure 1. A conceptual model depicting environmental conditions and processes influencing the persistence of westslope cutthroat trout (WCT) and tradeoffs between intentional isolation and invasion by brook trout (BKT). Arrows indicate conditional dependencies between variables. Input variables (prior conditions) believed to affect WCT and BKT populations are those having only arrows from them (shaded ovals, e.g., *gradient*, *temperature*, *stream width*, etc.). Dashed lines indicate variables originating outside the local stream network. This model was implemented as a Bayesian Belief Network (see Figure 2) by developing conditional probabilities between dependent variables.

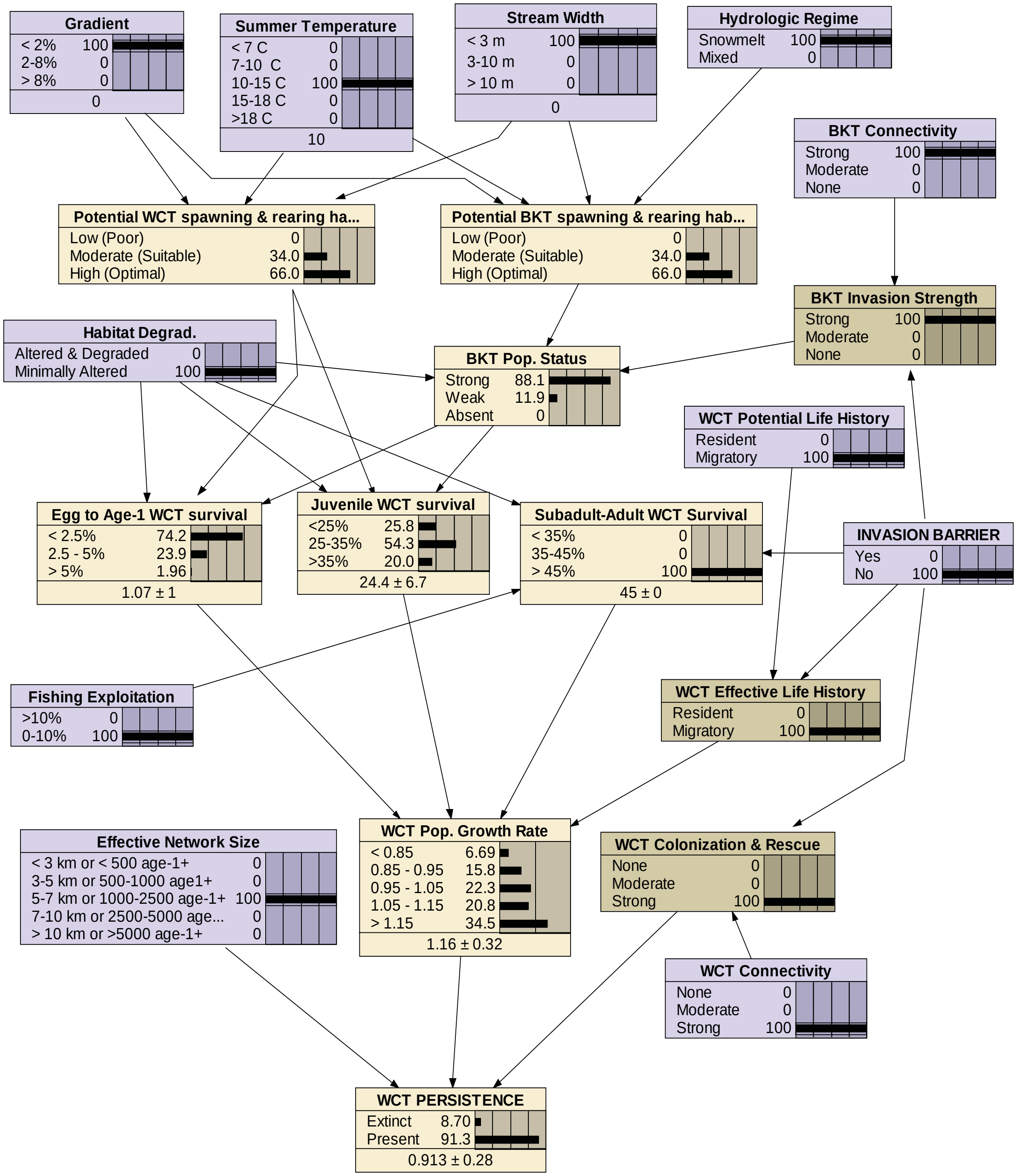

Figure 2. Bayesian Belief Network (BBN) to analyze tradeoffs between intentional isolation and invasion. The state or range of values each variable can take are listed below the title of each variable (e.g., for gradient, the possible states are <2%, 2-8%, and >8%). The size of the bar and the corresponding percentage values next to each state indicate the probability that the variable is in that state, conditioned on the state of the variables that influence it. To evaluate the effects of barrier installation or removal in a particular stream, the user can determine the initial conditions for a stream network by entering probabilities for the input variables, change the state of invasion barrier (i.e. from Yes to No), and measure the change in probabilities of persistence, or any intermediate variable of interest. In this example all input variables were set to 100% for one of the possible states.

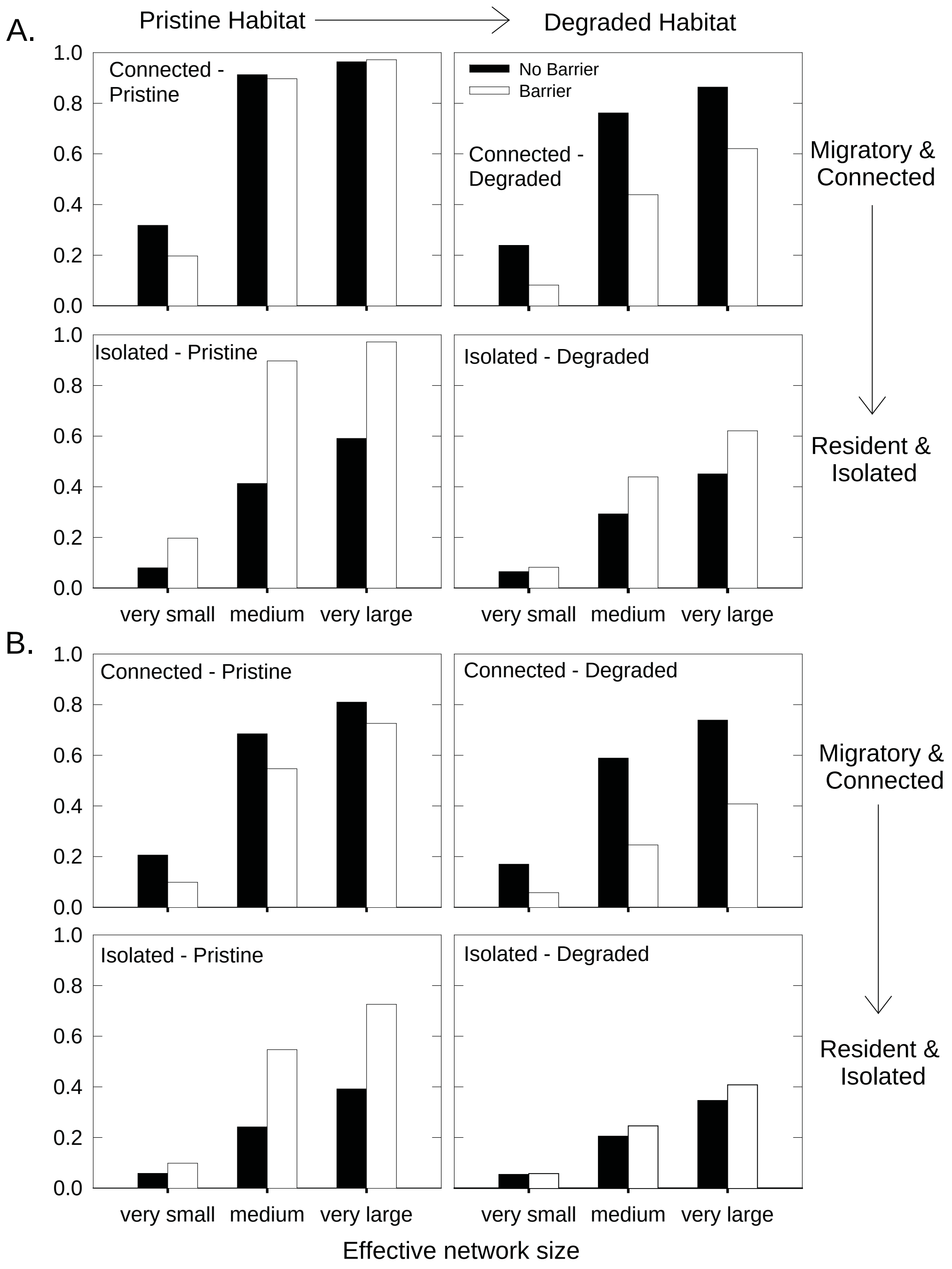

Figure 3. Predicted response of westslope cutthroat trout (WCT) to installation of an invasion barrier using the Bayesian Belief Network . Bars denote the predicted probability of persistence relative to habitat size and quality, life history expression and connection to other WCT populations), under low (A) and high (B) fishing exploitation. Results assume that brook trout invasion is imminent in a stream network with a snowmelt hydrologic regime, characterized by small (<3 m wide) low-gradient (<2%) tributary streams with moderate summer water temperatures (10-15°C). For reference, the middle black bar in the upper left panel of Figure 3B represents the prediction for the initial conditions represented in Figure 2.

Results and Discussion

Analysis with the BBN across a range of environmental conditions indicated the predicted tradeoff between isolation and invasion was strongly influenced by size of the stream network (or WCT population) to be isolated and existing demographic linkages within and among cutthroat trout populations. Intentional isolation was predicted to benefit demographically isolated WCT populations facing likely invasion by brook trout. Intentional isolation generally reduced the probability of persistence for migratory populations regardless of invasion threat. The relative benefits or risks associated with isolation depended strongly on the size and quality of available habitats that would be isolated (Figure 3).

Our results suggest that the utility of a barrier should be weighed based on some understanding of these characteristics. Peterson et al. (In Press) provide several examples of how the BBN could be used to evaluate management alternatives and prioritize limited resources associated with the installation or removal of barriers. We believe the model can also facilitate communication among parties interested in these management issues.

The BBN we developed was based on current understanding of brook trout invasions and the consequences of incidental or intentional isolation for WCT. Like any model, potential users should be aware of its limitations. Predictions can only be interpreted in terms of the relative differences between management options or a set of environmental conditions, not as absolute probabilities (e.g., Ralls et al. 2002). A BBN provides guidance during the decision process, but does not supplant or replace a human decision (Marcot 2006), nor does it substitute for the professional knowledge of an experienced fishery biologist. It does, however, allow biologists and managers to more clearly think about the relative effects of brook trout and isolation on WCT populations, and to quickly visualize and evaluate the effects of complex interactions. As a working hypothesis, the BBN can be directly tested, updated, or modified using examples from fishery management or challenged and revised based on new empirical or theoretical results.

The use of this BBN does not solve the often opposing problems of brook trout invasion and habitat fragmentation facing WCT or other native fishes in western North America. Rather, it provides a process and framework for thinking through the issues, clearly documenting and defining knowledge and uncertainty, and identifying conservation values and objectives. Site-specific analysis using our model or similar BBNs may help identify management options and tradeoffs in a particular stream. The greater utility, however, may be using the model to explore the relative benefits of isolation or connection across a collection of WCT populations and using that information to implement more strategic conservation programs and prioritize limited resources.

A working version of the model and a user's guide may be obtained from: Doug_Peterson@FWS.gov.

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Restoration of Native Rio Grande Cutthroat Trout in the Upper Rio Costilla Basin, New Mexico: The Long Journey Home

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Abstract

The impact of nonnative salmonids on the native Rio Grande cutthroat trout *Oncorhynchus clarkii virginalis* in the upper Rio Costilla basin of northern New Mexico has long been a concern of managers as evidenced in a 1938 letter from biologists to the state game commission. In the 1970s a substantial, ultimately unsuccessful effort to remove nonnative trout in the watershed with electrofishing and sodium cyanide was implemented. In the late 1990s the New Mexico Department of Game and Fish, Colorado Division of Wildlife, and Vermejo Park Ranch initiated discussions regarding chemical renovation of upper Costilla Creek to restore native cutthroat trout, which culminated with a piscicide treatment of 22 km of stream and four small lakes in July 2002. The native cutthroat trout population was reestablished by stocking primarily juvenile fish, beginning in fall 2002. In 2004 during a supplemental stocking event, rainbow trout *O. mykiss* were inadvertently stocked into the renovated portion of the watershed. An immediate and intensive electrofishing effort removed as many of these fish as possible. During analyses of this error, it was discovered that the genetic history of the New Mexico portion of the broodstock source used to reestablish the cutthroat trout population included hybridization with Yellowstone cutthroat trout *O. c. bouvieri*. Annual surveys of the restored Rio Grande cutthroat trout population indicated that the restored fish began reproducing in 2005, and posttreatment population abundance and average individual size was similar to pretreatment estimates within 3 years. Random genetic sampling in 2005 did not detect the presence of rainbow trout or Yellowstone cutthroat trout genes in the restored population; however, in 2007 putative first generation rainbow x cutthroat trout hybrids were documented in the population. Regardless of the setback in recovery experienced here, the collaborative process for recovery of Rio Grande cutthroat trout in the upper Rio Costilla basin remains strong, and further, has initiated a proposal that, if fully implemented, would expand this native trout restoration effort to over 100 stream kilometers in the Rio Costilla basin over the next decade.

Introduction

Similar to the fate of many other North American salmonids across their native ranges, Rio Grande cutthroat trout *Oncorhynchus clarkii virginalis* currently occupy a much reduced portion of their historic range, primarily due to interactions with nonnative fishes and anthropogenically driven habitat degradation (see for example the discussions in Behnke 1992 and Young 1995). The subspecies, native to the upper basin portions of the Rio Grande, Pecos, and possibly Canadian river drainages in southern Colorado and northern New Mexico (Sublette et al. 1990; Calamusso and Rinne 2004), is now found in only about 5 to15% of historically inhabited range (Sublette et al. 1990; Stumpff and Cooper 1996; USFWS 1998). Because of this decline, both the Colorado Division of Wildlife (CDOW) and New Mexico Department of Game and Fish (NMDGF) consider the Rio Grande cutthroat trout a species of special concern or management and are actively engaged in conservation and restoration activities regarding the subspecies, including, among other things, securing and expanding existing populations, monitoring contemporary population demographic and genetic attributes, improving and restoring habitat conditions, and establishing new populations in renovated habitats (Paroz et al. 2002; Alves et al. 2004). While these activities have generally focused on public waters, both agencies recognize the importance of incorporating the private land component into their conservation strategies and have strived to collaborate with private landowners when developing and implementing restoration and conservation objectives.

Vermejo Park Ranch, a 236,925-hectare remnant of the original 1841 Maxwell land grant, was purchased by Ted Turner in 1996. The ranch, situated in north central New Mexico on the New Mexico-Colorado state line, continues to operate as a working ranch with livestock, timber, methane, and guest service (hunting and fishing) enterprises; however, the Turner organization has implemented a land management philosophy focused on conservation of native species embodied by its mission statement: "*To manage Turner lands in an economically sustainable and ecologically sensitive manner while promoting the conservation of native species*." A renewed focus on native aquatic communities by the Turner organization established that while small core (of high genetic purity; UDWR 2000) populations of Rio Grande cutthroat trout persisted in the Vermejo (Canadian) River headwaters on the ranch, low-order tributaries in the Rio Costilla (Rio Grande drainage) basin supported only nonnative salmonids. Subsequently, in the late 1990s discussions among the NMDGF, CDOW, and Vermejo Park Ranch (founding members of the Costilla Watershed Working Group) laid the initial groundwork that culminated in chemical removal of nonnative trout and introduction of Rio Grande cutthroat trout in a portion of Costilla Creek in 2002.

History of Native Fish Conservation Efforts in the Upper Rio Costilla Basin

Costilla Reservoir, a 19,736,000-m^3 (16,000 acre-ft) irrigation impoundment formed when Costilla Dam closed in 1917, and its upstream tributaries lie entirely within Vermejo Park Ranch and form what is considered the upper Costilla basin (Figure 1). The valley floor of the basin approaches 3,000 m and stream hydrology is typified by spring snowmelt runoff and late summer low flows. Rio Grande cutthroat trout were likely the only native fish species in the basin; however, the Rio Grande sucker *Catostomus plebeius* and the Rio Grande chub *Gila pandora* may have historically resided in the lower portions. Stocking records of NMDGF indicate that nonnative brook trout *Salvelinus fontinalis* and rainbow trout *O. mykiss* were initially stocked into the upper basin in 1915 and 1917, respectively. Stocking of exotic salmonids continued until the early 1990s, in part to sustain a popular fee-fishing program on Vermejo Park Ranch.

Nonnative and hybrid trout were ubiquitous in the basin by the 1930s and in 1938 the New Mexico State Game Commission was urged to consider removing nonnative fish from Costilla Reservoir and its tributary streams in deference to the native cutthroat trout, which was rapidly disappearing from the watershed.

"Costilla Lake has great possibilities as a spawn producing lake, if it were stocked with the proper fish which should be rainbows or natives. I suggest the latter because it is a natural native water. The spawning conditions would be better since the natives spawn later than the rainbow and also there is a great shortage of this species and they should be propagated on a larger scale to meet the present and increasing demands…. The fish that now abound in the lake should be removed and the lake restocked with the New Mexico natives."

Letter from Jimmie Johnson, Fish Specialist, to the State Game Commission, July 11, 1938.

Unfort unately, no action was taken.

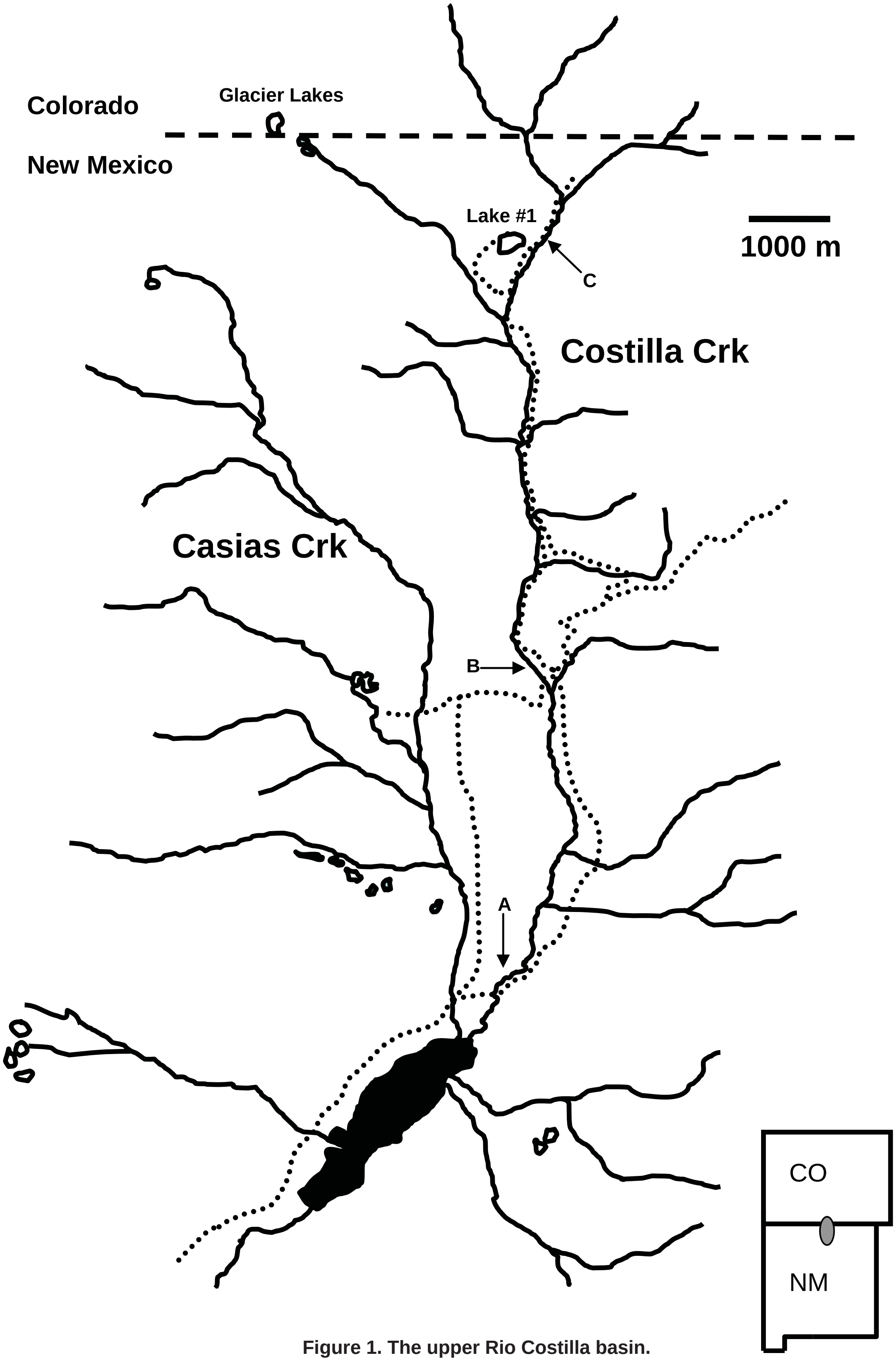

Figure 1. The upper Rio Costilla basin.

In fall 1976 an infiltration type (flow forced underground by passing through an artificial cobble screen into an outlet pipe) barrier to fish movement was installed on Costilla Creek above Costilla Reservoir (Site A, Figure 1). For the next 2 years from June to September, electrofishing and sodium cyanide applications were periodically used to collect and remove nonnative trout from the stream above the infiltration barrier. Fish visually appearing to be cutthroat trout were revived in fresh water and released back into the stream. Sodium cyanide was applied in tabular form at a rate of approximately 0.35 g/m3 (12.5 g/cfs) of flow every 150 m along the stream channel. Approximately 13,430 fish were captured over the 2 years and the percentage of fish visually appearing as native cutthroat increased from 14% in 1977 to 79% in 1979. However, with no further removal efforts after 1978, the percentage of putative cutthroat trout in the population decreased to 52% by 1982. The infiltration barrier ultimately plugged with fines and failed, and population monitoring and native fish conservation activity ceased in the early 1980s. Visually appearing cutthroat trout comprised only 15% of the population during pre-piscicide treatment surveys in 2002, and almost all of those individuals were partially hybridized (with rainbow trout) based on molecular genetic analyses.

In 1997 initial overtures were made by Vermejo Park Ranch to NMDGF and CDOW regarding a piscicide-based stream renovation project for restoration of native Rio Grande cutthroat trout in the upper Rio Costilla basin. In 2000 the ranch constructed a wire-gabion falls barrier (Site C, Figure 1) that isolated a small portion of Costilla Creek; however, upon further discussion concerning the potential long term effects of isolating a small population above a movement barrier (e.g., Novinger and Rahel 2003), the Costilla Watershed Working Group agreed that the proposed project area should be enlarged if possible. In July 2002, a second wire-gabion barrier was constructed (Site B, Figure 1) that isolated approximately 22 km of stream and 4 small lakes from the remainder of the upper Rio Costilla basin. The site chosen for the terminal barrier was as low in the drainage as possible given the low stream gradient and wide valley downstream. Following product label directions (Aquabiotics 2002) and protocols similar to those described in Gresswell (1991), Stefferud et al. (1992) and now Moore et al. (2005), a single, 10-ppb application of Fintrol®, an antimycin-based piscicide, was administered across the project area in late July 2002. Chemical was applied to the lakes by dispersing into the propeller wash and pumping to depth to ensure complete mixing of the chemical in the water body. Flowing water was treated for 8 h using constant flow drip stations (described by Stefferud and Propst 1996) spaced every 305 m along the stream channel. Slack and side channel waters were sprayed with backpack sprayers containing a diluted solution of antimycin. Residual antimycin was detoxified below the terminal barrier using a 1-ppm potassium permanganate drip. Flows in the treatment area during application were well below the long term average, with mainstem Costilla Creek flowing approximately 42 L/s (1.5 cfs) during treatment at the terminal barrier. One small side tributary required two consecutive treatments to fully eradicate all nonnative fish. Posttreatment gill netting and electrofishing surveys were unable to capture any fish within the treatment area.

Reestablishing Native Rio Grande Cutthroat Trout

The Costilla Watershed Working Group determined that the upper barrier (Site C, Figure 1) would remain in place as insurance to protect at least a portion of the treatment area until it was determined with high confidence that no nonnative fish remained in the treatment area and no fish could pass upstream over the terminal barrier (Site B, Figure 1). Consequently, a decision was made to segregate the fish stocked above and below the upper barrier into less and more genetically diverse groups to facilitate potential research regarding genetic fitness of future generations. In other words, the Working Group choose to stock Rio Grande cutthroat trout from CDOW hatchery sources across the entire project area, but supplement only that portion of the treatment area below the upper barrier with additional Rio Grande cutthroat trout from New Mexico hatchery sources, likely providing a genetically more diverse founding population in the lower portion of the restored area. A hypothesis was that the smaller, potentially less genetically diverse population introduced above the upper barrier might manifest a significantly different population genetic structure after multiple generations than the more robust population below the upper barrier; ultimately beginning to elucidate genetic questions associated with choosing a founding population source and the isolation of small populations (see discussions in Hildebrand and Kershner 2000; Kruse et al. 2001; Novinger and Rahel 2003 for example).

For three consecutive years starting in the fall of 2002, CDOW annually stocked approximately 10,000, 25- to 50-mm long fingerling Rio Grande cutthroat trout into the main stem and lower sections of tributaries throughout the treatment area (1 fish per 2 m of stream or 4 m^2 surface area). The NMDGF stocked an additional 4,700 one year and older Rio Grande cutthroat trout into the main stem between the two barriers over the 3-year period from 2002 to 2004. Fin clips were collected from at least 60 fish during each stocking event, preserved in ethanol, and held in cold storage to document the baseline or founding genetic characteristics of the newly introduced population.

Because of their value to the guest fishing program, the two largest renovated lakes, Lake #1 (5.7 ha) and upper Glacier Lake (2.6 ha; Figure 1) were stocked with larger brood fish as well as fingerlings in attempt to immediately provide angling opportunity. Glacier Lake received an initial stocking of 750 fingerlings per hectare in the fall of 2002 with subsequent introductions of several hundred large (> 350 mm) brood fish from the NMDGF hatchery system the following summer and additional fingerling (1,000) and age-2 (800) fish in 2004. Lake #1 was initially stocked with 1,500 brood fish during the summer of 2003; however, less than one-half of these fish survived due to transportation stress and warm water temperatures. At the request of Vermejo Park Ranch, an additional 4,200 fish ranging in size from 150 to 375 mm long were stocked by NMDGF in June of 2004 to support guest angling. Both lakes were stocked with fingerling fish from CDOW in August 2006 at a rate of 250 fish per hectare. Throughout the stocking cycle in the streams and lakes all fingerling fish came from CDOW and all age-1 or older (larger) fish came from NMDGF.

Population Recovery in the Renovated Section of Costilla Creek

In 2001, eight 100-m sampling sections were established for pre- and posttreatment population monitoring with standard three-pass electrofishing techniques (e.g. Peterson and Cederholm 1984; Riley and Fausch 1992). With the exception of 2003, the same four sections have been monitored every year in July or August since 2002, including sites above and below the upper barrier. Inferences regarding population abundance over a longer period can also be made from data collected during population sampling from 1977 to 1981.

The strategy of stocking fingerling fish for three consecutive years allowed the population to recover (as measured by individual mean size and abundance) to pretreatment levels within 3 years (Table 1). The average size fish sampled during the two years prior to piscicide treatment (2001-2002) were similar and not significantly different (ANOVA $P > 0.05$) from the size of fish captured in posttreatment sampling from 2005 through 2007. In fact, the averages were startlingly similar. Actual numbers of fish (> 80 mm long) captured at each 100-m sampling site and their overall size range were also very similar when comparing the pretreatment (2001-2002) and post-recovery (2005-2007) periods. Population data collected during the sodium cyanide treatments and monitoring in the late 1970s and early 1980s suggest that Costilla Creek within the treatment area has supported a consistent trout population over time.

Reproduction by restored Rio Grande cutthroat trout was documented for the first time in the spring of 2005 and was probably the result of the 2002 age class reaching maturity. Spawning by some of the larger fish stocked by NMDGF may

Table 1. Average numbers and sizes of salmonid fishes captured prior to and after a 2002 piscicide treatment and subsequent restocking in Costilla Creek. Species present prior to treatment included brook trout, rainbow trout, Rio Grande cutthroat trout, and hybrids in the 1977-1981 samples; the addition of brown trout Salmo trutta in the 2001-2002 samples; and only Rio Grande cutthroat after 2002. Annual average fish sizes with the same numbered superscript are not significantly different ($P > 0.05$)

Year	Number of 100-m sites sampled	Number of fish > 80 mm per site[b]	Average size (mm) of fish > 80 mm	Size range (mm)
1977	-	-	144.5	-
1978	-	-	152.0	-
1979	-	-	175.5 ^{4}	80-261
1980	-	-	152.2 ^{2,3}	80-261
1981	-	-	147.6 ^{2}	81-295
2001	2	52.5	164.8 ^{3,4}	95-293
2002	8	48.3	166.9 ^{3,4}	80-306
2002[a]	4	61.3	168.6 ^{4}	80-306
2003	3	20.0	102.1 ^{1}	82-130
2004	4	20.3	147.2 ^{2}	104-196
2005	4	52.0	165.1 ^{3,4}	93-260
2006	4	56.0	166.3 ^{3,4}	85-246
2007	4	64.3	164.5 ^{3,4}	82-270

[a] *these four sites are a subset of the eight sampled in 2002, but match the sites sample from 2003-2007.*

[b] *the 1977-1981 samples were not conducted over a standard length, thus number per 100-m reach could not be calculated; these numbers represent actual fish captured.*

have occurred at an earlier date; however, it was not detected (but see discussion in the following section). Further, although NMDGF stocked over 4,000 larger fish into the lower section over the 3 years, few of these fish were seen during posttreatment electrofishing surveys, especially in 2003 and 2004 when these fish should have been noticeably larger than the younger year classes stocked by CDOW. It is suspected that many of these fish may have moved downstream after stocking, resulting in densities in the treatment area low enough to avoid detection.

Inadvertent Rainbow Trout Stocking

In early 2004, due to limited survival of larger fish stocked in 2003, Vermejo Park Ranch requested that any larger Rio Grande cutthroat trout available in the NMDGF hatchery system be stocked into Lake #1 to increase densities and provide a limited catch-and-release fishery for anglers. In June of 2004, NMDGF provided several thousand age-1 and older fish (see stocking discussion above), the largest of which went into Lake #1, with a portion of the age-1 individuals (approximately 1,500) stocked into the restored section of Costilla Creek between the barriers. Near the end of the stocking event, staff collected a morphologically irregular fish – a fish visually identified as a suspected rainbow trout. Locations where fish had been stocked into the stream were immediately electroshocked and two additional suspect fish were collected. All three were later genetically confirmed as pure rainbow trout.

Investigation at the Seven Springs Hatchery where the New Mexico Rio Grande cutthroat trout broodstock was held confirmed that rainbow trout eggs had been previously brought into the hatchery and through administrative error or escapement had contaminated a group of similar age Rio Grande cutthroat trout. Further genetic evaluation of the entire New Mexico Rio Grande cutthroat trout broodstock program also confirmed the presence of as much as 20% Yellowstone cutthroat trout *O. c. bouvieri* hybridization in the broodstock (Pritchard and Cowley 2005). It was confirmed that both rainbow trout and hybrid Yellowstone cutthroat trout had been introduced into the Costilla Creek restoration area below the upper barrier.

Based on the percentage of rainbow trout remaining at the Seven Springs Hatchery, NMDGF estimated that at least 30, and probably closer to 50, rainbow trout had been introduced into Costilla Creek. Political opposition to the continued use of piscicides in New Mexico in 2004 precluded an immediate re-treatment of the affected area; thus, an extensive electrofishing removal effort was undertaken. On July 8 and 9, the entire 8.5-km section of Costilla Creek between the barriers was electrofished at least once and 21 rainbow trout (including the two captured immediately after stocking) were removed. Subsequent passes through the section on September 8 and 10 yielded 19 and 4 rainbow trout, respectively. Acknowledging that using these passes to estimate a population size violates several assumptions of the three-pass depletion model, we nevertheless used these numbers (21, 19, and 4) to estimate a potential rainbow trout population in the restored area of 50 individuals (95% confidence intervals 44-61) – similar to what NMDGF originally estimated. Further electrofishing on September 27 and 28 captured another 7 rainbow trout – for a total of 51.

The Costilla Watershed Working Group understood it was probable that a few rainbow trout remained in the system, but was cautiously optimistic that overwinter mortality, out-migration (from the project area), and additional electrofishing in 2005 might eliminate any remaining rainbow trout prior to significant reproduction occurring as expected in the spring of 2006 (as 3-year olds). We also agreed that if future electrofishing failed to recover any additional rainbow trout or hybrids, periodic genetic sampling would be conducted in attempt to detect both future rainbow trout and Yellowstone cutthroat trout genetic influence. In 2005, in addition to sampling the four standard population monitoring sites, a single electrofishing pass was completed through the entire affected reach. No rainbows were observed in 2005 or during population monitoring in 2006. In 2005, a random sample of 90 adult fin clips was analyzed for presence of Yellowstone cutthroat trout – none was detected (Douglas and Douglas 2006). In 2007, anglers began reporting suspected hybrid fish within the restoration area, and fall population monitoring surveys also captured suspected hybrid fish that were 140 to180 mm in length. These are 2-year old fish that would have been spawned in the spring of 2005. Fin clips from suspected hybrids are currently under analyses at a genetic laboratory, and if the results confirm rainbow presence, it would strongly suggest that: our rainbow trout suppression efforts failed and the larger (for age) hatchery rainbow trout spawned as 2-year olds (most likely); rainbow trout are successfully passing over the terminal barrier (less likely); or anglers are inadvertently moving rainbow trout over the terminal barrier (possible). No hybrids were angled or captured in any sampling above the upper barrier.

Future

The Costilla Watershed Working Group remains strongly committed to Rio Grande cutthroat trout restoration in the upper Rio Costilla basin. Although disappointed, we are currently assessing options for removing or containing the possible hybridization in the restored area of Costilla Creek and believe that a highly genetically pure population of Rio Grande cutthroat trout in that area is still an obtainable goal. In 2003, the Working Group expanded to include the Carson National Forest and the Rio Costilla Cooperative Livestock Association, the next two downstream (from Costilla Dam) land managers or owners, as well as other interested parties including Trout Unlimited, New Mexico Interstate Stream Commission, and the U.S. Fish and Wildlife Service, among others. The Working Group has initiated a bold effort, formalized in a 2003 Memorandum of Understanding and 2007 Environmental Assessment, to expand the initial restoration effort in Costilla Creek to over 100 km and 20 lakes including connected waters on Vermejo Park Ranch, Carson National Forest, and the Rio Costilla Cooperative Livestock Association - if fully implemented. The first phase of this expanded effort was initiated in 2007 with a piscicide (rotenone) treatment in the Comanche Creek drainage, a large Costilla Creek tributary downstream from Costilla Reservoir. The Working Group has also developed a draft Candidate Conservation Agreement with Assurances to protect private land activities, if successful restoration of

Rio Grande cutthroat trout occurs and the subspecies becomes nationally listed under the Endangered Species Act. That document should be finalized and signed in 2008. This larger effort is expected to require a decade or more to complete; however, the Costilla Watershed Working Group is excited by the conservation gain for Rio Grande cutthroat that this, and other similar projects, represent if successfully completed.

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Effects of Impoundments and Hydroelectric Facilities on the Movement and Life History of Redband Trout in the Upper Klamath River: A Summary and Synthesis of Past and Recent Studies

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Abstract

In the 77-km section of the Klamath River, between the outflow of Upper Klamath Lake and the Oregon-California Border, the physical and ecological environment of redband trout *Oncorhynchus mykiss newberrii* has been altered by four hydroelectric dams. Spencer Creek, which enters the Klamath River just upstream of J.C. Boyle Dam, is an important spawning area and source of juvenile recruitment for redband trout in the upper Klamath River. In 1959, the year after J.C. Boyle Dam was completed, fish ladder trap counts showed adult redband trout migrated upstream in the Klamath River in large numbers to spawn in Spencer Creek. By 1962, trap counts had declined by at least 90%. Despite this decline, studies conducted in the late 1980s showed that a significant spawning run and juvenile outmigration persisted in Spencer Creek. These findings raised questions about the adult and juvenile life history of the Spencer Creek spawning population. We used radio telemetry and PIT-tag technology to address these questions. Our results show that upstream movement of adult redband trout over the dam to Spencer Creek is rare and suggest that the Keno Reach of the Klamath River is the main source of spawning adults in Spencer Creek. We also found that movement of juveniles from Spencer Creek downstream past the dam has been restricted to those infrequent periods when spill occurs. These findings suggest that the life history diversity displayed by Spencer Creek spawners has been constricted by J.C. Boyle Dam, likely reducing trout abundance and productivity downstream of the dam.

Introduction

Redband trout *Oncorhynchus mykiss newberrii* life histories range from headwater populations that complete their life cycle within a few kilometers of their natal stream to fluvial and adfluvial populations that migrate extensively over their life cycle to use riverine and lake habitats (Behnke 1992; Buchanan et al. 1994). Life history diversity is important to the stability and persistence of trout populations, because it provides the ability to exploit a diversity of available habitats and thus provides a means of buffering against environmental stochasticity. Alteration of the riverine environment that results in persistent changes in habitat can reduce life history diversity. The net effect of a reduction in life history diversity can lead to reduced population productivity and viability.

Dams and associated management for hydroelectric production and irrigation have modified the environment of native redband trout in the Upper Klamath River (Hecht and Kamman 1996; IMST 2003; PacifiCorp 2004a). These changes include habitat degradation, passage obstruction, dampened peak flows, poor water quality, and increased competition from introduced species.

An improved understanding of the life history of these trout populations is needed to address management concerns and guide fish passage and dam operation protocols that minimize detrimental impacts. In this paper we summarize findings of past studies, present the results of new research, and attempt to synthesize these findings to describe life history features of Upper Klamath River redband trout populations. We also assess how operations of hydro facilities have influenced these life history patterns.

Study Area

The study area encompasses the Klamath River between Link River dam at river kilometer (RK) 406.9, which is the outlet of Upper Klamath Lake, and Shovel Creek (RK 330.4), which is near the Oregon-California border (Figure 1). Downriver of the dam, Link River flows 1.9 km to Lake Ewauna, which is now part of the 31.8-km long reservoir created by Keno dam (RK 370.4). Downriver of Keno Dam, the Keno Reach of the Klamath River flows through a canyon and consists of a wide channel with rapids, riffles and pocket water among cobble, boulders and bedrock. The Keno reach discharge depends on seasonal patterns and irrigation demands and ranges from summer base flows of <10 to >300 m^3/sec in spring. This reach ends at the head of Topsy Reservoir (RK 363.2), which is a 6.4-km long pool created by J. C. Boyle dam (RK 360.0). Spencer Creek, an important spawning tributary, flows 28.8 km from the Cascade Mountains and enters the Klamath River at Topsy Reservoir.

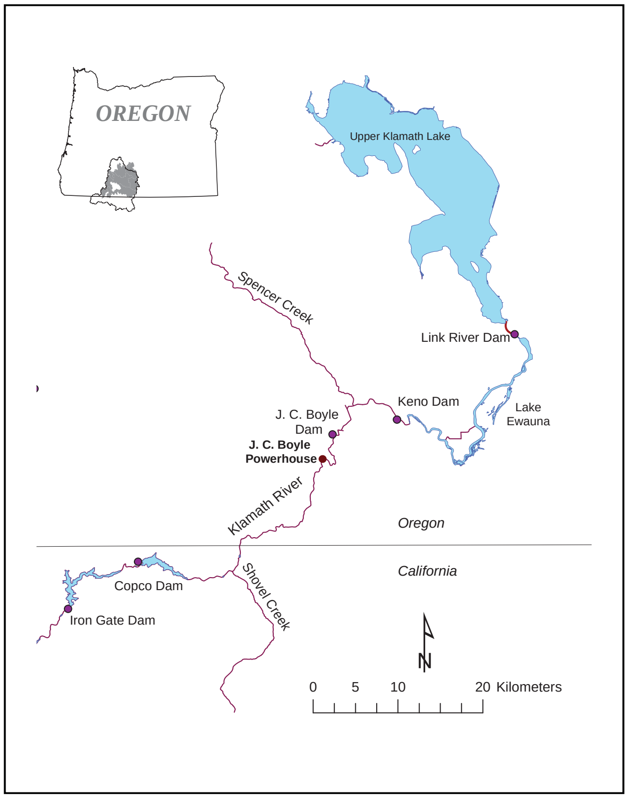

Figure 1. Upper Klamath River showing locations of important spawning tributaries for redband trout and locations of dams and associated hydroelectric facilities. The reach of the Klamath River between J. C. Boyle Dam and J. C. Boyle Powerhouse is referred to as the Bypass Reach and the reach of the river between the J. C. Boyle Powerhouse and the mouth of Shovel Creek is referred to as the Peaking Reach.

From J. C. Boyle Dam to the powerhouse, the Klamath River Bypass Reach flows through a canyon at the minimum allowable discharge of 2.83 m^3/sec (0.57 m^3/sec from the screened fish bypass facility and 2.83 m^3/sec from the fish ladder and attractor) except for infrequent and short periods of spill. Cool groundwater springs augment flow in this 6.4-km reach so that discharge is about 9.91 m^3/sec when it reunites with the powerhouse outflow.

Most of the Klamath River flow is stored at J.C. Boyle Dam and then diverted through a concrete canal for power production. Typical summer canal discharge for peak power production ranges from 21.2 to 42.5 m^3/sec for a few hours during the day. The Klamath River Peaking Reach extends from the powerhouse outlet (RK 352.6) to Copco Reservoir (RK 325.0). Peaking Reach discharge fluctuates daily from about 9.91 m^3/sec, when there is no power production, to 80.7 m^3/sec during peak power production. Shovel Creek, another important spawning tributary, enters the Klamath River (RK 329.6) in California. Since its construction in 1917, Copco Dam has prevented upstream fish passage. Upstream passage at all other dams in the study area is provided by fish ladders.

Review of Past Studies

Redband trout life history in the upper Klamath River has been investigated by mark-recapture of adult fish caught in fyke traps in the fish ladders of Link River, Keno, and J.C. Boyle dams and by trapping fish in weirs near the mouths of Spencer and Shovel creeks. Trap catches in the ladders of Link River and Keno dams during 1988-1991 (Hemmingsen et al. 1988 1992; Buchanan et al. 1989, 1990, 1991) showed some movement of adults from the Keno reach into Lake Ewana but very little movement of adult trout into Upper Klamath Lake. At Link River Dam, less than eight redband trout per year were estimated to ascend the fish ladder to enter Upper Klamath Lake in 1988, 1990, and 1991. In 1989 however, 147 fish were estimated to pass upstream over the dam, 94% of which were captured from April to June. At Keno Dam, the estimated number of redband trout ascending the fish ladder alternated from about 200 fish in 1988 and 1990 to about 60 fish in 1989 and 1991. Although limited in scope, these results suggest that connectivity between redband trout populations in the Upper Klamath River and tributaries of Upper Klamath Lake is sporadic and represents only a small fraction of the adults produced downstream of Upper Klamath Lake.

Trap counts at J.C. Boyle Dam fish ladder from 1959 to 1962 suggest that, following dam construction in 1958, there was a rapid decline in abundance of adult redband trout migrating upstream past the dam. In 1959, an estimated 5,529 redband trout used the fish ladder to pass over J.C. Boyle Dam. Within 3 years, the estimated number of migrating fish declined by nearly 60%. Adult redband trout movement over J.C. Boyle Dam was monitored again from February 1988 through December 1991 (Hemmingsen et al. 1988, 1992; Buchanan et al. 1989, 1990, 1991). Between 1988 and 1990, the estimated total number of fish passing over the dam averaged 502 trout (range: 412-588), which was less than 10% of the estimated total in 1959. Only 70 redband trout passed over dam in 1991, which was less than 2% of the estimate in 1959. In addition to the decline in abundance of the upstream migrants there was also a significant decline in fish size. The average length of redband trout captured from the ladder during March through May decreased significantly ($p<0.01$, one-way ANOVA) from 30 cm in 1961 to 18-20 cm in 1989-1991.

Despite the loss of adult migrants over J.C. Boyle Dam, Spencer Creek continues to be an important redband trout spawning stream and source of juvenile recruitment in the upper Klamath River basin. In 1988, 348 redds were counted in a 13.6-km reach in April and May (Oregon Department of Fish and Wildlife – ODFW, unpublished data). Similarly, 132 and 113 redds were observed in an 8.6-km reach of Spencer Creek on a single day during peak spawning in 2003 and 2004, respectively. Because spawning in Spencer Creek is thought to occur from February through June and peak in April and May, these counts probably represent only a fraction of the total annual number of redds. In 1989-1991, weir traps were installed near the mouth of Spencer Creek to capture upstream and downstream migrant redband trout (Buchanan et al. 1989, 1990, 1991; Hemmingsen et al. 1988, 1992). In 1989 high flows prevented efficient trapping. In the two latter years, the traps operated continuously through the migration period. Resulting abundance estimates totaled 1,032 and 1,830 adults and 41,681 and 26,247 juveniles for 1990 and 1991, respectively. Scale analysis of 99 adult redband trout suggested most migrated from Spencer Creek at ages 1 and 2 and returned to spawn for the first time at age 3. Ages of spawning fish ranged from 2 to 8 years (Borgerson 1992).

To estimate the magnitude of juvenile recruitment into the Klamath River Bypass Reach, over 25,000 juvenile trout outmigrating from Spencer Creek were fin-clipped and a rotary screw trap was operated 200 m downriver of J.C. Boyle Dam from April 1991 through May 1992. Over this period, only 54 marked trout from Spencer Creek were recaptured in the screw trap. Although these catches were not intended to estimate abundance, the researchers were surprised by the low numbers of juveniles that passed below the dam (Buchanan et al. 1991; Hemmingsen et al. 1992). These results suggested that the operation of J.C. Boyle Dam may impede recruitment of juvenile trout from Spencer Creek to downstream portions of the Klamath River.

Spawning survey and weir trap results of Beyer (1984) indicate that Shovel Creek is also important to reproduction of redband trout in the upper Klamath River basin. Based on a mark-recapture study, Beyer estimated an adult migratory population of 1,187 fish during the spring of 1982. Redband trout spawning on the mainstem Klamath River is difficult to detect, because turbid conditions prevent examining the river bottom, except in the shallower stream margins. However, spawning has been documented in the bypass reach of the Klamath River (PacifiCorp 2004). During snorkel and bank surveys on 30 April 2003, 56 redds were counted between RK 354 and 356 of the Bypass Reach. This was considered a minimum estimate of the total number of redds, because turbidity limited observations to the stream margins and the survey occurred on a single day of the spawning period (PacifiCorp 2004b).

These studies suggest that redband trout in the upper Klamath River function independently from populations inhabiting Klamath Lake tributaries. Further, it appears that the operation of J.C. Boyle Dam and has led to a sharp decline in the number of adult trout migrating upstream to spawn in Spencer Creek and may also impede juvenile trout dispersal from Spencer Creek to downriver sections of the Klamath River. Finally, the importance of spawning habitat in the main stem river and Shovel Creek is unclear. From 2003 to 2005, we used radio telemetry and half-duplex passive integrated transponder (PIT) technology to gain a better understanding of the movement of adult redband trout populations in the Keno, Bypass and Peaking reaches and juvenile dispersal from Spencer Creek.

Methods

To assess adult movement, large redband trout (220-501 mm fork length) were angled with flies and surgically implanted with radio transmitters (interperitoneal) or PIT tags (dorsal sinus). In the Keno Reach, fish were captured on 26-27 September and 21-22 October 2004 and 14-15 March 2005 and given radio transmitters (6 to 18-month battery life) or 23-mm half-duplex PIT tags. A total of 36 redband trout were tagged; of these, 23 received radio transmitters and 34 were given PIT tags. From September 2003 to August 2004, 7 adult redband trout were radio-tagged in the Bypass Reach and 65 were radio-tagged in the Peaking Reach.

To improve our understanding of juvenile redband trout dispersal from Spencer Creek and assess downstream passage over J.C. Boyle Dam, we radio-tagged and PIT-tagged outmigrating juvenile trout captured in a weir trap near the mouth of Spencer Creek in 2004 and 2005 and tracked their movements. Radio tagging in 2004 began near peak discharge, while tagging started a month earlier than peak discharge in 2005. Interperitoneal radio transmitters (43- to 74-d battery life, 1.1 g, Lotek, Inc.) were surgically implanted in 80 and 75 juvenile trout in 2004 and 2005, respectively, with a median fork length of 110 mm (range, 91-174 mm). Additionally, in 2005, 307 fish (range, 85-170 mm) received PIT tags (half-duplex, 23 mm). Only radio-tagged trout observed more than once after release were included in the analysis.

Radio-tagged fish were tracked via fixed telemetry stations, and mobile tracking (on foot, vehicle, and airplane). Telemetry stations were installed on J.C. Boyle Dam, the Klamath River Bypass Reach, and the powerhouse diversion canal and outlet. Antennae at each station monitored distinct non-overlapping zones and were able to determine when radio-tagged trout entered Topsy Reservoir forebay and whether they passed the dam via the juvenile bypass pipe, the fish ladder, or the powerhouse diversion canal. In 2005, a solar-powered telemetry station was installed at the upstream end of Topsy Reservoir to monitor fish movement into the first 500 m of the Keno Reach. Adult radio-tagged fish were tracked twice monthly and more frequently during the March-May peak spawning period. Radio-tagged juvenile trout were tracked at weekly or shorter intervals from 10 May through 5 July in 2004 and from 7 April through 11 July in 2005. The tracking route included the Keno Reach of the Klamath River (to Keno Dam), Spencer Creek, Topsy Reservoir, and the Klamath River Peaking Reach (to RK 344).

To monitor movements of PIT-tagged fish in 2005, PIT-tag receiver stations (Oregon RFID, Portland, Oregon) were installed at the mouth of Spencer Creek and 300 m downstream of J.C. Boyle Dam in the Bypass Reach. Telemetry stations were tested at least monthly, PIT-tag antennae were tested twice weekly, and data obtained from all receiver stations were downloaded at least every week.

Results

Adult Movement

Tagged adult redband trout from the Keno Reach of the Klamath River were strongly associated with Spencer Creek during the spawning period and returned to, or near, their tagging location in the Keno Reach after spawning. Eighteen fish were tracked throughout the spawning period or until they were observed in Spencer Creek. Through mobile radio-tracking or detection at the PIT-tag receiver station, 61% (11/18) were observed in Spencer Creek (Figure 2). Based on the first and last observations recorded at the PIT-tag receiver station of five of these fish, spawning fish spent an average of 21 d (range, 10–39 d) in Spencer Creek. Another 28% (5 of 18) were radio-tracked into Topsy Reservoir near the mouth of Spencer Creek (Figure 2).

These fish entered the reservoir near the beginning of the spawning period, before the PIT-tag receiver station was installed in Spencer Creek, and when the interval between tracking observations (26 d) was greater than the average time spent spawning in Spencer Creek. It is therefore plausible that these fish also spawned in Spencer Creek but were missed by the trackers. Only two radio-tagged fish remained in the Keno Reach during the tracking period. Of the fish that were tracked to Spencer Creek or Topsy Reservoir during the spawning period, only eight survived spawning and had functioning radio transmitters at the end of the spawning period. All eight returned to the Keno Reach; more specifically, three returned to their tagging location, four were observed within 0.3 km, and one was last observed 1.0 km away.

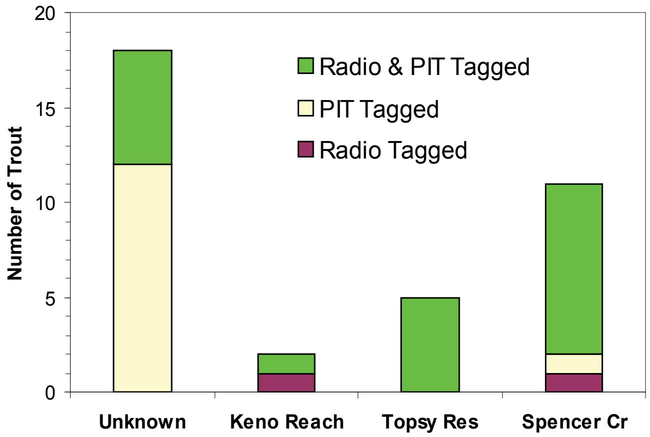

Figure 2. Location of adult redband trout during the spawning season that were radio and PIT tagged. All fish were captured in the Keno Reach during the fall of 2004 and early spring of 2005.

Fish tagged in the Bypass and Peaking reaches experienced unusually high rates of mortality and tag ejection. In the Bypass Reach, only two fish were tracked through the spawning period or to known spawning areas. Both moved downstream about 2.4 km to known spawning areas in the lower Bypass Reach. Two radio-tagged trout from the upper Bypass Reach (RK 354.4) showed upstream movement in fall; both fish were recorded at a fixed telemetry station 150 m below the J.C. Boyle fish ladder (RK 356.8) in early October and both fish appeared to be preyed upon before entering the fish ladder. One transmitter was recovered in November on the river bank next to a narrow (4-5 m wide) bedrock and boulder shelf that fish must ascend to access the J.C. Boyle fish ladder. The other transmitter was found on Topsy Reservoir shore (RK 360) and was not recorded by either of the two fixed telemetry stations monitoring the fish ladder.

In the Peaking Reach, 27 radio-tagged trout were tracked throughout the spawning period or to known spawning areas (Table 1). Eighteen fish remained in mid Peaking Reach (RK 333-352) during the spawning period and were not observed near known spawning areas. One Peaking Reach fish (tagged at RK 344) moved 9.6 km upstream to a lower Bypass Reach spawning area (RK 352) on 20 June, and two others moved 5.6 and 8.0 km upstream near the J.C. Boyle powerhouse tailrace but did not move into the Bypass Reach. Tagged trout were also strongly associated with Shovel

Table 1. Radio-tagged trout (>200 mm fork length) locations during the spawning period. All fish were tagged in the mid-Peaking Reach (RK 343-346) and tracked at least once per week.

Location	River Kilometer	Trout (N)
Copco Reservoir	320	2
Shovel Creek Mouth	330	3
Shovel Creek	330	3
Lower Peaking Reach	333-339	9
Mid Peaking Reach	340-347	7
Upper Peaking Reach	348-352	2
Bypass Reach	>352	1

Creek during the spawning period; three were tracked into Shovel Creek between 9 April and 10 June. Three others were suspected of spawning in Shovel Creek because they were tracked near the mouth of Shovel Creek in early April, were not observed during April and May, and then were subsequently relocated upstream in mid Peaking Reach. Two others were tracked downstream into Copco Reservoir and may have also spawned in Shovel Creek.

Movement of Juveniles

In 2004, no radio-tagged juvenile trout from Spencer Creek moved to the Klamath River below J.C. Boyle Dam. By mid July, when all transmitter batteries had expired, 71% of radio-tagged trout remained in lower Spencer Creek and 25% in Topsy Reservoir (Figure 3). Summer growth and survival of juvenile redband trout in lower Spencer Creek and Topsy Reservoir is unknown; however, past studies have shown that the reservoir does not stratify with water temperatures >25° C and low dissolved oxygen in summer that are stressful to redband trout (http://www.pacificorp.com/File/File16144.pdf). Further, the reservoir contains a high abundance of nonnative fishes relative to redband trout (Desjardins and Markle. 1999) and reservoir water levels fluctuate daily for peak electricity production.

These conditions suggest that summer residence in the reservoir and lower Spencer Creek may adversely affect juvenile trout growth and survival. Only 11% of radio-tagged trout were observed in the upper reservoir or in the Keno Reach. It should be noted, however, that tracking methods used in 2004 may have missed fish that moved upstream into the Keno Reach.

Although a substantial proportion (69%) of radio-tagged trout remained in lower Spencer Creek and Topsy Reservoir in 2005, more fish moved upstream toward the Keno Reach after exiting Spencer Creek and recruitment downstream of J.C. Boyle Dam was observed.

By mid-July 2005, 34% of radio-tagged trout remained in lower Spencer Creek, 31% were found in upper Topsy Reservoir or in the Keno Reach, and 17% were observed downstream of the dam (Figure 3). Telemetry receiver stations detected one fish moving downstream via the fish ladder, at least four through the fish bypass facility, two via the power diversion canal, and four may have passed over the dam through the spillway during peak discharge in May.

Differences in juvenile dispersal between 2004 and 2005 seemed to be related to the dramatic differences in Klamath River discharge and operation of J.C. Boyle Dam. In 2005, mean daily discharge was above 85 m^3/sec for most of May and peaked at 127 m^3/sec. These high flows caused dam operators to open the spillway for 2 weeks in May and a week in June, increasing discharge

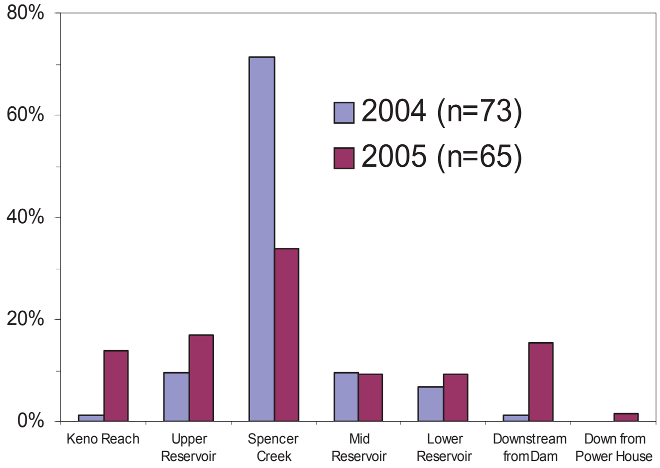

Figure 3. Location of juvenile redband trout, captured and radio-tagged on Spencer Creek, on the final tracking observation in 2004 and 2005.

in the Bypass Reach from 4 m^3/sec to almost 57 m3/sec. Over 70% of the downstream passage of juvenile trout over the dam occurred when the dam spillway was open. In 2004, peak discharge of the Klamath River only reached 57 m^3/sec and the spillway was not opened during the study period. These results suggest that inter-annual variability in discharge and dam operation affect juvenile fish passage over J.C. Boyle Dam and recruitment to the Bypass Reach of the Klamath River.

Dam operators generally do not spill water at J.C. Boyle Dam until Klamath River discharge exceeds 85 m^3/sec. Over the past 25 years, the Klamath River exceeded this threshold a median of 4.5 d per year (range, 0-61 d), and in 12 of these years flow did not exceed 85 m^3/sec. During the years when J.C. Boyle Dam does not spill water, juvenile trout recruitment from Spencer Creek to the Klamath River Bypass Reach may be reduced or completely prevented. Recruitment to the Bypass Reach is further reduced by fish entrainment in the powerhouse diversion canal. In 2005, 18% of radio-tagged juvenile trout that passed downstream over J.C. Boyle Dam were entrained in the powerhouse canal. One of these fish shed its tag in the tailrace of the J.C. Boyle Powerhouse. The intake for the powerhouse canal is screened to prevent fish entrainment, but based on the above observations and annual salvage efforts by PacifiCorp, the screen has not effectively excluded fish.

In 2005, movement of PIT-tagged and radio-tagged fish in Spencer Creek was similar, suggesting that radio tagging did not adversely affect behavior relative to PIT tagging. At least 60% of the PIT-tagged trout and 65% of the radio-tagged fish outmigrated from Spencer Creek. Of the PIT-tagged fish that outmigrated, over 50% exited 1 d after release, and 80% left within 1 week. About 65% of the outmigrating radio-tagged trout left within a week of release. It was not possible to compare PIT-tag and radio-tag results for the Bypass Reach, because the PIT-tag antenna was disabled on two occasions when the J.C. Boyle spillway was opened during high flows in May and June.

Discussion

The physical and ecological environment of redband trout in the Upper Klamath River has been altered by dam construction and operation. These alterations have also affected redband trout life history and abundance. Recent and past studies of redband trout in this region provide important information on the current status and life history of redband trout, and highlight impacts since dams were constructed, that may aid in managing for long-term sustainability of these populations.

Reasons for the lack of connectivity among Upper Klamath River redband trout and redband trout inhabiting the Upper Klamath Lake basin are unclear. Passage may be impaired because of restrictions associated with the design of the fish ladders of Link River and Keno dams; however, prior to the construction of Link River Dam, a natural falls existed at the outlet of Upper Klamath Lake (Hamilton et al. 2005). The degree this falls influenced connectivity among these trout populations is unknown, but recent analysis shows Upper Klamath River redband trout to be genetically distinct from populations collected from lake tributaries (Pearse 2007).

Spencer Creek is the only known spawning area and source of juvenile recruitment in the upper Klamath River basin upstream of J.C. Boyle Dam. Historically, these fish had diverse life histories. Prior to the construction of Copco Dam in 1918, Spencer Creek likely served as a spawning site for steelhead Oncorhynchus mykiss as well as resident redband trout (Hamilton et al. 2005). In 1959, the year after J.C. Boyle Dam was completed, adult redband trout migrated from what are now known as the Peaking Reach and Bypass Reach of the Klamath River in large numbers to spawn in Spencer Creek and then returned to these reaches after spawning (Gerlach and Hanel 1964). Currently, the upstream migratory life history of the Peaking Reach population appears lost and the upstream migratory life history of the Bypass Reach population has been reduced to less than 10% of historical abundance and is composed of significantly smaller trout.

Adult redband trout from the Bypass Reach are now more strongly associated with spawning areas in the lower Bypass Reach and possibly locations in the Peaking Reach. Adult trout from the upper Peaking Reach downstream to near Copco Reservoir are strongly associated with Shovel Creek during the spawning period, and the upper Peaking Reach contributes some fish to the spawning population in the lower Bypass Reach.

From 1988 to 1991, the observed numbers of adult redband trout that entered Spencer Creek were clearly larger than the estimated numbers that passed J.C. Boyle Dam in recent years. The Keno Reach of the Klamath River, in particular, appears to be the primary source of spawning adults for Spencer Creek. Substantial proportions of Keno Reach adults spend at least part of winter in Keno or Topsy reservoirs and generally return to the Keno Reach shortly after spawning in Spencer Creek. Juvenile recruitment from Spencer Creek to the Keno Reach and the upstream end of Topsy Reservoir occurs in both low and high discharge years.

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Scale Analysis and Movement of Stream Resident and Coaster Brook Trout in the Hurricane River, Michigan

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Abstract

The purpose of this study was to describe the length at age of brook trout, *Salvelinus fontinalis* from the Hurricane and Mosquito rivers in Pictured Rocks National Lakeshore (PRNL), Michigan, and the movement characteristics of passive integrated transponder (PIT) tagged brook trout in the Hurricane River to evaluate the age structure of coaster brook trout. Four groups of brook trout scales were compared with those of brook trout from the Hurricane River below Hurricane Falls. These four groups were wild fish from the Hurricane River above Hurricane Falls, from the Mosquito River below Mosquito Falls, from above Mosquito Falls, and stocked fish from the Mosquito River above Mosquito Falls. Hurricane River fish below the falls differed from wild Mosquito River fish above the falls at age 1 ($Z= -5.188$; $p< 0.001$) and stocked fish above Mosquito Falls at age 2 ($Z= -3.332$; $p< 0.01$). From April 2004 to July 2007, most movement of Hurricane River brook trout into Lake Superior took place in the fall with the highest frequency of movement in October. Sampling through the fall of 2007 and future analysis of the physical characteristics of these fish will help determine what makes a stream resident different from a coaster in the Hurricane River and the age when movement to Lake Superior typically occurs.

Introduction

Lake Superior once hosted a unique, popular recreational fishery for brook trout *Salvelinus fontinalis*. These fish were called "coasters", because they were typically caught near the Lake Superior coastline and were differentiated from the brook trout caught in streams. Coaster brook trout were known for being easy to catch and exceptionally large, compared to stream resident brook trout. Today there is functionally no fishery for coasters, but widespread interest in restoring it exists. The coaster brook trout project described herein is underway on the south shore of Lake Superior in Pictured Rocks National Lakeshore (PRNL), Alger County, Michigan.

The Lake Superior watershed contains fluvial, lacustrine, and adfluvial populations of brook trout (Huckins et al. In Press). Fluvial fish are often called stream resident brook trout, because they live in tributary streams (and beaver impoundments) and presumably do not enter Lake Superior. The lacustrine fish stay within the lake their entire lives, while adfluvial fish grow in the lake and spawn in tributaries. Because lacustrine and adfluvial fish spend part or all of their lives in Lake Superior, they are called "coasters". Coasters were historically found in many of Lake Superior's north and south shore streams, including tributary streams within what is now Michigan's PRNL. Today, the coaster population is thought to be small with the Salmon Trout River on the south shore, the waters around Isle Royale National Park, and the Nipigon River system containing coasters (Wiland 2006). There are many hypotheses behind the reduction in coaster numbers, but some combination of overfishing, habitat degradation, and introduction of nonnative species may have played a role.

Recently, new length and bag limit restrictions have been set in Lake Superior and some of its tributaries to specifically protect coaster brook trout (Lockwood et al. 2001; Huckins et al. In Press). In Michigan, these regulations include a 51-cm minimum length limit and a one-fish daily possession limit in Lake Superior (Michigan DNR 2006a) and a 46-cm minimum length limit and a one-fish daily possession limit in select Lake Superior tributaries, where coaster research is currently underway (Michigan DNR 2006b). Coaster brook trout are subject to the recreational fisheries in Lake Superior because of their common use of near shore, shallow habitat (Newman et al. 1999).

Today, states, Canadian provinces, tribes, universities, government agencies, and nonprofit groups are working together to study the status of coaster brook trout, and options for their restoration in Lake Superior (Wiland 2006). One project pertaining to coaster restoration is currently under way in PRNL. The three streams involved in this project are Seven Mile Creek, Mosquito River, and Hurricane River. Each of these rivers was stocked with coaster strain brook trout from 2000 to 2005 as part of the restoration; subsequently, wild brook trout have been documented moving into Lake Superior. To monitor the restoration effort, stationary Passive Integrated Transponder (PIT) antenna systems were installed near the mouth of each stream and both wild and stocked brook trout were implanted with PIT tags.

Work by previous graduate students in these streams has led to a greater understanding of their movement (Stimmell 2006) and physiology (Sreenivasan 2005). To date, no study has been directed at the age and growth structure of the PRNL coasters. The present study will help to determine the age of fish moving to Lake Superior from the Hurricane River and if fish in the Hurricane River below Hurricane Falls grow at a different rate than their counterparts in the two other PRNL streams.

Methods

Hurricane River is a second order stream located in the eastern portion of PRNL, Alger County, Michigan. The study reach for this project extends from the mouth of the river at Lake Superior upstream about 135 m to Hurricane Falls. Sampling occurred at least bi-weekly from September to December 2006 and May to August 2007. Additional sampling for this project will continue bi-weekly until December 2007. A sampling event consists of electrofishing upstream from the river mouth to Hurricane Falls. The stream is divided into two sampling units, each about 67 m long. The lower unit extends from the river mouth to the stationary PIT system located underneath the bridge for Lakeshore Trail. The upper unit begins on the upstream side of the bridge and ends at the base of the falls. Each unit is electrofished separately, and the fish are released back into the unit from which they were captured.

After capture, brook trout were weighed (g) and measured (mm). All brook trout ≥ 100 mm long were scanned for a PIT tag and sexed if possible (i.e., presence of a kype, eggs, milt). If not already present, a 23-mm tag was surgically implanted into the body cavity, and both a lower caudal clip and scale sample were taken. The lower caudal clip will serve as a means to conduct genetic analysis of PRNL brook trout at a later date. The caudal fin is clipped because it is capable of regrowth, results in a small percentage of fin area being removed, and was not used as a clip for stocked fish. Scale samples were taken from the left side of the fish between the lateral line and the dorsal fin (Bishop 1955; Alvord 1956; Pfeifer 2005). The scales were wet mounted between two microscope slides (Allen 1956; Hatch 1961; Wilson et al. 2003). Scales from fish ≥100 mm long were sampled from the Hurricane River during November and December 2006 and May to August 2007. Scale samples were removed from brook trout <100 mm long during August 2007. Fish < 100 mm long are too small to be PIT tagged and to prevent sampling the same fish multiple times, an upper caudal clip was taken. August was chosen as the time to begin collecting scales from these smaller fish, because most young-of-the-year brook trout have developed scales by this time (Cooper 1951). Brook trout from the Mosquito River below Mosquito Falls and the Hurricane River above Hurricane Falls were captured, tagged, and sampled for scales as described for the Hurricane River from June to August 2007 as part of normal seasonal sampling. Brook trout < 100 mm long from these streams were scale sampled on one trip in August. In addition, scale samples from both stocked (known age) and wild fish from the Mosquito River above Mosquito Falls during May to December 2003 and May to December

2004 were used in age-at-length analysis. Brook trout captured from above Mosquito and Hurricane Falls are considered to be stream residents that never enter Lake Superior. Those fish captured below the falls on either stream may be either stream residents or coasters.

A microfiche reader was used to examine mounted scales. The number of annuli was read on up to five scales (depending on the number available) from each sample. The age assigned to the fish was based on the number of annuli most frequently counted on the sample of scales.

To test the accuracy of scale reading, scales from both stocked and wild fish were read. After reading was finished, the stocked fish were separated from the wild fish and the known age of the stocked fish compared to the estimated scale age. Reader accuracy for the known-age stocked group was 75%.

Movement data for brook trout were collected by the stationary PIT antenna located on the Hurricane River. Brook trout were deemed to have moved lakeward, if they were recorded passing through the antenna after being captured upstream and they were not recaptured after the last antenna recording. These fish presumably went to Lake Superior. Fish that moved to the lake were organized by the month and calendar season during which they moved. Antenna data were available from April 2004 to July 2007. Fish that were not last detected on the stationary antenna were grouped separately from coasters. These fish could have been residents that never left the Hurricane River, or could have left, but were not detected by the antenna, lost their tag, or experienced either natural or fishing mortality.

Movement data were sorted by month as well as calendar season for analysis. Spring was considered March 20th to June 20th, summer was June 21st to September 22nd, fall wasSeptember 23rd to December 20th, and winter was December 21st to March 19th.

Kruskal-Wallace and Mann-Whitney U comparisons were used to test for significance between mean lengths. The Bonferroni method was used as a *post-hoc* test for significant Mann-Whitney U results.

Results

The following results describe the length-at-age data collected thus far for the various brook trout groups sampled, scale age accuracy of a stocked group, and movement of brook trout in the Hurricane River from April 2004 through July 2007.

Scale Aging

Two hundred and fifty-seven brook trout scales were aged from the five stream groups (Table 1). Brook trout from the Hurricane River below the falls had a mean length at age 1 in the middle of the four other groups and had the smallest mean length at age 2. These fish were significantly smaller than wild Mosquito River fish above the falls at age 1 ($Z= -5.188$; $p< 0.001$) and stocked Tobin Harbor strain fish above Mosquito Falls at age 2 ($Z= -3.332$; $p< 0.01$). There was no significant difference in length at age 1 or age 2 between brook trout from the Hurricane River below the falls and those above the falls. At age 1, there tended to be a narrower grouping of points around the median than at age 2. In addition, all

Table 1. Sample size and mean length ±1SE for brook trout at age 1 and age 2 based on scale samples.

Group	N		Mean Length (mm)	
	Age 1	Age 2	Age 1	Age 2
Hurricane River	47	6	122 ± 2.72	152 ± 5.27
Hurricane River above falls	39	14	119 ± 2.17	175 ± 9.99
Mosquito River	23	5	119 ± 2.35	169 ± 16.32
Mosquito River above falls	45	31	151 ± 3.82	165 ± 6.54
Stocked above Mosquito Falls[1]	17	30	141 ± 8.13	218 ± 8.91

[1] *Stocked in fall 2002 and sampled in 2003 and 2004, these fish are of known age.*

groups exhibited overlap in length between the two ages and at least one outlier for each age.

From age 1 to age 2, Tobin Harbor strain brook trout stocked above Mosquito Falls had the greatest percent increase in length (55%), while wild brook trout from above Mosquito Falls had the smallest (9%). Wild brook trout from above Hurricane Falls (47%) and below Mosquito Falls (42%) were near the high end of these extremes. Wild brook trout from below Hurricane Falls (25%) had the second lowest percent increase in length from age 1 to age 2.

Brook Trout Movement

Brook trout in the Hurricane River below Hurricane Falls moved into Lake Superior from March to November (Figure 1). Frequency of movement of fish was highest in October followed by June. When grouped by calendar season, fall had the highest frequency of movement to the lake and winter none (Figure 2). There was no significant difference in length at time of tagging between fish that were detected moving and those that were not.

Discussion

Tobin Harbor strain brook trout were stocked above Mosquito Falls in 2002, and thus, of known age when sampled. Reader accuracy for these fish was 75%. Most errors were due to overestimation of age. This was due to false annuli or "checks" on the scales that may have occurred as a result of a temperature change when the fish were stocked (Hatch 1961). The actual age of the stocked group was used in statistical analysis.

Both the stocked and wild brook trout from the Mosquito River above the falls were sampled throughout spring, summer, and fall. The lower Hurricane River groups above and below the falls were sampled from spring through summer. The lower Mosquito River group was sampled once in late spring. Because the Hurricane River groups and the lower Mosquito River group were sampled during a limited time, it is possible that the data from these three groups are skewed toward slightly smaller fish. At the conclusion of this study, samples from all groups will have been taken throughout the three seasons, thereby accounting for length differences during different times of the year.

Brook trout from below Hurricane Falls had a mean length in the middle of the four other groups at age 1. Despite this, they tended to be smaller than the other groups at age 2. Stimmell (2006) found that proportionally more tagged fish in the Hurricane River moved to Lake Superior than did those in the Mosquito River. Their small size and limited length increase from age 1 to age 2 in addition to the restricted habitat present

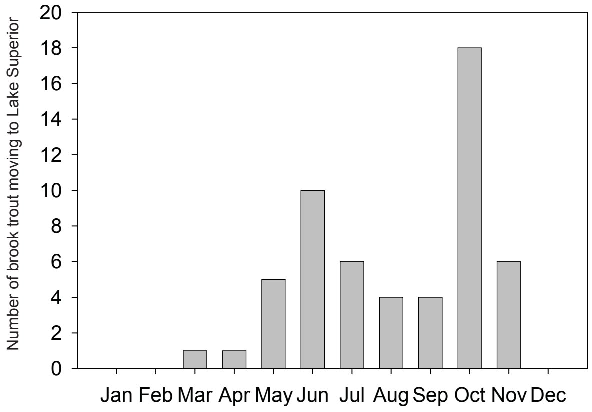

Figure 1. Distribution of brook trout tagged in the Hurricane River below Hurricane Falls and moving into the lake, 2004 to July 2007.

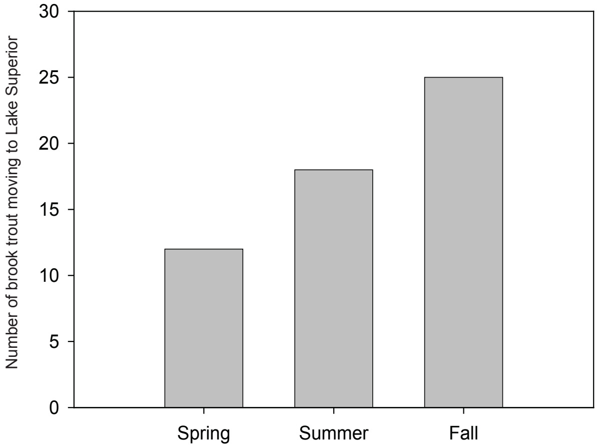

Figure 2. The number of tagged brook trout from the Hurricane River that moved into the lake during each season 2004 to 2007

below Hurricane Falls suggests that food resource availability may be an issue for these fish.

Movement to the lake of Hurricane River tagged brook trout was greater during the fall than in spring or summer. Greater movement during these time periods is typical for migratory brook trout (Smith and Saunders 1958; Curry et al. 2002; Lenormand et al. 2004). Brook trout moving to Lake Superior during the spring are likely young fish doing so for the first time. Those moving in the fall may be older, sexually mature fish that are looking for a location to spawn or have already spawned in the river. After scale collection in fall 2007, we will be able to statistically compare the age of fish entering Lake Superior from the Hurricane River during different seasons.

Throughout the fall, additional scale samples will be collected from brook trout in the Hurricane and Mosquito rivers, as well as Sevenmile Creek (which was excluded from analysis due to small sample size). Future samples will include all brook trout ≥ 50 mm long to help develop a better understanding of the age structure within these streams and differences in growth. By using linear regression we will be able to assign ages to brook trout tagged in the past and determine the age when Hurricane River brook trout typically enter the lake.

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Evaluation of a Brook Trout Removal Project to Establish Westslope Cutthroat Trout in Canmore Creek, Alberta

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Abstract

Electrofishing and trapping were used to remove nonnative brook trout *Salvelinus fontinalis* from Canmore Creek, Alberta, to facilitate establishment of native westslope cutthroat trout *Oncorhynchus clarkii lewisi* in a 1.6-km section of stream above impassable falls. Over the period 1997–2002, a total of 8,106 brook trout were removed; 74% of the total was removed in the first 2 years. Sample methods were highly size selective, with young-of–the-year (YOY) accounting for 82% of the total catch by trapping and 41% by electrofishing. Electrofishing conducted after cessation of the removal program confirmed that brook trout were still abundant in the stream, with over 330 brook trout/km present in 2006. Although a total of 10,000 YOY cutthroat trout have been stocked since fall 1998, cutthroat trout accounted for less than 2% of the electrofishing catch in 2004 and 2006. Despite the small scale of the project and the extensive effort to remove brook trout, the establishment of a cutthroat trout population in Canmore Creek was unsuccessful. We suggest that the project could likely have succeeded if the effort expended removing YOY had been focused on mature brook trout and if efforts had been made at the outset to eliminate, or prevent immigration of, brook trout from a nearby pond.

Introduction

Brook trout *Salvelinus fontinalis*, although not native to Alberta, are present in many montane and foothills waters as a result of extensive stocking. In southern Alberta, brook trout populations have generally increased while native westslope cutthroat trout *Oncorhynchus clarkii lewisi* and bull trout *Salvelinus confluentus* populations have declined. Attempts to conserve and restore native salmonids often require removing or reducing nonnative species. Methods to reduce or eliminate nonnative trout populations have involved electrofishing, chemical treatment, angling, or a combination of methods (Larson et al. 1986; Kulp and Moore 2000; Meyer et al. 2006; Earle et al. 2007a,b). Total or near total removal of nonnative fish appears to be only occasionally accomplished, but is most successful in small, simple streams that do not have dense riparian vegetation or much in-stream woody debris (Kulp and Moore 2000; Shepard et al. 2002; Shepard and Nelson 2004). Even so, some level of success requires enormous effort (Thompson and Rahel 1996; Shepard et al. 2002; Shepard and Nelson 2004).

Canmore Creek is a small, relatively simple stream in the Canadian Rocky Mountains with a resident population of nonnative brook trout. Our objectives in this study were to assess if (1) repeated electrofishing and trapping successfully removed or sufficiently reduced brook trout from Canmore Creek; and (2) stocking westslope cutthroat trout following brook trout removal efforts resulted in the successful establishment of this native species in the stream.

Project Background

In 1996, TransAlta Utilities Corporation (TransAlta) funded a study to assess the feasibility of establishing cutthroat trout in Canmore Creek. It was presupposed that cutthroat trout were originally present in the stream and had been displaced by illegally introduced brook trout, although reports regarding the historical presence of cutthroat trout were purely anecdotal. The feasibility study concluded that temperature and habitat conditions were not limiting factors to the introduction of cutthroat trout, but recommended that brook trout be eliminated or reduced prior to stocking (Golder 1997). Following up on these recommendations, TransAlta initiated work between 1997 and 2002 to remove brook trout and enhance habitat in Canmore Creek above the upper falls.

Study Area

Canmore Creek is located 1 km west of the town of Canmore, Alberta (Figure 1). The stream is approximately 3.5 km in length and flows from the Rundle Canal to the confluence with the Bow River. Rundle Canal is a 30-ha reservoir that stores water for hydroelectric generation at the TransAlta Rundle Plant. The majority of the stream flow comes from springs seeping through the canal berm and the stream originates from a culvert at the base of the berm. Canmore Creek also receives surface runoff from adjacent low-lying areas and from a number of groundwater springs located along the stream's length.

Stream flows in Canmore Creek are very consistent throughout the year. Discharge averaged 0.23 m^3/s in winter and early spring and 0.26 m^3/s during the summer and early fall (1982–1991; Golder 1997). Temperatures were recorded in the upper reach every 12 min with a thermograph between July and September 1996 and ranged from a daily mean of 9°C during early July to 13°C in late August and early September (Golder 1997).

A spillway canal is located south of the stream and only flows back into Canmore Creek in emergency situations when water is spilled from the Rundle Canal. Approximately 1.0 km downstream from its source, an unnamed tributary enters Canmore Creek via a man-made pond, locally known as Dog Lake. This pond was illegally stocked with brook trout and during high water events, a flowing connection between the pond and

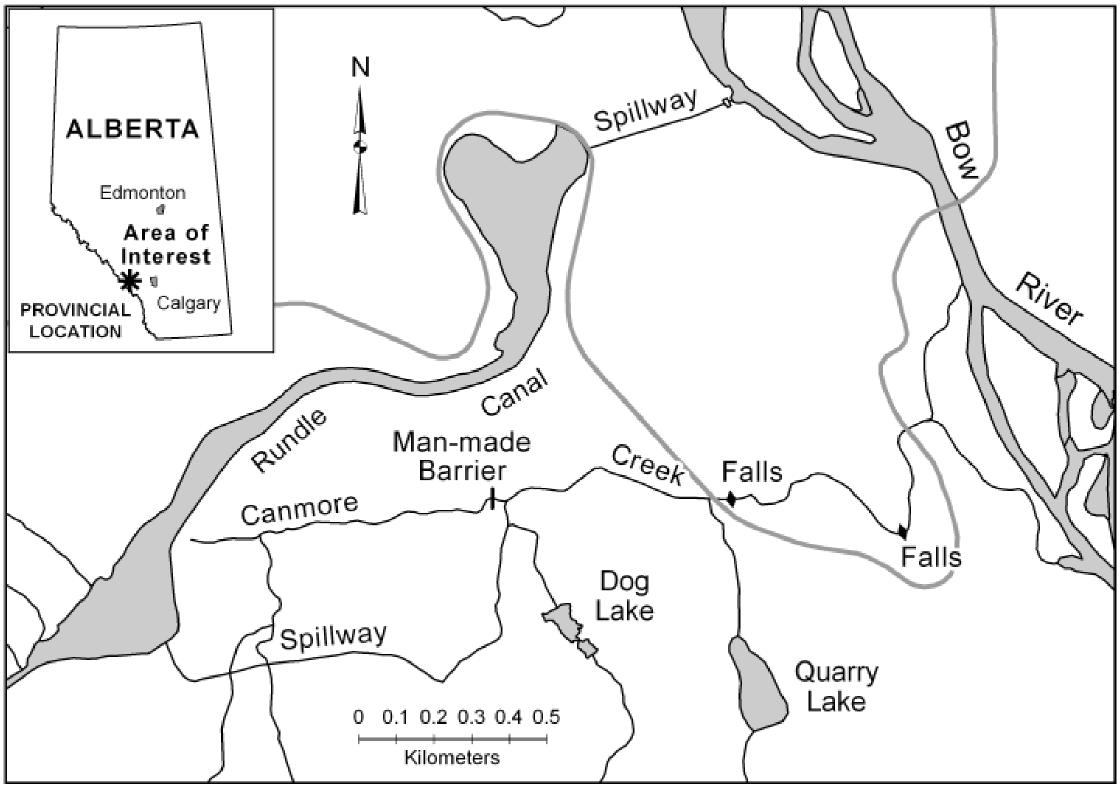

Figure 1. Map of Canmore Creek, Alberta, showing the Rundle Canal, spillways and fish passage barriers.

Canmore Creek exists. To prevent brook trout from accessing the upper 1.0 km of stream, a man-made barrier was constructed in 1997 prior to the first stocking of cutthroat trout. The barrier was originally 0.6 m high and was constructed of large rock placed in a v-weir design (BVHD 1997a). In 2002, the barrier was modified to a height of 1 m (BVHD 2002a).

The specific study area for this project is that section of stream from the source to the Spray Lakes Road, a distance of 1.6 km. An impassable waterfall is located immediately downstream of the road, thereby isolating the upper portion of the stream. The stream originates at an elevation of 1,400 m and the channel gradient of the upper 1.6 km is approximately 2.5% (Golder 1997). The wetted widths in the upper 1.6 km range between 2 and 4 m. Overhanging vegetation is common, but large woody debris in the channel is limited.

Methods

Brook trout were removed using a combination of backpack electrofishing and trapping. Electrofishing removals were conducted in May, July, September, and October 1997, and again in May 1998. Electrofishing started at the upper waterfall and proceeded upstream. Sections of the stream were blocked off with small-mesh nets and the fish between the nets were removed. Two passes with the electrofisher were completed at each section during all surveys in 1997 and 1998, with the exception of May 1997. The density and biomass were reported using the results from the first pass. For purposes of comparison to electrofishing data collected after 1998, the density and biomass were standardized to number of fish/km and kg/km.

Traps, constructed from 2-L plastic drink bottles, were designed by Bow Valley Habitat Development (BVHD) (1997b), primarily to capture small (<130 mm long) fish. The traps were primarily set along stream margins in areas of low velocity. In 1997, traps were set starting at the stream's source and continuing downstream in 300-m sections for 1,600 m of main stem and 700 m of tributary springs. In 1998, a 600-m reach from the upper falls to the constructed barrier and a 100-m section above the barrier were sampled. In 2000, 1,600 m of main stem and 700 m of springs were sampled. In 2002, the upper 1,075 m of stream above the fish barrier was sampled.

Lengths (fork length) and weights were collected from fish captured during electrofishing, while lengths only were collected from fish caught in the traps. On occasion, for both electrofishing and trapping data, a range of lengths was provided for a subset of fish. In these cases, the proportions of fish in these 5-mm length bins were determined from a length-frequency histogram of fish measured during that sampling event. From the proportion, a total number of fish was assigned to each length bin using the mid-point length of that bin. Where weight data were missing, weights were derived using length-class-specific condition factors from fish captured during previous sampling events. Weights were not generally taken for fish ≤70 mm long and were extrapolated using the length and a condition factor of one.

Stocking of native cutthroat trout young-of-the-year (YOY) commenced in 1998 (600 fish) and continued in 2000 (1,300 fish), 2002, 2004, and 2006 (2,700 fish each time). The cutthroat trout (total of 10,000 fish) were stocked in early to mid-September in several locations above the uppermost waterfall.

Following the last of the removal sessions in 2002, Alberta Fish and Wildlife electrofished Canmore Creek to assess the species composition and evaluate the success of stocking cutthroat trout. One-pass electrofishing was conducted in August 2002 in a 200-m section located above the man-made barrier and in April 2006 in a 300-m section just upstream of the Spray Lakes road crossing. In July 2004, a four-pass removal-depletion population estimate was conducted over a 300-m section just above the man-made barrier; block nets were used to isolate the sampled area. The population estimate, 95% confidence intervals, and capture probability for each species was estimated with the maximum likelihood model using the software MicroFish (Van Deventer and Platts 1989). For the 2004 data, density of fish (number/km) was calculated using the data from the first pass of the population estimate.

Results

Electrofishing and Trapping Removal of Brook Trout

Over the period 1997–2002, a total of 8,106 brook trout were removed; 74% of the total was removed in the first 2 years. Electrofishing in 1997 and 1998 resulted in the removal of 2,507 brook trout, 59% of which were fish >70 mm fork length (Table 1). A large percentage of the July 1997 catch consisted of YOY brook trout (Figure 2), but fish up to 265 mm long were caught. Reductions were observed in the number and length of brook trout from the start to the end of the electrofishing

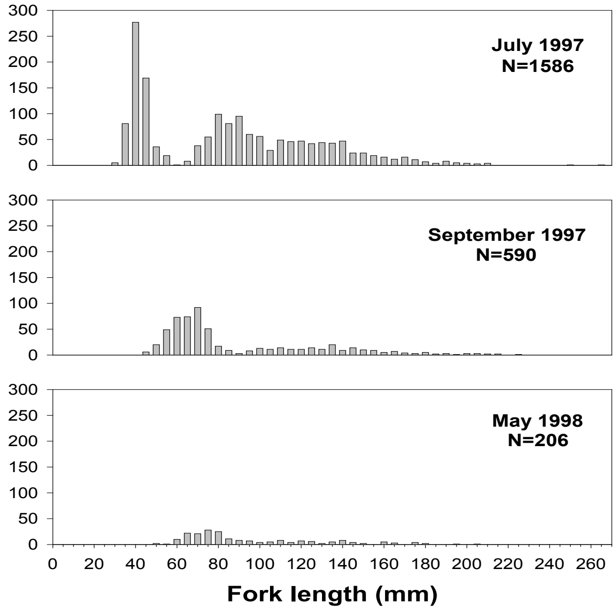

Figure 2. Length frequencies for brook trout captured by electrofishing during the removal program.

Table 1. Total number of brook trout (BKTR) and cutthroat trout (CTTR) and number per kilometer captured by trapping and electrofishing in upper Canmore Creek, 1997 to 2006.

Year	Month	Distance sampled (m)	BKTR ≤70	BKTR >70	BKTR All	CTTR ≤70	CTTR >70	CTTR All	Number/km[1] BKTR	Number/km[1] CTTR
						Electrofishing				
1997	May	500	26	99	125				182[2]	
	July	1760	634	952	1,586				525	
	Sept	1600	314	276	590				234	
1998	May	1600	56	150	206				84	
2002	Aug	200			[3]		20[4]	20[4]	[3]	100
2004	July	300		110	110[5]		2	2	163	7
2006	April	300	3	98	101		1	1	337	3
Subtotal			**1,033**	**1,685**	**2,718**		**23**	**23**		
						Trapping[6]				
1997	July–Oct	1600	2,833	298	3,131				1,705	
1998	July	700	214	125	339				484	
2000	Aug	1600	1,266	336	1,602		2	2	876	1
2002	May–June	1075	289	238	527		17	17	464	14
Subtotal			**4,602**	**997**	**5,599**		**19**	**19**		
Grand Total			**5,635**	**2,682**	**8,317**		**35[7]**	**35[7]**		

[1] Where more than one electrofishing pass was conducted (i.e., July and Sept 1997, May 1998, and July 2004), only fish caught in the first pass were used in the calculation.

[2] Does not include 34 fish for which no reach length information was provided; these fish are, however, included in the total number.

[3] Brook trout were caught but not enumerated.

[4] Includes seven fin clipped cutthroat trout that were previously captured by trapping in 2002.

[5] Includes all fish captured during four passes of population estimate.

[6] All fish captured in the springs are included in the total number but not in the number/km. Distances represent mainstem sampling only.

[7] Does not include seven cutthroat trout recaptured during electrofishing in 2002 that were previously captured by trapping in 2002.

removals. From July 1997 to May 1998, mean length declined slightly (from 112 mm to 104 mm) while the number of brook trout captured declined considerably (Table 1). The trapping component of the program resulted in the removal of 5,599 brook trout, most (82%) of which were YOY fish. Due to the size (20 mm) of the opening on the traps, capture was primarily limited to brook trout <130 mm in length, although fish as long as 211 mm were caught.

Brook trout density appears to have been greatly reduced following the removal of over 7,500 brook trout during the 1997–2000 period, as fewer brook trout were captured by trapping in 2002 (Table 1). However, at least 460 brook trout/km were in the upper portion of Canmore Creek prior to trapping in 2002.

In 2000 and 2002, a small number of cutthroat trout were also captured in the traps (Table 1). In 2000, their lengths were 150 and 170 mm; in 2002, they ranged between 100 and 130 mm long. Because cutthroat trout were stocked starting in 1998, the fish caught in 2000 would have been from the first stocking event, while the size of the fish caught in 2002 suggests that they were likely stocked in 2000. All cutthroat trout were captured above the man-made barrier, in the upper 1 km of stream.

In total, approximately 48 kg of brook trout were removed over the 1997–2002 period. Electrofishing accounted for 30 kg of the total and almost 60% of this amount was removed during the July 1997 sample period. Trapping accounted for 18 kg of brook trout with the highest amount also removed during the initial effort in July 1997. Electrofishing reduced the one-pass electrofishing biomass of brook trout from 6 kg/km in July 1997 to 1 kg/km by May 1998. In comparison, cutthroat trout biomass was very low (<0.4 kg/km) in both 2000 and 2002.

Post-Removal Program Electrofishing

Electrofishing conducted after the removal program ended in June 2002 confirmed that brook trout were still abundant in the stream, with over 330 brook trout/km present during the most recent sampling in 2006 (Table 1). Although the densities in 2004 and 2006 were lower than those encountered during the intensive electrofishing removal session in July 1997, they were comparable to or higher than those encountered in September 1997 and May 1998. Brook trout biomass increased from 3 kg/km in 2004 to at least 10 kg/km in 2006.

The removal-depletion population estimate conducted in 2004 resulted in estimates of 114 (100–129; 95% CI) brook trout in the 71–150 mm size range and 10 (10–11; 95% CI) brook trout >150 mm over the 300-m section. Based on the population estimate data, capture probability was 0.4 for the brook trout 71–150 mm long and 0.7 for brook trout >150 mm. The estimate for the smaller size class is similar to the number of brook trout captured over the same distance in 2006 (i.e., 101 brook trout in 300 m).

To obtain an approximate estimate of the number of brook trout remaining in the stream as of 2004, the population estimate data and capture probability were used to extrapolate the number in each size class. Since the population estimate was conducted above the man-made barrier, the extrapolation is limited to this area. For the smaller size class (71–150 mm) this resulted in an estimate of 943 (827–1070) brook trout in the upper 1.0 km of stream. For brook trout >150 mm long, it was estimated that 50 (50–55) fish remained.

Despite the increase in stocking rate after 1998, cutthroat trout densities declined, based on estimates of 100 fish/km in 2002 to only 3 fish/km in 2006. The decline in cutthroat trout densities, in conjunction with an increase in brook trout densities, resulted in cutthroat trout declining from less than 2% of the electrofishing catch in 2004 to less than 1% of the catch in 2006. Similarly, cutthroat trout biomass declined from 4.5 kg/km in 2002 to 0.1 kg/km in 2006. Fork lengths of cutthroat trout caught by electrofishing in 2002 ranged from 115 to 215 mm and averaged 158 mm. The largest cutthroat trout (215 mm) was most certainly from the first stocking in 1998 and would have been a potentially mature 4-year-old fish.

Discussion

Electrofishing and trapping removal of brook trout undertaken in 4 years in Canmore Creek resulted in major reductions of brook trout initially in terms of both numbers and biomass. However, electrofishing conducted since the removal program ended, indicated that the density and biomass of brook trout had rebounded to levels equal to or exceeding those in the early stages of the removal program.

Reports prepared after the initial electrofishing and trapping efforts, suggested that the majority of the brook trout population had been removed from Canmore Creek (Golder 1998; BVHD 1999). Removal efforts greatly decreased in 1998 and this partially explained the decrease in the number of brook trout captured in that year. Although Golder (1998) recommended that the lower 200 m of upper Canmore Creek be electrofished again prior to the introduction of cutthroat trout in fall 1998, this did not occur. However, trapping resumed in 2000 and 2002, with the majority of the catch consisting of YOY brook trout (BVHD 2001, 2002b). A similar situation was encountered in White's Creek, where initial brook trout removal efforts were thought to have been successful and, as a result, extensive removal efforts were not made in subsequent years (Shepard et al. 2002). Several years after the extensive removals were ceased, numerous brook trout were captured in the study reach; the authors suggested that brook trout had either successfully re-colonized the section of creek from lower reaches or some mature brook trout evaded removal efforts and successfully reproduced.

In Canmore Creek, the continued presence of YOY brook trout in the trapping catch indicated that mature brook trout remained in the system. In an evaluation of projects to conserve westslope cutthroat trout by removing brook trout, Shepard and Nelson (2004) recommended that, while efforts should be made to eliminate as many younger brook trout as possible during the first year, the initial efforts should focus on removing reproductive adults. The authors also suggested that it requires at least six, and may take up to ten, multiple-pass electrofishing removal efforts to totally eradicate brook trout. Furthermore, they found that it was more effective to conduct repeated brook trout removal efforts within a 1- to 3-year time period, rather than to conduct annual removal efforts over five or more years. In regards to Canmore Creek, the lack of sufficiently intensive electrofishing efforts over multiple years and the reliance on a method that resulted in negligible captures of mature fish, proved to be ineffective in permanently reducing the number of brook trout in the stream.

In spite of the removal of over 8,000 brook trout, and the stocking of 10,000 YOY cutthroat trout since 1998, the evidence suggests that survival of cutthroat trout in Canmore Creek was very poor following each stocking event. Peterson et al. (2004) found that at mid-elevation sites, age-0 and age-1 Colorado River cutthroat trout *Oncorhynchus clarkii pleuriticus* survived at 13 times and two times higher rates on average, respectively, at sites where brook trout were removed. Shepard et al. (2002) observed a dramatic—at least seven-fold—increase in the population of westslope cutthroat trout following removal of brook trout, with the most pronounced response for age-0 fish. In their study, Shepard et al. (2002) suggested that most streams have limited microhabitats suitable for YOY trout and consequently, intense behavioral interactions likely occur between YOY brook trout and cutthroat trout with brook trout dominating due to their larger size (a result of earlier emergence). Peterson et al. (2004) indicated the data in their study was consistent with the hypothesis that biotic interactions with brook trout suppress cutthroat trout populations, particularly during the first 2 years of life. Given the repeated presence and abundance of YOY brook trout in Canmore Creek and the documented interactions between the two species at this life stage, this is a possible explanation for the poor survival of stocked YOY cutthroat trout.

An additional problem in Canmore Creek is the very short area available to cutthroat trout and the subsequent risk of extinction. Prior to the construction of the man-made barrier, the section of stream above the upper waterfall was short (1.6 km). The barrier further fragmented the available habitat to 1.0 km upstream and 0.6 km downstream. A similar situation exists in White's Creek where the cutthroat trout population has a 3-km reach of available habitat (Shepard et al. 2002). The authors suggested that this presents a potential problem with long-term persistence of the population. Fortunately, White's Creek has several perennial springs within the restoration area and this provides a more stable environment and local refugia that might reduce the extinction risk from stochastic environmental events (Shepard et al. 2002). Similarly, Canmore Creek has several perennial springs in the upper 1.6 km, which provide suitable trout habitat.

TransAlta indicated that CAN$187,800 was spent on brook trout removal and fish habitat enhancement in Canmore Creek between 1997 and 2002, of which roughly $47,000 was expended on the removal program ($29,000/km). Similar studies have shown that costs to reduce or eliminate nonnative species in even small sections of streams can be extremely high. Meyer et al. (2006) estimated that the unsuccessful brook trout electrofishing removal project at a small Rocky Mountain stream cost about $61,200 overall or $7,846/km of stream treated. Shepard et al. (2002) estimated that $10,000/km, plus the cost of the barrier, was spent to successfully remove brook trout from a small relatively uncomplex stream in Montana.

The overall goal of the project, to establish a native salmonid in Canmore Creek, was worthy and it was apparent that the interest and financial support to complete the project were available. Furthermore, the short length of creek involved, combined with the relatively simple habitat as well as the presence of a natural barrier, made it a good candidate for brook trout eradication. In our opinion, the project failed partly because there was no specific designate responsible for compiling and analyzing all the data as the program progressed. The initial use of electrofishing, which proved much more effective in removing mature brook trout than trapping, was too short-lived and should have been intensified and continued beyond the second year of the program. The persistence of mature brook trout, through incomplete removal and, perhaps, downstream migration from Dog Lake, resulted in continued recruitment to the population and subsequent negative interactions with the stocked cutthroat trout. We suggest that the project could likely have succeeded if the effort expended removing YOY had been focused on mature brook trout and if efforts had been made at the outset to eliminate, or prevent immigration of, brook trout from Dog Lake.

Acknowledgements

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A Comparison of Two Methodologies for Estimating Catch Rate Using the Winter Brook Trout Fishery in Newfoundland and Labrador, Canada

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Abstract

Estimation of angler catch rates commonly involve on-site interview methods based on access point (complete trip) or roving (incomplete trip) creel surveys. On the island portion of Newfoundland and Labrador, Canada, the conservation authority relies on roving creel surveys to assess the brook trout *Salvelinus fontinalis* fishery. The mean of ratios estimator is the accepted method for deriving catch rate from incomplete trips. For completed trips the accepted method is the ratio of means estimator. To date, biases associated with catch rate estimators have been tested using statistical theory and simulation modeling rather than using actual catch statistics from anglers. In an attempt to validate the mean of ratios estimator, we used a modification of the roving creel survey design that allowed us to intercept anglers while fishing and again after completion of the fishery. Our results show that the mean of ratios estimator significantly overestimated the actual catch rate, which, in turn, impacts estimates of total harvest. We provide a model to correct for this potential bias.

Introduction

In the Province of Newfoundland and Labrador, Canada, the provincial government relies on routine winter creel surveys to determine the health of recreational brook trout *Salvelinus fontinalis* fisheries. These surveys, which employ a roving creel methodology, involve intercepting and interviewing anglers for effort and harvest information before completion of their fishing trips (Murphy and Willis 1996).

The accepted method for deriving catch rate from incomplete trips is the mean of ratios estimator. Catch rates derived from this estimator have been tested for accuracy using statistical theories and simulation modeling (Pollock et al.1997) and have not been, to our knowledge, validated for accuracy in the field. The interrelationship between environmental conditions and fish activity patterns can alter catch rates throughout a day (Shuter et al. 1998). Thus, the mean of ratios estimator potentially provides inaccurate estimates of catch rate.

We test the null hypothesis that the mean of ratios estimator is accurate by comparing catch rates measured from anglers during and after their fishing episodes.

Methods

Two watersheds, from the provincial winter roving creel program, were selected and conservation officers collected data from nine lakes within these watersheds during the 2005 and 2006 winter ice-fishing seasons. Officers were asked to perform surveys following the roving creel methodology with a progressive count (Hoenig et al. 1993).

Intercepted anglers were asked questions pertaining to the length of time fished, how many fish were caught, and how many rods were being used. Upon completion of each interview, anglers were asked to participate in an additional component of the survey. Those who agreed to participate were given self-addressed, postage-paid survey cards to be filled out upon completion of their fishing episodes. Each card had a serial number corresponding to the information in the roving creel logbook. Mail-in cards also included a stub that held the angler's name and phone number. This stub was kept by the officers in the event that follow up phone calls were required. The mail-in cards asked simple questions regarding catch and effort information from their fishing trip. As an incentive, anglers who completed and mailed their cards received an embroidered cooperating angler baseball cap.

Analysis

Comparison of catch rates derived from incomplete and complete trip data were conducted both at the individual angler level and at the lake level. To compare individual angler catch rates during and after their trip, we performed a paired t-test (SPSS v11.5) matching each pair of angler catch rates (incomplete to complete) to determine if differences existed. For the comparison of catch rates at the lake level, we calculated each lake's catch rate using the mean of ratios estimator for the incomplete trips and the ratio of means estimator for the completed trips (Hoenig et al. 1997; Pollock et al. 1997). We used a paired t-test to determine if the hypothesized one-to-one relationship existed. To account for observed differences between incomplete and complete catch rates, we used linear regressions to generate corrective models.

Results

For the 2005 and 2006 winter seasons, 258 survey cards were issued to anglers. In total, 249 cards were returned (96.5 % overall return rate). A total of 38 cards were eliminated due to inconsistencies between stub and card returns (unexplained gross reporting errors), and an additional 37 cards were eliminated after truncation of short trips (trips which were less then 30 min). A total of 174 survey pairs remained for analysis.

Catch rates measured during an anglers trip differed significantly from catch rates generated from data collected after completed trips (t = 2.326, df = 173 , P = 0.021). The mean catch rate for incomplete trips was 0.654 fish/h while the mean catch rate for completed trips was 0.564 fish/h. Catch rates generated from data collected from incomplete trips overestimated the actual catch rates by 16.0%. A plot of catch rates from complete trips versus catch rates from incomplete trips shows that as the predicted catch rate increases, so does the discrepancy between predicted and actual catch rates (Figure 1).

A comparison between the mean of ratios estimator and the ratio of means estimator at the lake level revealed a similar trend. The means of ratios estimator significantly overestimated catch rate (t = 3.656, df = 8, P = 0.006). On average it tended to overestimate by approximately 32.2%. A linear regression was generated as a corrective model (Figure 2). Table 1 shows a summary of

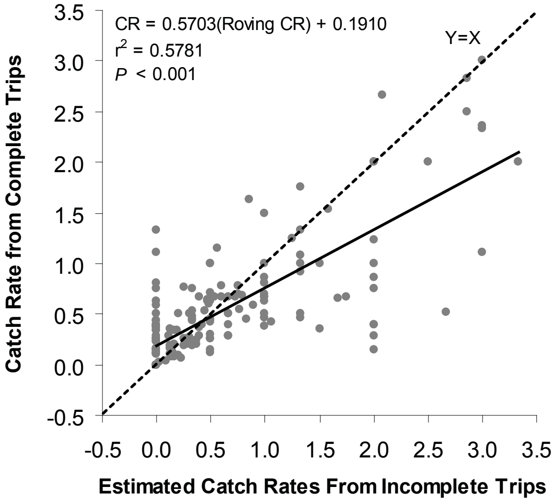

Figure 1. A comparison of catch rates generated at the individual level using roving creel interviews and mail-in cards (N = 174).

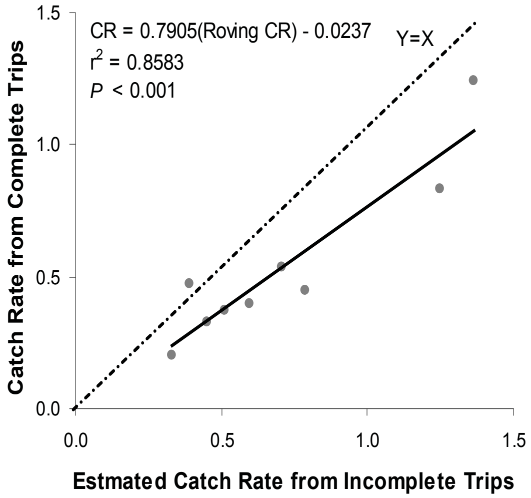

Figure 2. A comparisons of catch rates generated using the mean of ratios estimator and ratio of means estimator at the lake level (N = 9).

Table 1. Summary of incomplete and complete trip catch rate estimates for each lake (2005 and 2006 combined). Incomplete catch rates were calculated using the mean of ratios estimator, and complete catch rates were calculated using the ratio of means estimator; BT/H = brook trout per hour).

Route	Pond	Sample Size	Incomplete Catch Rate (BT/H)	Complete Catch Rate (BT/H)
Jonathans Brook	Big Jonathans Pond	52	0.786	0.451
Jonathans Brook	Jonathans Park Pond	12	0.390	0.473
Jonathans Brook	Whitmans Pond	6	1.365	1.240
Jonathans Brook	Lower Jonathans Pond	17	0.596	0.399
Middle Brook	Butts Pond	15	0.706	0.537
Middle Brook	Rodney Pond	26	0.512	0.374
Middle Brook	First Burnt Pond	9	1.248	0.831
Middle Brook	Second Burnt Pond	21	0.450	0.328
Middle Brook	Square Pond	16	0.333	0.204

catch rates calculated at the pond level using both estimators.

Discussion

Contrary to our expectations, we found the mean of ratios estimator significantly overestimated the actual catch rate. Using the generated regression to observe trend, the discrepancy between predicted and actual catch rates became larger as the incomplete catch rate increased.

Catch rates calculated using estimators such as the mean of ratios estimator are oftentimes based on the assumption that fish catchability remains constant. This theory implies that fish behavior patterns are totally random. We know this is not the case. The behavior of brook trout may be affected by habitat preferences, habitat defense, and diurnal movements. These non-random behaviors are often identified and exploited by anglers (Shuter et al.1998). All ponds within our study areas have traditional gathering areas for fishing. These areas, often referred to as “honey holes”, may become overexploited as fishing trips progress. Although truncation of data is performed to help curb this bias, it becomes very difficult to assess the effects of site-specific dependence.

We recommend that when using the mean of ratios estimator to estimate catch rate from incomplete trips, that a correction factor based on actual catch rates be developed for the fishery that is being assessed. Providing a corrective model will reduce the bias associated with the roving survey design.

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Using Nitrogen Stable Isotopes to Detect Long-distance Movement in a Threatened Cutthroat Trout

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Extended Abstract

Long-distance movements (LDMs) of individuals influence fundamental ecological and evolutionary processes, including population persistence and gene flow. However, accurate estimates of LDM are difficult to acquire in stream fishes, because these events may be rare and often require extensive sampling to detect. Improved methods are needed because LDM frequency affects conclusions about fish conservation and management. In this study, we describe and test the use of nitrogen (N) stable isotopes to identify and quantify LDM within a population of Bonneville cutthroat trout (BCT; *Oncorhynchus clarkii utah*) in the Bear River watershed, Lincoln County, Wyoming.

Nitrogen stable isotopes are commonly used to identify trophic interactions within a foodweb and as water pollution indicators. The ratio ^{15}N:^{14}N ($\delta^{15}N$) provides information about an individual's diet, because the heavier isotope, N^{15}, is typically enriched 3 to 4% from prey to predator. Within the same food web, insectivorous fish are predicted to have lower $\delta^{15}N$ than piscivorous fish. The $\delta^{15}N$ of stream organisms also changes across space due to human land use, because the influx of nitrate from agricultural or urban catchments raises $\delta^{15}N$ levels relative to catchments that are minimally disturbed.

We hypothesize that spatial differences in $\delta^{15}N$ due to catchment land use can be used to identify individuals that move between human-disturbed and minimally disturbed stream habitats. We capitalized on upstream-downstream differences in BCT diet and catchment land use in the Bear River watershed to test the use of $\delta^{15}N$ as a marker of fluvial BCT movements. Fluvial BCT that move to lower-elevation stream reaches are known to have increased rates of piscivory relative to resident fish. In addition, lower-elevation stream reaches are surrounded by lands used for agriculture and consequently have higher nitrate and nitrite concentrations than headwater tributaries in this watershed that are minimally disturbed. Therefore, we predicted that fluvial BCT would have higher $\delta^{15}N$ values than resident fish that remain in headwater tributaries.

To test this prediction, we compared $\delta^{15}N$ values of fluvial and resident BCT sampled in Hobble Creek, a headwater tributary in the Bear River watershed, in 2005 and 2006. To test the assumption that fluvial life history influences $\delta^{15}N$ values and not fish size, we compared $\delta^{15}N$ values of fluvial BCT to those of similar sized resident brown trout (BNT; *Salmo trutta*). Brown trout $\delta^{15}N$ values provided a known reference point for comparison because data from a two-way picket weir in Hobble Creek suggested that BNT are restricted to headwater stream habitats and do not move to downstream reaches. To test our two main assumptions that higher fluvial BCT $\delta^{15}N$ values reflect (1) downstream diet differences and (2) downstream $\delta^{15}N$ enrichment, we sampled BCT and BNT stomach contents and the $\delta^{15}N$ of multiple trophic levels at both main stem and headwater sites in the Bear River watershed.

We found that fluvial BCT $\delta^{15}N$ was significantly greater than resident BCT and BNT $\delta^{15}N$, indicating that fluvial life history, not size, influenced $\delta^{15}N$ differences. Our data also

showed that fluvial BCT had high diet overlap with resident BCT and BNT in headwater sites. We suggest that fish life history, and not fish size, drives large $\delta^{15}N$ differences, because we found that the influence of fish size on $\delta^{15}N$ was much smaller than the influence of life history on $\delta^{15}N$. Within a BCT life history group (resident or fluvial), there was no correlation between fish size and $\delta^{15}N$. We also found that similar sized fluvial BCT and resident BNT sampled in upstream tributaries had similar diets, but very different $\delta^{15}N$ values.

We found that $\delta^{15}N$ of primary producers and primary and secondary consumers was 3 to 7% greater in main stem sites than in headwater sites. We suggest that the fluvial BCT $\delta^{15}N$ signature reflects food sources from downstream sections of the main stem Bear River that are enriched due to agricultural pollution. The $\delta^{15}N$ of primary producers was 7.5% greater in downstream sections adjacent to agricultural catchments than in forested, upstream tributaries. Moreover, the higher primary and secondary consumer $\delta^{15}N$ at these downstream locations suggest that N pollution from agricultural sources is taken up through the food web. Agricultural N pollution and trophic-level diet shifts may act synergistically to increase fluvial BCT $\delta^{15}N$ levels.

We conclude that the high $\delta^{15}N$ values of fluvial BCT relative to resident BCT and BNT were acquired in main stem sites, not headwater sites and that $\delta^{15}N$ is a simple and accurate marker of LDM in fluvial BCT. Nitrogen stable isotope analysis is a powerful tool that has provided important information about ecological processes that are difficult to observe and measure, such as competitive interactions, stock discrimination, and site fidelity. In addition, it is faster, less expensive, and allows for larger sample sizes than use of other stable isotopes (e.g., strontium) and radio telemetry. In this study, we demonstrated an additional use of N stable isotopes: identification of individuals that move long distances in a population with multiple movement strategies. Use of N stable isotopes in combination with other site-specific stable isotopes or telemetry may provide fine-scale movement information that our approach lacks.

Application of $\delta^{15}N$ to understand movement patterns has broad application in stream networks and terrestrial landscapes because of natural processes and human land uses that produce a mosaic of N isotopic landscapes. Fishes and amphibians make landscape-scale movements in stream networks that are disturbed by N-enriching processes, such as forest fires, road activity, and agriculture. Likewise, terrestrial organisms, such as birds, move across landscapes that are filled with sewage treatment plants and agricultural fields. This technique may be especially useful in tracking movements between upland and lowland locations because human land use is often greater in lowland sites. Research that capitalizes on the mosaic of land uses to describe the flow of individuals across space can provide knowledge of the spatial structure of populations, and will improve our ability to design viable ecological reserves.

Fluvial Arctic Grayling Movement Patterns in the Upper Big Hole River, Montana: Insight From Past Tagging Data and Direction for Future Research

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Extended Abstra ct

A diverse assemblage of stakeholders is contributing resources to conserve and recover fluvial arctic grayling *Thymallus arcticus* in the upper Big Hole River watershed (southwestern Montana), the last area in the lower 48 states where a reproductively-viable assemblage of this grayling life-history type persists, At present, fluvial Arctic grayling occupy less than 5% of the historic range in Montana, and monitoring of the Big Hole River population suggests distribution and abundance are declining, Understanding Arctic grayling movement and habitat use within the Big Hole River watershed is essential for conservation planning and effective habitat restoration, In this study, we sought to (1) consolidate Arctic grayling tagging data from the Big Hole River watershed (1985-2005), (2) determine seasonal (spring and fall) distribution and movement patterns for Arctic grayling, (3) evaluate factors (such as ontogeny and flow regime) potentially influencing these distribution and movement patterns, and (4) conceptualize Arctic grayling movement within the context of a dynamic life-history model incorporating a variety of habitat needs.

Distribution and movement patterns for Arctic grayling in the Big Hole River watershed were assessed using data from fall and spring electrofishing surveys conducted by Montana Fish, Wildlife and Parks (MFWP) personnel between 1985 and 2005, During each survey, all grayling age-1 and older were individually marked with an alphanumeric visible implant (VI) tag, Based on the capture and recapture of these individually identifiable fish, movement patterns were evaluated within and among seasons and years, and related to fish length and annual flow regimes, Individual fish movement was defined as the difference between locations upon capture (by river kilometer) and recapture events, Potentially limiting flow conditions were quantified based on the sum of mean daily discharge from July 1 to October 1 of each year, We divided the resulting annual flow regimes into three percentile categories (<33%, 33%-66%, and >66%, or low, moderate, and high flows; respectively).

Analyses of mark-recapture locations suggest that fluvial Arctic grayling in the Big Hole River watershed exhibited two distinct seasonal distribution patterns from 1985 to 2005, Arctic grayling either tended to remain in the same area of the stream network (independent of season), or they occupied an upstream section of the network in the spring and subsequently moved downstream by the fall, Arctic grayling also exhibited strong inter-annual fidelity to seasonal habitat, Spring distribution patterns suggest most spawning occurred in an upstream section of the system, and similar distribution patterns of age-0 grayling in the fall suggests these fish reared near the spawning areas, Smaller fish (≤250 mm total length) tended to occupy the same locations, independent of season, but larger fish (>250 mm) often exhibited extensive movement among seasons (0-80 km), Movement distances were highly variable during years of moderate and high flows, but during years of low discharge, Arctic grayling primarily moved greater distances between spring and fall habitats.

The movement patterns observed in the historical data strongly supports current watershed-scale strategies for meeting habitat restoration goals, and further emphasizes the value of considering Arctic grayling recovery in the context of a dynamic life-history model incorporating a variety of habitat requirements among seasons and years, and throughout the life of individual fish, Insights gained from evaluating past trends in spring and fall population monitoring underscore information gaps in our understanding of fluvial Arctic grayling movement and habitat use in the Big Hole River watershed. For example, results suggest that during years of low flow, and corresponding high ambient water temperatures, refugia may be a critical seasonal habitat requirement for Arctic grayling, Evaluating this hypothesis will require more frequent sampling of fish distribution than traditionally occurred with historical monitoring, and corresponding habitat characteristics should be assessed at finer spatial scales, Nonetheless, a dynamic-life history framework and past monitoring data provide a foundation from which to develop hypotheses and prioritize future research regarding the dynamic relationship between Arctic grayling movement patterns and seasonal habitat requirements.

WILD TROUT
SYMPOSIUM

The Trout Unlimited North Coast Project – Using Private and Public Partnerships and the Landscape Approach for Salmon and Steelhead Recovery on California's North Coast

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Abstract

Private landowners with several hundred thousand acres on California's North Coast are supporting salmon *Oncorhynchus* spp. and steelhead *Oncorhynchus mykiss* recovery and sustainable land use through cooperative partnerships with Trout Unlimited and government agencies. Since 1998, Trout Unlimited and our partners have invested over US$7.4 million conducting watershed assessments, reducing sediment input to streams from historic land use, removing fish passage barriers, restoring instream habitat with large woody debris, and conducting validation monitoring to evaluate the response of the fish to this restoration work. This case study presents a synopsis of the Private-Public landscape approach to restoration.

Introduction

Industrial timber companies collectively own about 1.2 million acres of the remaining redwood stands in northern California, which represents approximately 70% of all the remaining redwood forests (Figure 1). Restoring private commercial timberlands is crucial to salmon *Oncorhynchus* spp. and steelhead *Oncorhynchus mykiss* recovery in the region. North Coast coho salmon *Oncorhynchus kisutch* are listed as endangered under the federal endangered species act and Chinook salmon *Oncorhynchus tshawytscha* and steelhead are listed as threatened.

Trout Unlimited and our timberland partners believe it is possible to manage large blocks of productive forestland using high standards of environmental stewardship, while maintaining a successful business and providing natural resources for our modern society

The North Coast Coho Project (NCCP) commenced in 1998 when the Mendocino Redwood Company (MRC) purchased Louisiana Pacific's California holdings and became the largest private landholder in Mendocino County, California. Fish habitat was disturbed by timber harvesting and the removal of large woody debris.

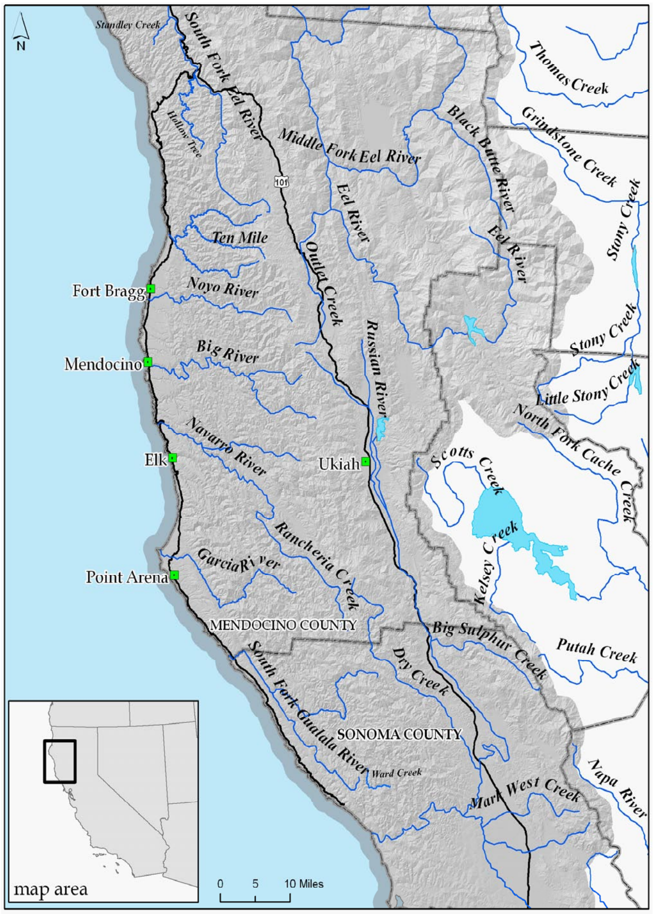

Figure 1. North Coast Coho Project Location Map

Trout Unlimited approached MRC about launching a joint project to restore streams on their new property. In an unprecedented agreement between a conservation organization and a forest products company, TU and MRC joined in an effort to restore beleaguered coho salmon and steelhead populations on California's North Coast using the landscape (watershed) approach. We are *Working Together to Ensure the Future of Wild Trout.*

The Mendocino Redwood Company is decommissioning and upgrading legacy logging roads, providing fish population data, and helping with instream restoration on six coastal streams: Hollow Tree Creek (Eel River), Cottoneva Creek, Noyo River, Big River, Garcia River, and Navarro River - all watersheds where MRC is the largest landowner. Trout Unlimited is securing funding and conducting habitat assessment work, developing restoration plans, and restoring degraded habitats

In 2001, the project expanded to another private timberland owner – the Hawthorne Timber Company, LLC, which purchased all of Georgia Pacific's landholdings in Mendocino County. Campbell Timberland Management (CTM) manages the property. The Hawthorne lands include several important coho salmon and steelhead watersheds, including the Ten Mile River, Pudding Creek, the Noyo River, and Big River.

The Mendocino Redwood Company and CTM manage almost 300,000 acres in Mendocino County and are the dominant landowners in at least a dozen key watersheds or sub-watersheds. This partnership has led to additional opportunities for TU to work with other landowners involved in the wine industry, gravel mining, and small landowners seeking to enjoy swimming during the hot summer months without the installation of summer dams.

Methods

The NCCP is uniquely based on partnerships among Trout Unlimited, private landowners, and State and Federal agencies working cooperatively to restore coho salmon runs on the North Coast of California. The NCCP focuses on science-based planning, habitat assessment, and restoration at the watershed scale and supporting the reintroduction of coho salmon into restored habitats using modern principles of conservation biology to take full advantage of investments in habitat restoration.

The Landscape Approach – Planning, Assessment, Restoration and Monitoring

The *Recovery Strategy for California Coho Salmon* (CDFG 2004) and input from our partners identify the highest priority watersheds for restoration work. This guides our project selection to focus on the streams with the best potential for coho salmon recovery. The focus of the NCCP is addressing limiting factors such as sedimentation from timber industry roads, lack of in-stream habitat (i.e. large woody debris), and degraded water quality due to sediment input from historic land use.

Planning is the NCCP's newest facet. Because watersheds function as a whole, TU has launched a new effort to develop watershed plans in critical coho salmon habitats. Specifically, these plans identify key restoration projects and include timelines and implementation cost estimates. Additionally, the plans collect historic and current watershed information and are used to guide watershed stakeholders to implement restoration work. A successful watershed plan is one embraced by many stakeholders and serves as the "blueprint" for restoration activities.

Comprehensive watershed assessments are prepared for current or former coho salmon-bearing watersheds. The assessments focus on road-related sediment sources, potential gravel mining impacts, and vineyard operations. Based on the assessments, restoration prescriptions and implementation plans are prepared to treat the highest priority sediment sources in the most cost-effective manner.

Restoration

Road upgrading involves a variety of treatments used to make a road more resilient to large storms and flood flows. The most important of these include upgrading stream crossings, removing unstable sidecast and fill materials from steep slopes, and applying road surface drainage techniques to improve dispersion of road surface runoff and reduce fine sediment delivery (Figure 2; Flosi et al. 1998; Weaver et al. 2006).

Road drainage techniques include berm removal, road outsloping, rolling dip construction, or the installation of ditch relief culverts (Figure 3). The goal of all treatments is to make the road as "hydrologically invisible," to disconnect the road from the stream system, and thereby protect aquatic habitat from the effects of fine sediment.

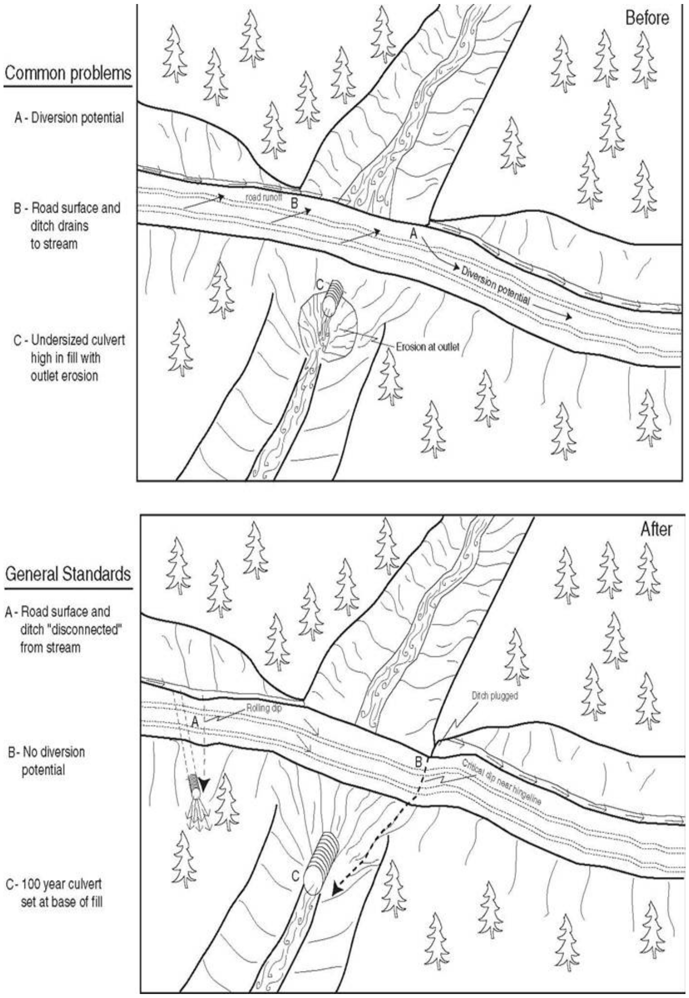

Figure 2. Components of an Upgraded Stream Crossing

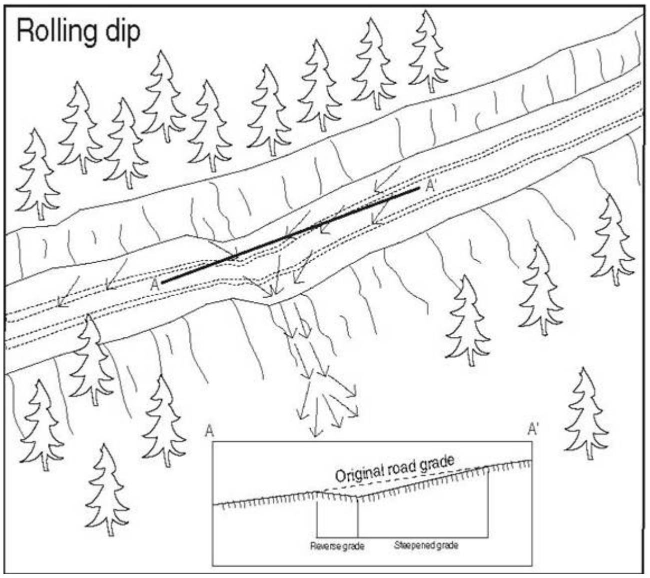

Figure 3. Road Drainage using Rolling Dips

Road decommissioning involves "reverse road construction." Full topographic obliteration of the roadbed is not normally required to accomplish sediment prevention goals (Figure 4). Generic treatments for decommissioning roads and log landings range from outsloping or simple cross-road drain construction to full road decommissioning (closure), including the excavation of unstable and potentially unstable sidecast materials and road fills, and the removal of all stream crossing fills.

Figure 4. Decommissioned Road and Restored Stream Crossing, Hollow Tree Creek, Eel River, Mendocino County, California

In-stream work is another key component of habitat restoration (Figure 5). In-stream work helps recreate the natural conditions that coho salmon and steelhead require to survive throughout the year. There are three general categories of the most commonly used in-stream structures: (1) cover structures, (2) boulder structures, and (3) log structures. Often a single structure or combination of structures will provide for rearing, spawning, and cover.

The placement of large woody debris (LWD) adds to the diversity of rearing habitat within the project reach. Habitat created through the placement of LWD debris is readily utilized by coho salmon and steelhead. The placement of in-stream structures also slows velocities of winter flows, and provides velocity refuges during high discharge events, and late summer refugia when stream flows are low.

Fish passage presents another challenge for the fish (Figure 6). Culverts, log landings, and dams have prevented migrating fish from accessing habitat. Trout Unlimited and our partners removed these obstructions and opened up miles of habitat that have not been accessible for decades. Field observations indicate salmon and steelhead are quick to reoccupy the newly reopened habitat.

Figure 5. Wood and Rock Instream Structures Austin Creek, Russian River, Sonoma County, California

Figure 6. Dam – Before and After

Monitoring

Because coho salmon are functionally extinct or found in such low numbers in many North Coast watersheds, TU is linking restoration with coho salmon reintroduction efforts in the Russian River watershed. Since 2001, a collaborative effort has been underway to re-establish coho salmon in the Russian River. Partners carefully capture, rear, and spawn coho salmon brood stock. They then release these offspring as young fish in area tributary streams. Partners also monitor their growth and survival, until the time arrives for them to move downstream and into the Pacific Ocean. This cycle is repeated annually including the monitoring of adults returning 3 years after their release to tributary streams.

Trout Unlimited and the National Marine Fisheries Service are supporting the Russian River Coho Recovery Program through monitoring at Lower Austin Creek. Our monitoring detected coho salmon from the program during the past several monitoring seasons (Figure 7).

Results

Over US$7.4 million of private landowner and agency funds have been invested in 10 northern California coastal watersheds for the benefit of coho salmon, Chinook salmon, and steelhead. Depending upon the project, private landowners contribute up to 40% of the total project cost. The average is about 20 to 30%.

The NCCP has made some impressive accomplishments since program inception in 1998 (Table 1). Hundreds of miles of industrial forest roads have been assessed, upgraded, and decommissioned. Dozens of in-stream structures are providing crucial habitat and miles of stream have been reopened for fish migration by the removal of fish passage barriers.

The amount of sediment prevented from influencing streams is determined by field estimates of the volume of material that can enter a stream from dirt fills, road runoff, stream crossings, and undersized culverts. Implementation of on-the-ground repairs (decommissioning roads, upgrading roads, removing and replacing culverts) prevents this huge amount of soil from affecting important fish habitat.

Figure 7. Rotary Screw Trap and Coho Salmon from Brood-stock Program (note clipped adipose fin)

Table 1. Accomplishments of the North Coast Coho Project since 1998

Restoration Activity	Results
Road Assessed, miles	706
Road Decommissioned and Upgraded, miles	411
Estimated Sediment Prevented from Impacting Streams, cubic yards	370,000
Instream Structures Installed	195
Miles of Stream Reopened to Fish	Over 11
Major Fish Migration Barriers Removed	5

Discussion

The NCCP demonstrates that public-private partnerships to restore threatened and endangered species can be achieved with little or no impact to private landowner’s business interests. Timber companies, gravel miners, vineyard owners, and rural residential landowners were initially hesitant to allow the “government” on their property. With almost a decade of success, the NCCP serves as a model for other landowners to conduct restoration work on their property.

Over a century of human impacts in North Coast watersheds are now being corrected using modern approaches to forest road management, removing fish passage barriers, and returning LWD to the streams. Salmon and steelhead have returned to places such as the Garcia River for the enjoyment of anglers and the public. *Working Together to Ensure the Future of Wild Trout* is what the NCCP is all about and the approach is being used throughout the United States to conserve, protect, and restore salmon and steelhead and their watersheds.

Acknowledgements

The North Coast Coho Project would not be possible without the financial and technical support of the Mendocino Redwood Company, Campbell Timberlands Management, the California Department of Fish and Game, NOAA National Marine Fisheries, County of Sonoma and the United States Fish and Wildlife Service.

Trout Unlimited is proud to work with our partners restoring northern California coastal watersheds for salmonids and steelhead trout.

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Changes in Wild Rainbow Trout and Brown Trout Populations after a Stream Restoration Project on Big Spring Creek, Montana

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Abstract

From 1998 to 2001, Montana Fish, Wildlife and Parks and several partners reconstructed a 2,600-ft reach of Big Spring Creek and replaced an entrenched “ditch” with a meandering riffle-pool stream channel and floodplain. Populations of resident wild rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* were evaluated with 6 years of pre-project and 6 years of post-project mobile electrofishing data from the reconstructed section and two reference reaches of Big Spring Creek. Adult trout density (≥ 10 in) increased by 41% and total biomass by 79% in the 6 years immediately after the project in the reconstructed section. However, small rainbow trout (6 – 9.9 in) declined by 59% per mile. Adult trout increased by 14% and 9% in the other two reaches. Habitat in the reconstructed reach was evaluated before and 4 years after project completion. Stream length increased by 1,400 ft and pool habitat increased about 3-fold, and now composes about 30% of the reconstructed reach. This restoration effort has become a showcase for stream projects in Montana. It increased trout biomass and created a functioning flood plain. An adjacent walking trail and frequent use as an outdoor classroom has increased public awareness of Big Spring Creek.

Introduction

Stream projects to increase natural functions and aquatic integrity in altered streams are common (Roni et al. 2002; Quigley and Harper 2006, for example). However, few published studies have evaluated the fishery benefits of these projects for several years before and after project completion (House 1996; Roni et al. 2002; Moerke and Lamberti 2003;). The objective of this study was a long-term evaluation of the response of brown trout *Salmo* trutta and rainbow trout *Oncorhynchus mykiss* to a 2,600-ft reconstruction project on Big Spring Creek, Montana. The project aimed to create a flood plain and increase trout numbers, pool habitat, and public awareness of this 100-cfs trout stream. The previously straightened channel was replaced by a meandering riffle-pool configuration, which increased channel length by 1,400 ft. Two un-restored reference reaches were evaluated for comparison. At a minimum, trout populations were expected to maintain pre-project densities and increase relative to stream length.

Study Area

Big Spring Creek is a spring creek that originates at 52°F Big Spring, 8 mi south of Lewistown, Montana and flows 31 mi to the Judith River. Big Spring Creek was highly modified during the 20th century. It has many straightened reaches, flows under the city of Lewistown, has a flood canal around Lewistown, and three large irrigation ditches are diverted downstream of Lewistown. Flood-control dams on four tributaries dampen the storm flow peaks. However, most of the stream has a natural meandering riffle-pool configuration. Agricultural land and rural homes with small acreage typify the area between the Big Spring and Lewistown. Agricultural land borders Big Spring Creek downstream of Lewistown. Daily average water temperatures typically peak near 65°F in the creek downstream of Lewistown and at 55°F in the upper creek in mid-July. Daily summer peaks can reach 70°F below town. Montana Fish, Wildlife & Parks (MFWP) has an instream flow right of 110 cfs on Big Spring Creek. During spring runoff, flows typically peak near 250 cfs above town and 400 cfs below town. Recently, flows have been as low as 50 cfs downstream of Lewistown due to irrigation withdrawals and drought. The stream reconstruction project was located about 2 mi upstream of Lewistown at the Brewery Flats Fishing Access site. The channel was straightened *circa* 1910 for industrial development (Figure 1). Construction of the new meandering channel started in 1998. During the 3-year construction period a new channel was excavated, gravel was added to bed and coir fabric, and willow cuttings added to the new channel banks (Figure 2). Rocks and root wads were added to the outside bends for bank protection but were not added elsewhere in the creek. The creek was not diverted into the new channel until 1 year after construction to increase bank stability (Tews and Lere 2002). Fish populations were evaluated in the reconstructed reach and two reference reaches of Big Spring Creek - the Burleigh section located about 2 mi upstream of the project area and the Carroll Trail Section, located 4 mi downstream (Figure 3). Trout estimates in the Brewery Flats section were either for a 3,700-ft (pre-construction) or a 5,100-ft reach, of which 2,600ft were reconstructed. Both reference reaches exhibit a riffle pool configuration with some rock-armored areas. The Burleigh and Brewery Flats sections have similar flows and nutrients, but the Carroll Trail section typically has reduced summer flows, increased peak spring flows, and increased nutrient levels (Myhre 2006) than the two sections above Lewistown.

Figure 1. Brewery Flats stream area *circa* 1910 (upper picture) and after restoration in 2003 (lower picture). Note trees at top of both pictures.

Figure 2. Prior to diversion of water into the new channel, the fabric stabilization and new gravel bottom are easy to see.

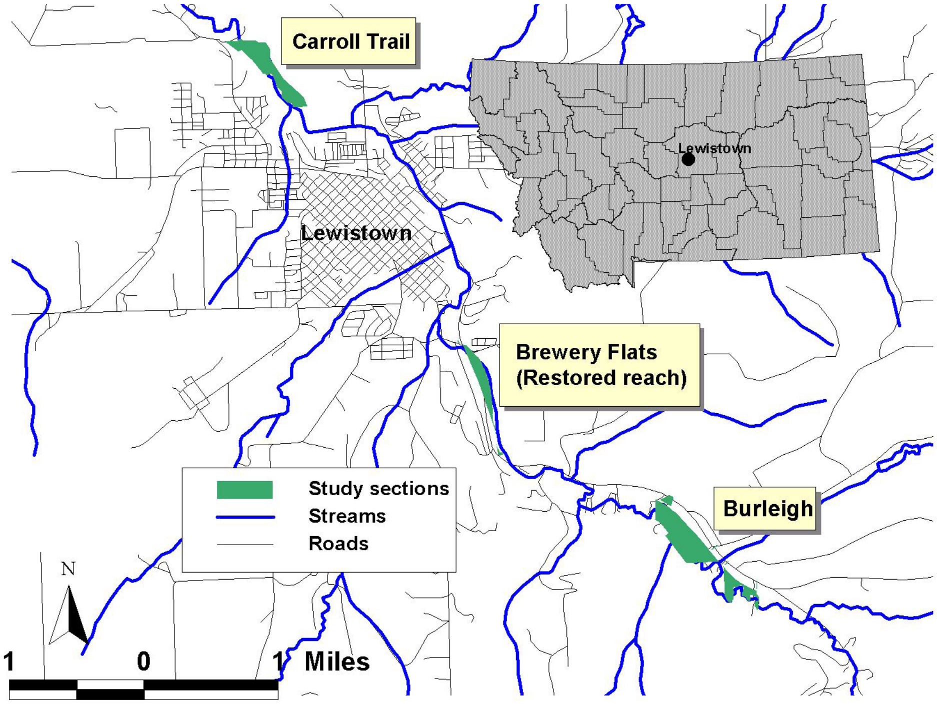

Figure 3. Location of electrofishing sections on Big Spring Creek, Montana.

Methods

Six years of pre-project and 6 years of post-project mobile electrofishing data were collected in late summer on the restored section and the two reference sections. One mark and one recapture run was completed in each section, except when small sample sizes necessitated a second marking and recapture run on either the Burleigh or Brewery Flats sections. The recapture run was typically completed 1 week after the marking run. An adult trout in Big Spring Creek is considered to be ≥10 inches long. The mark-recapture estimates were calculated with the MFWP FA+ program using the log-likelihood estimator model. Pre- and post-project fisheries data were compared with 2-sided t-tests at the 90% level to minimize type II error. Habitat parameters including depth, width, and bank stability were measured before and 4 years after project completion using the methods of Overton et al. (1997). Habitat measurements were taken on the 2,700-ft reconstructed reach at Brewery Flats and included the entire reach.

Results

In the restoration section, the pre-project average adult trout density was 619/mi compared with a post project average of 873/mi (Table 1). Trout density was 41% (P=0.05) higher during the 6 years immediately after the project in the restored section, compared to increases of 14% (P=0.32) and 9% (P=0.99) in the other two sections (Table 1). Total adult trout increased by nearly 100% in the Brewery Flats (restored) section, due to the increase in stream length. Mean adult trout numbers at Brewery Flats were 746/mi. The Carroll Trail reference section had more adult trout every year than either section above town (Figure 4). This is consistent with the three-decade period of record where, Carroll Trail has had nearly 3-fold higher estimates of adult trout (1,760/mi versus 600/mi) than the Burleigh section. In this study, mean adult trout estimates during the 12-year period varied from 2,106/mi (Carroll Trail) to 530/mi (Burleigh) m. In 2006, brown trout peaked at 50% of the total adult trout all sections, but were occasionally as low as 10% of the adult trout captured.

Table 1. Trout estimates for 6 years of data before and 6 years of data after a stream reconstruction project on Big Spring Creek Montana. P values are from 2-sided T test.

Section	Before	After	Change	P-value
All trout > 10 in				
Burleigh (upper) number/mi	494	566	+13%	0.32
Brewery Flats (Restoration) number/mi	619	873	+41%	0.05
Brewery Flats (Restoration) number in section	434	855	+97%	0.001
Carroll Trail (lower) number/mi	2015	2197	+9%	0.99
Rainbow trout 6.0 – 9.9 in				
Burleigh (upper) number/mi	286	118	-59%	0.30
Brewery Flats (Restoration) number/mi	557	226	-59%	0.016
Brewery Flats (Restoration) number in section	391	256	-34%	0.13
Carroll Trail (lower) number/mi	891	886	-0.4%	0.99
Biomass all trout >6 in				
Burleigh (upper) lb/mi	519	628	+21%	0.16
Brewery Flats (Restoration) lb/mi	621	807	+30%	0.10
Brewery Flats (Restoration) lb in section	436	780	+79%	0.002
Carroll Trail (lower) lb/mi	2034	2369	+16%	0.40

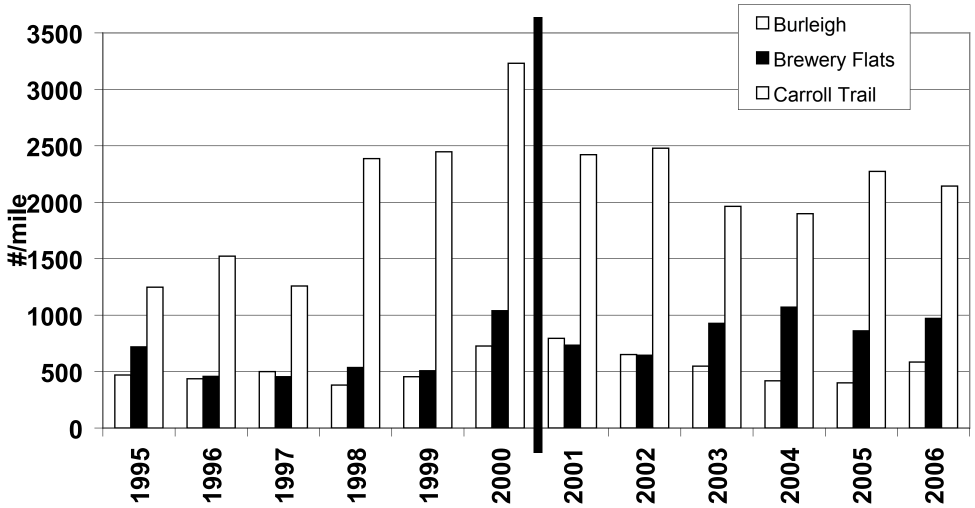

Figure 4. Population estimates for combined rainbow trout and brown trout ≥10 in total length on three sections of Big Spring Creek before (left of black line) and after a stream reconstruction project on the Brewery Flats section.

Capture rates of small brown trout were usually too low for estimates, so that only small rainbow trout estimates were evaluated. Rainbow trout <10 in long were at record low levels for 4 years after the reconstruction project but were somewhat higher in 2005 and 2006 (Figure 5). During the entire post-restoration period, rainbow trout <10 in declined in the reconstruction reach by 59% (P=0.016). Small trout also declined by 59% in the control section above town (P=0.30) but remained essentially the same below town (Table 1). Biomass increased in all sections but the increase was only significant in the Brewery Flats reconstructed section, where total biomass increased by 79% (Table 1). Average total length of rainbow trout increased in all reaches after the project was completed with significant increases in adult rainbow trout length in both reaches upstream of Lewistown

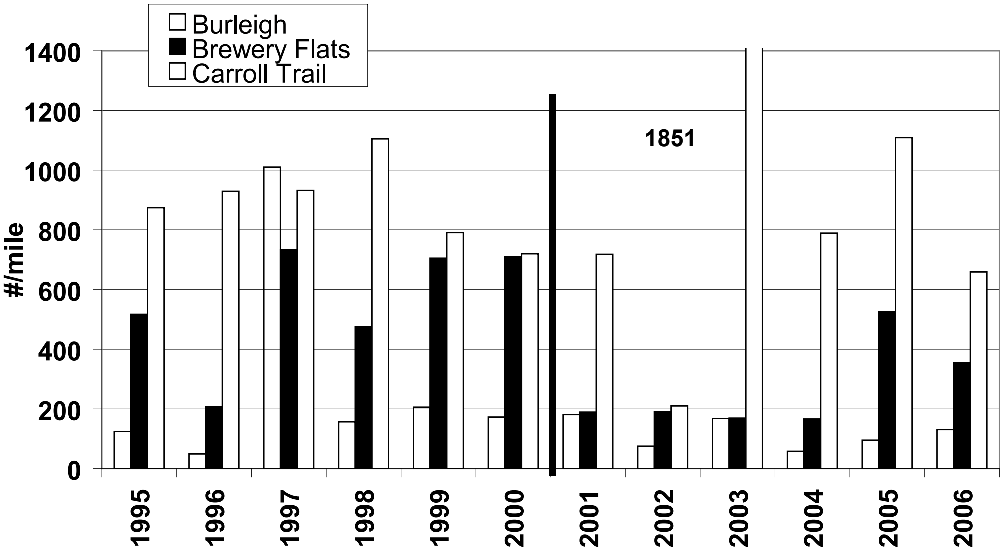

Figure 5. Rainbow trout population estimates (<10 in total length) on three sections of Big Spring Creek before (left of black line) and after a stream reconstruction project on the Brewery Flats section.

(Table 2). In general, brown trout size increased going upstream and did not change much during the study. Brown trout only increased in size in the Burleigh reference section (Table 2). Pool habitat increased over 3-fold (Table 3). Total creek area increased by 47% and mean pool depth increased by about 0.5 ft. Just 4 years after the project was completed stable banks had increased from 15% to 83% of the channel area. By 2005, undercut banks had only developed along 28.9% of the stream. The stream channel was armored with coir fabric; hence, it is not surprising undercut banks were not well developed by 2005 (Figure 2). By 2005 the woody debris in this reconstructed reach was still less than it had been prior to the project (Table 3).

Table 2. Mean total length of trout before and after a stream restoration project at the Brewery Flats section of Big Spring Creek. Means were derived from annual average.

Section		Rainbow trout ≥ 6 in	Rainbow trout ≥10 in	Brown trout ≥ 10 in
Burleigh	Before	11.0	13.2	15.6.
	After	12.5	13.5	16.1
	P-value	0.19	0.09	0.014
Brewery Flats	Before	10.4	11.9	14.2
	After	11.2	12.4	14.2
	P-value	0.18	0.015	0.94
Carroll Trail	Before	11.8	13.1	13.6
	After	12.2	13.6	13.5
	P-value	0.53	0.13	0.42

Discussion

This project has been a clear success by increasing trout biomass, creating a floodplain, and increasing public awareness. The trout biomass at the Brewery Flats area increased by nearly 80%, and adult trout numbers nearly doubled after the reconstruction project was completed. These large increases were due in part to increases in channel length, but density increases were also significant. Increases were not significant in the control sections. Trout 6-9.9 in declined immediately after the project, but some of this decline was reversed late in the study. Even 4 years after the project was completed, undercut banks and woody debris were lower than previous to project construction in the reconstructed reach, which likely resulted in less cover for small fish. Floodplain and public benefits were not empirically evaluated but are evident. This high-profile project has been featured in statewide conferences as a showcase of how such projects can succeed both in environmental and social aspects. Spring peak flows flooded much of the Brewery Flats area at least three times after the project was completed (Figure 6). Flooding of the Brewery Flats riparian area did not happen prior to the project. Public benefits are exemplified by the popular trail adjacent to the new stream channel and the area's frequent use as a public classroom. The city of Lewistown has recently received hundreds of thousand of dollars in grants to clean

Table 3. Pre- and post-construction habitat measurements taken at Brewery Flats.

	Pre SEP 1999	Post JAN 2005
Flow (cfs)	127	107
Area (ft^2)	88,698	130,431
% Fast	91.3	62.0
% Slow (Pools)	8.7	38.0
Mean Maximum depth Pools (ft)	3.83	4.65
Pocket pools (N)	46	3
Pocket pool depth (ft)	1.80	1.27
Overall		
Mean Depth (ft)	1.41	1.49
Mean width (ft)	35.3	36.6
% stable banks	15.6	83.1
% undercut banks	63.2	28.9
Large woody debris (total pieces)	96	54 (37 added)
Single pieces	19	26
Aggregates	45	1
Root wads	34	27

Figure 6. Flooding at Brewery Flats as on left, has happened several times since the reconstruction project was completed. The picture on right was taken during base flow and shows the trail bridge installed during the reconstruction project.

up toxic compounds from the property adjacent to Brewery Flats and should soon be adding this parcel to the city park system.

Each stream is unique, so that the success of this project may not occur elsewhere. Some projects on streams with different characteristics have not been as successful (Moerke and Lamberti 2003, for example). The increase in trout on Big Spring Creek may be due in part to the limited extent of channelization on the stream. It may be difficult to monitor additional changes on Big Spring Creek attributable to the reconstruction project. Whirling disease was recently found in Big Spring Creek. It is likely that whirling disease impacts will start influencing subadult trout numbers on the lower creek in 2007, confounding trout population changes due to the reconstruction project.

Acknowledgements

Steve Leathe, Mark Lere and Ted Hawn were instrumental in completing the reconstruction project. I would like to thank Paul Hamlin and numerous others of the Region 4 MFWP fisheries staff for help collecting the data. The evaluation was supported by Federal Aid Sport Fisheries funds.

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Spring Creek Habitat Enhancement and Restoration Projects Result in Increased Utilization by Wild Snake River Fine-Spotted Cutthroat Trout

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Abstract

Lack of spawning habitat is a primary factor limiting recruitment into the Snake River fine-spotted cutthroat trout, *Oncorhynchus clarkii* subsp., population of Jackson Hole, Wyoming. Cutthroat trout residing in the Snake River rely on tributary spring creeks for spawning and nursery habitat; high flow velocities, sediment movement, and turbidity make the main stem unsuitable reproductive habitat. Several anthropogenic activities (e.g., flood control, grazing, agriculture, and irrigation) have isolated and degraded tributary spring creeks. Reach-level restoration efforts with varying degrees of invasiveness have been undertaken but seldom include monitoring of target species utilization. Pre- and post-construction monitoring of cutthroat trout spawning activity has been conducted over the past few decades in conjunction with large-scale spring creek enhancement projects in the Jackson Hole area. Monitoring data demonstrate up to 100% increases in use by wild spawning native cutthroat trout following restoration activities that enhance channel morphology, connectivity, function, and available spawning and cover habitat. Holistic design and construction of projects can benefit both the local and regional population by providing essential habitat for wild cutthroat trout with no need for stocking or transplanting.

Introduction

Evidence of currently used spawning habitat within the main and side channels of the Snake River is generally lacking. In-channel spawning may be limited due to large dam-regulated fluctuations in flows (with very high flows occurring during spring run-off and spring spawning), channelization resulting from the flood control levee system, substantial movement of sediment and bed material, and high levels of suspended sediment and turbidity during the spawning season. Under current conditions, the majority of Snake River fine-spotted cutthroat trout, *Oncorhynchus clarkii* subsp., spawning in Jackson Hole is therefore confined to several spring-fed tributaries flowing into the Snake River.

Trout typically enter these spring creeks between March and May, and spawning occurs between March and July, depending upon location. Fry emerge throughout late spring and early summer and reside in the creek systems throughout their first year. Few age-0 fish can be found in the main channel of the Snake River during the summer, but some juvenile fish migrate to the river during January and February of their first year (Kiefling 1978). Therefore, spring creeks used for spawning function not only as important reproductive habitat but also as important nursery habitat.

Prior to the construction of the Snake River flood protection levee system, the valley's spring creeks provided Snake River fine-spotted cutthroat trout with an abundance of suitable spawning areas, a variety of riffle-pool habitat sequences, and protective cover. Annual floods associated with snowmelt and spring run-off served as flushing and cleansing agents in creeks located throughout the historical floodplain of the river by removing recently deposited fine sediment and recharging spawning areas with new gravel. Additionally, large woody debris recruitment provided a continuous source of structural cover for resident and spawning fish.

Following construction of the levees in the late 1950s and early 1960s, spawning habitat began degrading as the Snake River became more channelized and confined. Flushing flood flows no longer cleansed existing gravel or deposited new gravel in important historical spawning areas, and such areas became consolidated with heavy accumulations of sediments that originated from natural and human-caused (agriculture, irrigation, livestock grazing) sources. This habitat degradation resulted in reduced suitability of spawning areas and a decline in fish movement into the spring creek systems.

Since operation and maintenance of the Snake River flood protection levee system have become a federal responsibility, the permanence of flood control in Jackson Hole has been ensured. Therefore, the continuation of flood control will undoubtedly result in a corresponding increase in residential and commercial development of the Snake River floodplain protected by the levees. Existing development and new development will continue to have important cumulative impacts on fish habitat in the numerous spring creeks found in this area, unless precautions are taken to minimize such negative impacts and efforts are undertaken to improve degraded habitat.

In 1970, the Wyoming Game and Fish Department (WGFD) inventoried Snake River tributaries to determine spawning potential and actual spawning in the context of potential habitat restoration projects (Kiefling 1984). They found that actual spring creek spawning was below potential, even though suitable habitat (rated marginal to good) was available. Numerous examples of habitat degradation were identified and in subsequent years, the WGFD attempted to correct and improve problems. Their efforts focused primarily on improving fish access and on providing spawning areas for cutthroat trout in several spring creeks along the Snake River, including Three Channel Spring Creek. The WGFD built spawning beds, excavated adjacent deep-water habitat, and installed large woody debris (LWD) for cover. In most cases, enhancement efforts were successful and the numbers of spawning fish increased. The WGFD was essentially functioning as the seasonal Snake River flood flows by artificially flushing accumulated silts and rejuvenating spawning gravels.

The WGFD expended time, effort, and money on spawning enhancements in Three Channel Spring Creek and was rewarded with excellent responses by spawning fish. However, little enhancement work occurred in the spring creek after the early 1980's and the habitat had again become or continued to be degraded in places. Biota Research and Consulting, Inc. (Biota) was hired in 1993 to assess the condition of a private landowner's reach of Three Channel Spring Creek, to suggest and implement appropriate restoration activities, and to document the annual spawning activity of native cutthroat trout.

The project area spans approximately 3,700 linear feet of Three Channel Spring Creek on private property located roughly 5 mi north of Jackson in Teton County, Wyoming. Restoration efforts occurred along approximately 2,000 linear feet of the East Fork, 1,000 linear feet of the Middle Fork, and 700 linear feet of the Main Fork of Three Channel Spring Creek. Objectives of the project included rejuvenating existing spawning sites and creating new suitable spawning areas. In addition, various in-stream habitat enhancements (e.g., excavations, channel constrictions, placement of rock and wood structure, replanting woody vegetation) were completed to provide critically important escape and protective cover for fish while restoring channel morphology, system function, and riparian condition. The desired outcome was an increase in cutthroat trout spawning activity, a larger resident fish population, and a more pristine spring creek system.

Methods

In an attempt to document the response of Snake River fine-spotted cutthroat trout to the spawning habitat enhancement and channel restoration activities, redd surveys were conducted on an annual basis coinciding with the reproductive period of native cutthroat trout. The primary restoration effort was completed in 1993, and subsequent maintenance projects were completed in 1999, 2002, and 2006. Methods incorporated during redd surveys and restoration activities are described below.

Restoration and Enhancement

A channel restoration and habitat enhancement plan was developed for the project area reach of Three Channel Spring Creek and was implemented in the fall of 1993. The restoration design focused efforts in two categories: spawning and cover habitat improvements. Spawning habitat enhancements involved either the rehabilitation of existing spawning sites or the creation of new spawning sites. Rehabilitation of existing spawning sites involved the cleansing, redistribution, and replacement of gravel. New spawning sites required the placement of purchased 0.75- to 1.5-in diameter washed gravel. The placement of spawning gravel to construct spawning beds was often preceded by the removal of excessive cobble and unsuitable sediment in order that spawning gravels could be installed without adversely impacting the water surface elevation, floodplain connectivity, or the particle size distribution of created spawning riffles.

Cover habitat enhancements were varied. At some sites inundated with fine sediment or compacted cobbles, material was excavated from the creek bed to deepen water, provide cover, and increase the ratio of pool and riffle habitat units. Several existing small islands were enlarged and emergent wetlands were created along banks in some locations in order to serve as channel constrictions that focused flows, increased sinuosity, and created current heterogeneity. The placement of overhead woody structure and current deflectors was integral to many of the cover habitat enhancements. Installed woody structures included logs, trees with branches and roots, large branches, rootballs, and clump willows. Existing overhanging bank vegetation was protected when possible, and additional live plant materials and native seed mixes were installed after construction to restore and enhance the riparian plant community.

The primary restoration effort was completed in the fall and winter of 1993. Subsequent treatments designed to restore deteriorating spawning beds and maintain in-stream cover were completed in the winters of 1999, 2002, and 2006. Such efforts primarily involved reconstructing spawning beds with purchased 0.75- to 1.5-in washed gravel, but additional work was done to remove fine sediments from spawning beds, install cover and deflector logs where necessary, and create additional wetlands. Therefore, all four distinct restoration and maintenance efforts were holistically designed to improve in-stream habitat for native cutthroat trout while restoring channel morphology and function, increasing flow dynamics, and developing wetland and riparian connectivity under the existing hydrologic regime.

Redd Surveys

Cutthroat trout spawning redds were counted weekly through the project area between late May and mid- to late-July from 1994 to 2007. The annual sampling period was selected based on review of past spawning records for Three Channel Spring Creek and under advisement of the WGFD.

Each sample involved walking the entire reach of Three Channel Spring Creek in the project area in search of redds. When redds were observed, a rock painted fluorescent orange was placed in the excavated depression to mark it as being counted and then the location was mapped on aerial photography at a scale of 1 in = 50 ft. Painted rocks allowed the observer to identify previously counted redds and observe redds through time. Many redds remained obvious throughout the study period, but others were altered by the spawning efforts of other pairs of fish. Superimposition of redds (caused by a pair of fish constructing a redd on top of another pair's redd) was sometimes observed, but data were not collected on this phenomenon.

In an attempt to be conservative and not overestimate spawning activity, specific criteria were established and used to define a redd for the purposes of this survey. Only redds that had obvious excavation areas and associated tail-spills were counted. Redds without clear tail-spills were not counted in the samples. Redds under construction or occupied by spawning fish during the survey were not counted in the sample when first observed but were counted in the next sample if, at that later time, redd definition criteria were met. Fish observed constructing redds or in the act of spawning were, whenever possible, not disturbed. Some redds were extremely large in size and possibly represented spawning efforts by more than one pair of fish. However, unless two or more readily identifiable tail-spills were observed, the redd was marked and counted as one.

Results

Annual spawning redd surveys conducted by Biota documented spawning activities in the project area reach of Three Channel Spring Creek from 1994 to 2007. Survey data results are depicted in Table 1 and are organized by fork (or branch) of creek.

The redd surveys conducted by Biota document relative annual spawning activity from the mid-1990's to 2007. The project completed in 1993 aimed to restore channel morphology, in-stream and spawning habitat, and the adjacent riparian area. Redd surveys completed in 1994 documented a subsequent increase in observed redds (over that observed by the WGFD in 1993). Each subsequent spawning bed and in-stream habitat maintenance effort was also followed by an increase in observed redds. Figure 1 depicts annual redd survey data in conjunction with completed restoration and enhancement activities since 1993.

The annual redd survey conducted after the initial restoration effort documented 208 redds through the project area, in comparison to 19 redds documented by the WGFD in the project area the prior year. The next spawning bed maintenance occurred in 1999 and is associated with a subsequent increase in documented redds of 97%, from 274 to 541. Another spawning bed maintenance project was completed in 2002 and was followed by an increase in documented redds of 5%, from 379 to 397. The most recent spawning bed maintenance project was completed in 2006 and was followed by an increase in documented redds of 12%, from 232 to 264.

Discussion

The four restoration projects completed by Biota in the project area reach of Three Channel Spring Creek were followed by annual redd surveys that documented subsequent increases in spawning activity of native cutthroat trout. However, the most recent projects, completed in 2002 and 2006, are associated with a less dramatic increase in redd count results. A possible explanation for

Table 1. Number of redds surveyed during study in project area reach of Three Channel Spring Creek, 1994-2007.

Date	Main Fork	Middle Fork	East Fork	West Fork	Total Redds
1994	29	64	115	n/a	208
1995	21	63	62	n/a	146
1996	27	126	104	n/a	257
1997	7	113	107	n/a	227
1998	15	123	129	2	269
1999	18	153	101	2	274
2000	81	216	239	5	541
2001	66	171	184	0	421
2002	64	164	151	0	379
2003	70	160	167	0	397
2004	39	128	213	0	380
2005	17	81	107	2	207
2006	44	83	104	1	232
2007	55	97	109	3	264

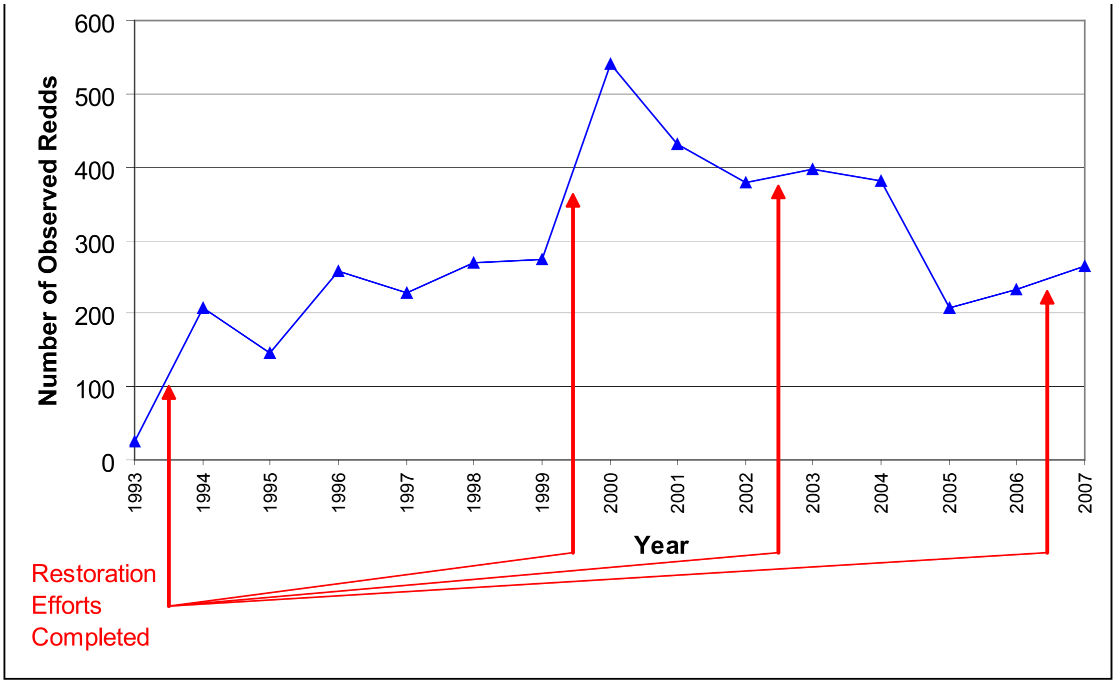

Figure 1. Redd Count Survey Data Three Channel Spring Creek Newton Property, Teton County, Wyoming

this is that between 2000 and 2002 numerous habitat enhancement and restoration projects were completed on adjacent reaches of Three Channel Spring Creek. Such projects likely resulted in an increase in available suitable spawning habitat in the spring creek system. Available spawning habitat was then less of a limiting factor on overall spawning activity, as spawning fish were spread out over more suitable areas along the creek. Restoration efforts then resulted in more subtle increases in spawning activity, because a smaller fraction of the spawning community was spawning in the project area.

The WGFD has conducted annual redd surveys through the project area reach of Three Channel Spring Creek since 1970. The WGFD redd count data set is plotted along with the results of redd surveys conducted by Biota in Figure 2.

There are discrepancies between redd count data collected by WGFD and that collected by Biota for this study. This is primarily due to the fact that the groups use different survey methodologies for quantifying spawning activity, although they share common criteria for defining completed redds. The WGFD conducts redd surveys once a year after the spawning season is complete, during which redds are counted and the number of fish pairs that likely spawned in each feature is estimated based upon the size of the redd. This method involves subjectivity on the part of the observer in estimating the number of fish that spawned in each location, and this method likely underestimates the total number of redds because a single survey late in the season may not detect all redds, which frequently disintegrate or become obscured over time from natural erosion, livestock trampling, aquatic vegetation growth, superimposition of redds, weather, and siltation. In contrast, the methodology used by Biota for this study is more prone to overestimate spawning activity because redds that are in the initial stages of use may be counted twice if the painted rock marker is displaced or hidden between two weekly samples, as by gravel excavation associated with subsequent redd construction or spawning. Another disadvantage of this methodology is that it requires significantly more labor and staff to conduct weekly surveys throughout the spawning season.

Although comparison between the two available redd count data sets is problematic, both data sets have documented increases in spawning activity in response to channel restoration and spawning

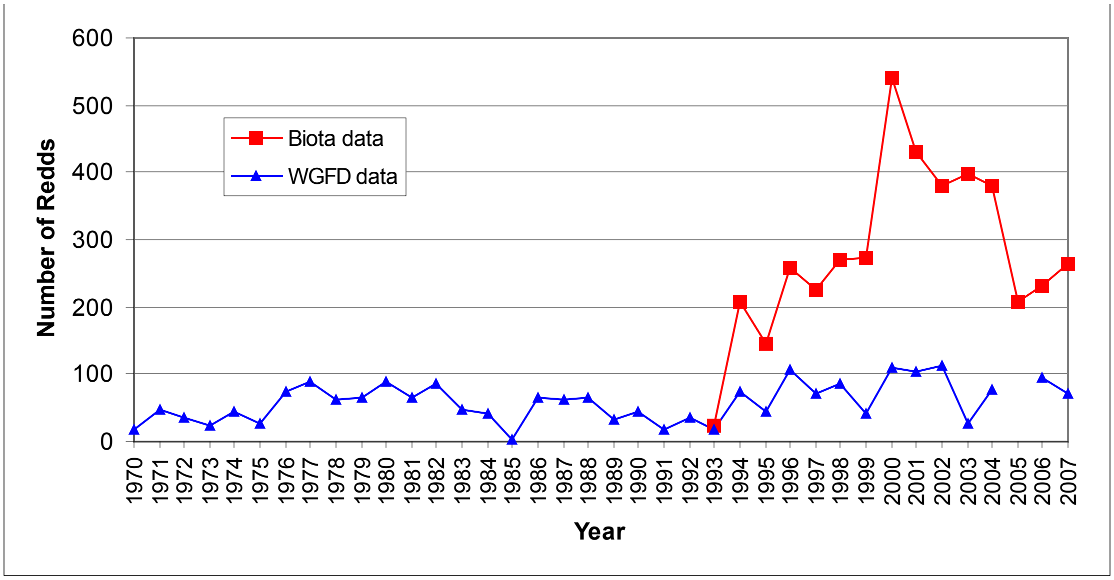

Figure 2. Annual Redd Survey Data Three Channel spring Creek Project Area

bed maintenance efforts. The restoration projects completed in 1993, 1999, 2002, and 2006 were followed by redd surveys that documented increased numbers of observed redds. This suggests that spawning habitat quality and availability is, to some degree, a limiting factor in the reproductive activity of native cutthroat trout in the system. Efforts to restore, enhance, and maintain such valuable spawning habitat in proximity to escape and cover habitat result in increased spawning activity and therefore increased opportunities for recruitment of young age classes of Snake River cutthroat trout into the drainage.

Acknowledgements

Much gratitude is extended to regional biologists with the Wyoming Game and Fish Department for sharing spawning data, experiences, and observations over the years. Without such generous data sharing and cooperation, effective restoration and maintenance projects would not be possible. Also a great deal of thanks is directed to Trout Unlimited, who helped implement the 1993 restoration effort. Thanks are especially directed to the landowners for their willingness, commitment, and support in facilitating these restoration efforts (and the necessary pre- and post-project monitoring). Without their help the restoration and learning opportunities that have occurred in Three Channel Spring Creek would never have been realized.

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Belmont Creek: A Splendid Example of Wild Trout Habitat Restoration

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Abstract

In 2003, Montana Trout helped fund a project of the Missoula (Montana) Field Office of the Bureau of Land Management to restore a badly degraded reach of Belmont Creek, a designated core recovery stream for the threatened bull trout *Salvelinus confluentus* in western Montana. The project location is typical of many small valley streams in the northern Rocky Mountains, but the project's elements have replication values for many other locations. This project was significant because (1) it used resource-sensitive and cheap methodologies that intentionally rejected a "Rosgen"-style, engineering-heavy approach, and (2) it was very effective at restoring natural processes and functions essential for current and long-term habitat benefits for native wild trout.

Introduction

Montana Trout is a small nonprofit organization based in Missoula, Montana, and dedicated to the restoration of wild trout habitats and populations. In 2001, 1 year after formation, Montana Trout partnered with the fisheries staff of the Missoula Bureau of Land Management (BLM) office to implement what would be our first project. The BLM had recently acquired a section of land containing the lower reaches of Belmont Creek, a tributary of the Blackfoot River in western Montana. Only a few years before, this stream had been designated by Montana Fish, Wildlife and Parks (MFWP) as a core recovery area for the federally endangered Bull trout *Salvelinus confluentus*, owing to Belmont Creek's historical significance as an important spawning and rearing stream for this threatened fish (MBTSG 1995). The fluvial form of Westslope cutthroat trout *Oncorhyncus clarkii lewisi*, a designated sensitive species in Montana, also occupies Belmont Creek, as do introduced rainbow trout *Oncorhyncus mykiss* and hybrids *Oncorhyncus spp.* of these two species (Pierce et al. 1997). The BLM's heavily-impacted reach of Belmont Creek inspired newly hired fisheries biologist M. Jo Christensen to apply stream restoration practices she had honed over the past several years while working in Oregon and Alaska. However, a lack of agency funding prevented the project from being implemented. Montana Trout offered Ms. Christensen aid in securing the needed funding for Belmont Creek's restoration, which was successful and enabled the project to move forward. To fully appreciate the importance of this project, however, a little context is in order.

Over the past few decades, a remarkable amount of change has transpired in terms of how people interact with trout streams in the northern Rocky Mountain region. A half-century ago in this region, the very idea of stream restoration was out of step with social values driven by a utilitarian, resource extraction-oriented value system. During the last two decades, the science and practice of stream restoration has grown rapidly in response to recognition that negative impacts to rivers and streams need to be remedied and mitigated. As stream restoration methodology and philosophy has evolved, heavily engineered (and often costly) approaches have become popular, often with a focus on creating forms (rather than restoring processes and functions) and with mixed results (Kondolf 2006). However, other approaches more sensitive to the simple restoration of the processes and functions found in nature exist as well. This presentation describes how a focus on restoring natural processes and functions was put into practice using a low-cost, low-technology, and low-impact method. The strategic placement of whole downed trees into the active channel of a seriously degraded wild trout stream (Belmont Creek) resulted in a quick return of desired natural processes and functions, in turn enhancing wild trout habitat, all of which translated into a splendid example of wild trout habitat restoration.

The importance of woody debris in creating and maintaining the processes that in turn create habitat for salmonid fishes has been well documented (Keller and Swanson 1979; Swanson et al. 1982, Sedell and Swanson 1984). Woody debris in the reach of Belmont Creek proposed for work was largely absent due to active removal as well as deterioration of riparian vegetation that would naturally contribute woody structure. Bureau of Land Management (BLM) biologists recognized that many of the natural processes and habitats lacking in Belmont Creek were those associated with large woody material and developed a restoration plan involving the placement of whole downed trees within Belmont Creek's active channel and on the floodplain. The goals and objectives for the restoration of Belmont Creek's meadow area were to (1) restore *processes* that maintain wet-meadow hydrology to facilitate channel aggradation to enable floodplain interaction and the return of the native wetland plant community, and (2) restore *structure* that creates and maintains diverse aquatic habitat until native vegetation can take over to increase aquatic habitat diversity, increase the number of complex pools and residual pool depth, and create useable spawning habitat for native trout.

Study Site

Belmont Creek is a 17.7-km long tributary on the north side of the lower Blackfoot River in western Montana, about 32 km northeast of Missoula, Montana. Belmont Creek drains a watershed about 7,689 ha in size, with a high elevation of 2,034 m and a low elevation of 1,094 m where Belmont Creek joins the Blackfoot River (Sugden, 1994). Plum Creek Timber Company owns almost the entire watershed. The section of land, obtained by the BLM in 2000, at the low end of Belmont Creek contains a large meadow. The rest of the Belmont Creek drainage is relatively steep and, historically (beginning in the 1960s), was heavily logged with an extensive road network (about 2.8 km/km^2). The meadow area was once a moist wetland with a dynamic, braided stream dominated by beaver activity. Woody debris sources were likely historically abundant owing to the heavily forested slopes immediately adjacent and upstream from the project (J. Christensen, BLM, personal communication).

During the last century, this meadow area was used as a livestock pasture. The stream was trenched into one channel and subsequently lined with riprap along the streambanks (Figure 1). Livestock grazing and a lowered water table resulted in the loss of most of the meadow area's riparian vegetation and hydrophytic plants. When the BLM obtained this reach of Belmont Creek, the stream had become incised, shallow, over-widened and featureless, largely dominated by large cobble and rubble. Pool habitat was almost absent. The adjoining meadow was largely bare soil with a vegetation composition largely (over 95%) of noxious weeds (spotted knapweed *Centuaria maculosa*, cinquefoil *Potentilla simplex*, oxeye daisy *Chrysanthemum leucanthemum*, and tansy *Tanacetum vulgare*) and exotics (timothy *Phleum pratense* and kentucky bluegrass *Poa pratensis*). A ragged line of old, decadent shrubs grew along the channelized reach of Belmont Creek within the meadow area. Substrates within a size category suitable for spawning comprised only 1% of the substrate in the reach. Belmont Creek is considered a priority for restoration and protection as habitat for bull trout, a native char

Figure 1. Belmont Creek pre-project (2001).

growing to over 760 mm in length and listed as a "Threatened" species under the federal Endangered Species Act in 1999. Montana Fish, Wildlife and Parks (MFWP) information about the historic abundance of bull trout in the Blackfoot River along with documented evidence of bull trout within Belmont Creek itself, and the fact that Belmont Creek was one of the only bull trout spawning streams in the lower Blackfoot River with a perennial connection to the river, led to this ranking of Belmont Creek (R. Pierce, MFWP, and J. Christensen, personal communication).

Methods

Two major restrictive conditions were imposed upon the restoration of Belmont Creek at the outset of planning for this project. The meadow area contained the remnants of a log structure built around the turn of the century by early settlers, and also contained prehistoric artifacts. Additionally, it was important to avoid physical damage to the few intact, functioning wetlands and to the sensitive streambanks that were not well stabilized by vegetation. To protect cultural and archaeological resources and to prevent damage to streambanks associated with the use of heavy machinery, draft horses trained in logging were used (Figure 2). The draft horse team pulled downed trees into staging areas and then, with a system of cables and pulleys, elevated and moved the downed trees into place. The draft horse team approach was proven effective in that no damage to either archeological resources or to riparian habitats was created during the course of the project's implementation.

Figure 2. Belgian draft horse team on site.

An initial step was to identify places in the channel where wood would naturally "rack up", if it were being contributed naturally (these places are usually at tight corners, geologic nick points, at the upstream ends of islands, and so forth). Sites for wood placement in Belmont Creek were ultimately selected by focusing on channel aggrading as a major goal. Sites were selected for maximum response. Once suitable locations were thus identified, further assessment occurred to identify features that would allow new structures to stay generally in place (such as wedging tree pieces against standing trees, large boulders, tight corners, and similar places). The presence of suitable anchors and blocks at the proposed structure sites was important in determining where an elevated block system could be used. One very over-widened area was selected in the project reach, because it was immediately upstream of a solid, treed island that would be a natural point for wood to rack up (and the wood has racked up there, quite wonderfully!), even though care was generally taken to avoid shallow, over-widened areas unless other tree pieces were going to be placed along the channel margins (the water in over-widened places, though quite shallow even during high flows, can have sufficient depth to float a tall tree and negate placement). In this instance, however, that tree piece movement was desirable.

As important as embedding trees, was the identification of places where new wood pieces should NOT be placed. These might hypothetically include sites with sensitive plant species, or where there is already good localized habitat (e.g., areas where fish are actually spawning, good salamander or frog habitat, as indicated by the presence of eggs, or nesting sites of ground nesting or bank nesting birds). Sites that were avoided in the Belmont Creek project reach included an American dipper (ouzel) *Cinclus mexicanus* nest, a small off channel area where western toads *Bufo boreas* were breeding, and heretofore-mentioned historical resources.

After placement sites were assessed, the logistical planning for bringing in the project's trees and logs was done. The "decking" sites were chosen by selecting places where it would be relatively easy to get tree pieces into the channel. About 90 trees were brought to the project site and piled in decking areas. The trees ranged from 45 to 100 cm in diameter at the base, and retained some branches and roots. These trees were moved to structure sites by the draft horse team, and placed in position with either direct hauling or using a block-and-tackle cable system (Figure 3). Structures were created by installing "key" pieces and adding subsequent layers of individual trees at varying angles (Figure 4). At times, tree pieces were maneuvered with further finesse using hand-held implements. A total of 22 complex woody jams (structures) were created within the 580 m of the project reach.

Figure 3. Whole trees being placed in Belmont Creek. Note cable (indicated by arrow) attached to log and via tackle (behind shrubs in background) draft horses.

Figure 4. Representative structure site on Belmont Creek illustrating juxtaposition of tree pieces in order to fragment currents at high flows. Note that some tree pieces are completely above the stream surface, which is typical during times of lower flow.

Key pieces were those that provided an anchor point for subsequent tree pieces, as well as structure to engage and hold any large wood moving downstream from the stream above. Tree pieces were not anchored with cable or otherwise secured, except for the natural points that held them in place. Anchoring or fixing structures into place has been shown to prevent channels from adjusting to alterations, resulting in damage or failure of the structure (Beschta and Platts 1986). Additionally, retaining flexibility in the structures ensured that tree pieces rose and fell with water levels to maximize habitat creation at all flows.

The placement of numerous pieces in various positions maximized diversity in flow patterns, making currents break and flow "in 100 directions at once" (J. Christensen, personal communication) to create a variety of channel-shaping flows at varying velocities, in turn creating areas of stronger current with greater scouring abilities and areas of gravel deposition suitable for trout spawning. An important aspect of the creation of each structure was placing pieces at a position where they would interact with the highest volume flows of Belmont Creek (Figure 5). This short period of high flow, generally prompted by snowmelt, produces almost all of the channel-forming activity resulting from interaction with the structures. At other times, e.g. during periods of low flow, the structures tend to be above the water surface.

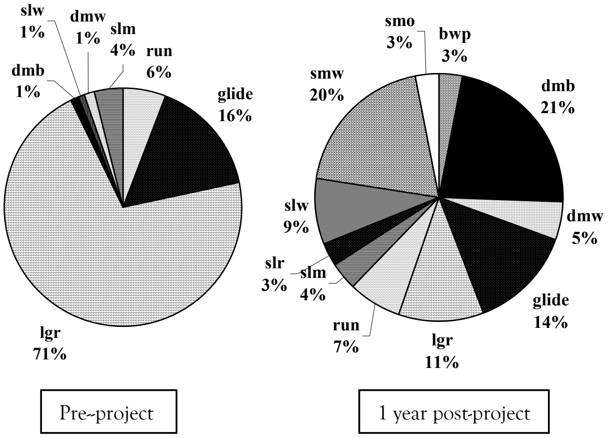
Figure 5. Placed tree pieces during Belmont Creek's high flow, when channel-forming action is greatest.

Monitoring of the project was (and continues to be) essential for determining results and effectiveness. Monitoring began in 2003, and continues. The objectives in monitoring the Belmont Creek project are (1) to compare habitat and species in geomorphically analogous treatment and reference areas, and (2) to conduct detailed habitat inventories, pebble counts, measurements of bed profile and channel elevation changes. Spawning surveys (visual surveys of the numbers and distribution of redds) continue to determine the overall success of the project in increasing the suitability of the project reach for wild trout spawning. Snorkel surveys comparing fish abundance and habitat associations in treatment and reference areas have followed accepted methodologies (Dolloff et al. 1991; 1993; 1996) for determining species use, since electrofishing is inappropriate in waters occupied by bull trout. Comparisons of plant abundance, species composition, biomass, and percentage of bare ground also continue to be monitored in portions of the meadow affected by project and reference areas.

Results

The result of this project was a vastly transformed project area. The wetted width of Belmont Creek in this reach was dramatically reduced, and the low flow channel is no longer wide and shallow but narrow and deep. At the reach scale, habitat diversity was considerably enhanced (Figure 6). For example, riffle habitat comprised over 70% of the pre-project habitat. Riffle habitat is now about 10 % of the reach. Pool habitat increased by 62% after installation of the woody material. Additionally, a variety of new habitat types were created including diverse pool types.

At the site scale, a typical structure created by this project included numerous habitat enhancements. In drops created by the structures, residual pools have formed. Both bull trout and westslope cutthroat trout have been observed frequenting the complex pools formed by the structures. The placed tree pieces have recruited and stabilized fines in deposition areas along stream margins, narrowing the wetted area and providing growth sites for riparian vegetation. The streambed has generally aggraded in association with the placed structures, which have also had the effect of trapping and retaining gravels instream. The percent of substrate in the reach suitable for trout spawning has increased from 1% to 30%. (Figure 7). Wild trout have been routinely observed spawning in these freshly deposited instream gravels. Pool numbers in the project reach increased dramatically (Figure 8), with pool abundance increasing from 2 to 44 in the first year post-project. Because post-project years 3 (2004) and 4 (2005) had considerable beaver activity in the project reach, with associated ponding and the concealment of naturally occurring pools, pool numbers were not censused during those years. Mean residual pool depth also increased from about 13 cm (pre-project) to 41 cm (5 years post-project).



Habitat types classified by flow velocity, depth, and position in the channel, and (if applicable) pool forming element are as follows: bwp = beaver dams/woody structure dam pool; dmb = beaver dam pool; glide =self-explanatory; lgr =low gradient riffle; run =self-explanatory; slm, slr, smw, smo = scour pools formed by wood and classified by location in channel.

Figure 6. Habitat Diversity at the Reach Scale before and after placement of woody debris.

Fish response to the project was particularly striking. In 11 years of redd surveys prior to the project, only four redds were counted in the project reach. In the first year post-project, the redd count was 78. After 5 years, during which beaver activity created substantial change, the stream is stabilizing and the redd count was 58 (Figure 9). During snorkel surveys, bull trout have only been observed in habitats created by woody

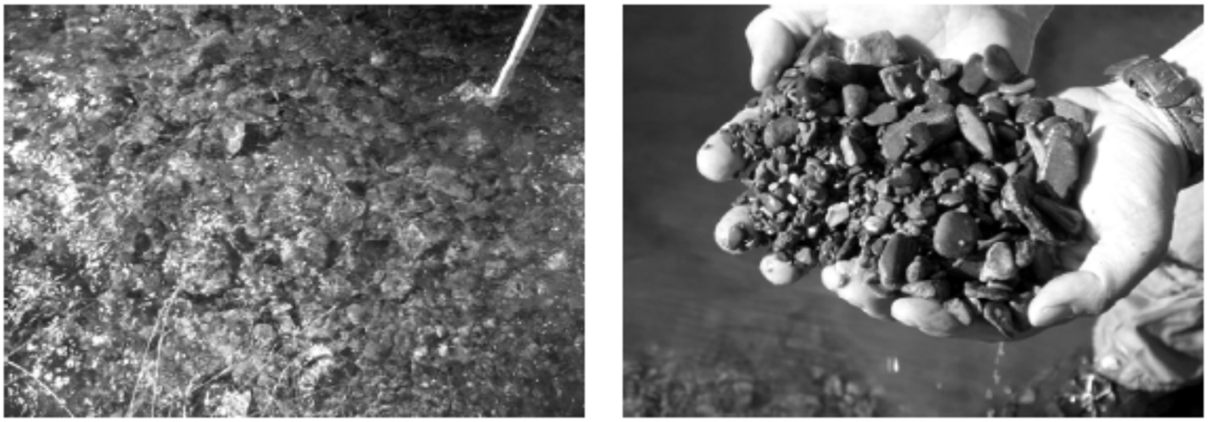


Figure 7. Representative substrate particle size in spawning areas pre-project (left) and post-project (right).

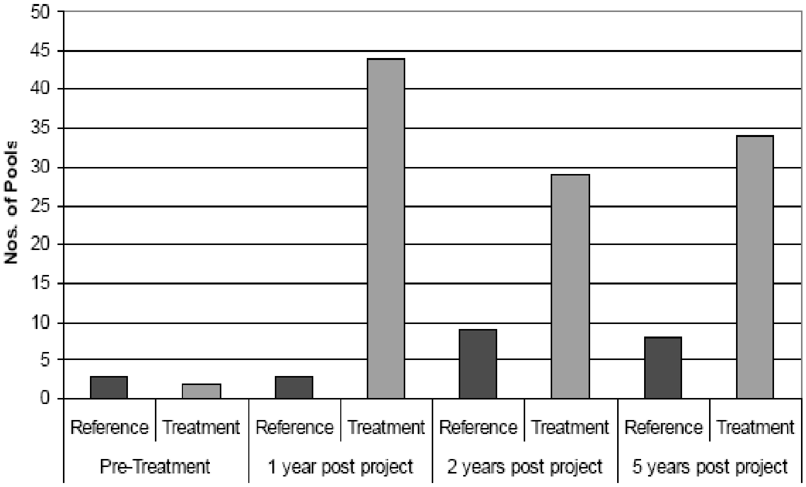


Figure 8. Pool abundance before and after installation of debris jams

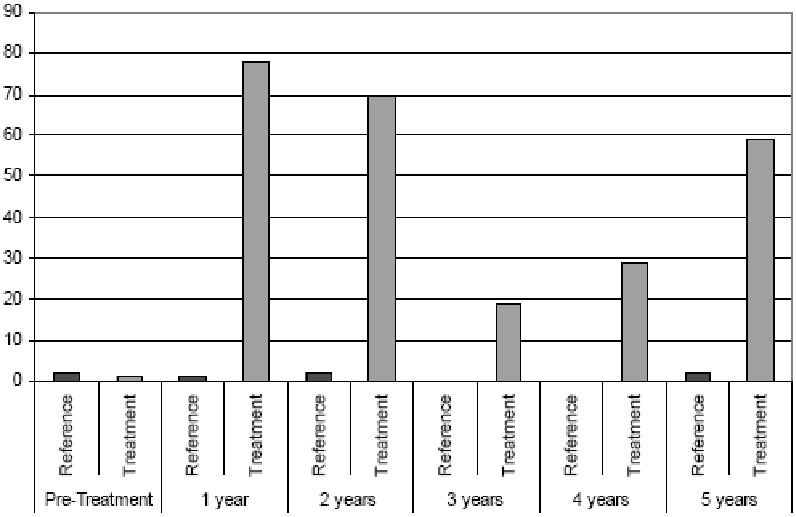


Figure 9. Numbers of trout redds in treatment and reference areas.

structure (primarily complex pools). No bull trout have been observed in untreated segments. Overall, trout abundance in habitats created by woody structures is 14 times greater than trout abundance in untreated reference areas. Additionally, habitats created by woody structure contained the greatest diversity of age classes. These observations do not infer population response, but a reasonable conclusion is that the project created preferred habitat for wild trout.

The meadow area's vegetation composition has particularly changed due to much moister soil conditions. In 2006, 4 years post-project, noxious weeds were present in less than 2% of transect areas, and now comprise less than 1% of plant biomass. Sedges, rushes and hydrophytic forbaceous vegetation now dominate the meadow, including colonies of nebraska sedge *Carex nebrascensis*, beaked sedge *Carex utriculata*, yellow sedge *Carex flava*, inflated sedge *Carex vesicaria*, baltic rush *Juncus balticus*, and small-fruited bulrush *Scirpus microcarpus.* Also present is dagger-leaf rush *Juncus ensifolius*, yellow monkeyflower *Mimulus guttatus*, and large-leaved avens *Geum macrophyllum.* The seed sources of this wetland vegetation are thought to have been dormant in the meadow's soil and responded to increases in soil moisture (J. Christensen, personal communication). Bare soil is now less than 1% of the ground surface, and willows are beginning to colonize riparian areas. Significantly, ponding caused by tree piece structures and beaver activity resulted in Belmont Creek braiding into multiple channels and reclaiming a previously occupied channel (Figure 10).

Discussion

The significant features of this project are that it (1) was relatively inexpensive (about US$7,000 in materials and contracted labor), (2) used simple, non-damaging technology (draft horses, cables and blocks) and, most importantly, (3) successfully and quickly met restoration goals without resorting to a heavily engineered approach. For example, currently popular approaches advocated by devotees of the "Rosgen" school of stream restoration might well have resulted in a plan to excavate a new channel in the Belmont Creek meadow. Strategic placement of tree pieces in the existing channel not only resulted in the restoration of natural processes and functions, but also in the creation of structures that directly benefit targeted wild trout species.

Figure 10. BLM staffer Melissa Maggio stands in one new channel of Belmont Creek, which is now braided in numerous channels in the meadow area. Note the abundance of hydrophytic vegetation.

The freshly deposited gravel bedload annually created by these structures is the preferred spawning substrate for westslope cutthroat trout (Schmetterling 2000). Bull trout and westslope cutthroat trout observed in the project reach were always seen in close association with the large woody debris structures created by this project.

An unexpected but tremendously beneficial circumstance was the return of beaver *Castor canadensis* to the Belmont Creek meadow. Prior to the project, a few beaver still occupied the Belmont Creek drainage upstream of the project area. The placement of all the large wood structures in the project reach provided beaver with suitable conditions for dam building. Those conditions had not existed for many decades. High flow volumes and velocities, coupled with the absence of any large instream wood, made conditions impossible for beaver to build any dams. Within 2 years of project implementation, every one of the project's structures was used by beaver for dam building. The "beaver era" of 2003 – 2006 masked the pool creation aspects of this project owing to the large amount of ponding created by beaver dams, but had the highly beneficial effects of enhancing the deposition of fines and raising the water level in the adjacent meadow sufficiently to re-activate the dormant seeds of wetland plants, while eliminating noxious weeds and mesic forbs. The structures within the project reach would likely have created the same result, but the beaver activity hastened the process considerably.

In building the large wood structures, tree pieces were not placed in or on top of high gradient channel units with very large diameter substrate particles, because the substrate was considered to be too big to be influenced by scouring currents. Care was also taken to not convert the entire project reach to complex woody pool habitat. The pool-to- riffle ratio appropriate for the site, as determined through comparison with a reference area (which could also have been a similar stream or predictive model), was maintained to allow retention of essential riffle habitats.

Because the Belmont Creek meadow was historically a wet meadow and beaver dam complex, the sort of large woody debris jams created by this project may never have been abundant. In initial assessments, BLM biologists noted a few pieces of large wood that had been transported in from the high gradient forested reach immediately above the meadow reach, and large wood pieces, as noted, were probably historically present due to the thickly forested slopes adjoining the meadow. However, the intent of this project was not to create a series of permanent large wood structures that would have to be artificially maintained. The placement of large wood in Belmont Creek's meadow reach was intended to give the stream the 'building blocks' to attain the elements of function that were critical for restoration of meadow hydrology and associated aquatic habitats. That goal has already been successfully met, although benefits will continue to accrue. The wood structures put in place are biodegradable and were a temporary fix until shrub and willow communities recover sufficiently to contribute structure on their own.

Acknowledgements

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Restoring Natural Channel Processes through Dam Removal

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Abstract

In October 2005, Cedar Creek Dam, which provided municipal water supply for the Town of Ione was removed, allowing Cedar Creek to flow freely to the Pend Oreille River for the first time in over 50 years. The project was the result of nearly 5 years of collaborative effort between the Town of Ione, Washington Department of Fish and Wildlife, and 12 local, state, tribal, and federal partners. The dam had become a threat to public safety and was preventing migration of native trout, including bull trout *Salvelinus confluentus*, westslope cutthroat trout *Oncorhychus clarkii lewisi*, and mountain whitefish *Prosopium williamsoni* to 12 miles of some of the best habitat in the Pend Oreille River watershed. The project included removal of the 19-ft high, 95-ft wide dam, excavation of 20,000 yd^3 of accumulated sediment, reconstruction of over 1,000 ft of stream channel, and restoration of riparian vegetation. Following design concepts promoted in Washington's Aquatic Habitat Guidelines, project objectives were to restore fish passage while facilitating restoration of natural channel processes including large wood and sediment transport, and riparian and floodplain function. A sustained high flow event in the spring of 2006 caused various levels of streambed incision. Adaptive management was employed, and additional channel modifications were made.

Introduction

On October 11, 2005, the Town of Ione, in partnership with the Washington Department of Fish and Wildlife (WDFW) and 12 other federal, state, tribal, and local partners, removed the Cedar Creek Dam (Figures 1 and 2). The dam was constructed in 1950 to provide a municipal water supply for the town. It was a complete passage barrier to migratory fish including bull trout *Salvelinus confluentus*, a species listed as threatened under the Endangered Species Act, westslope cutthroat trout *Oncorhychus clarkii lewisi*, and mountain whitefish *Prosopium williamsoni*. The dam was an un-reinforced concrete arch dam approximately 19 ft high with a crest length of 95 ft. It was constructed to impound approximately 10-15 ac-ft of water, but the reservoir at the time of removal was completely filled with sediment. The dam was in disrepair and at risk of failure at high flow due to abutment erosion and overtopping. The dam's reservoir was acting as a heat sink, likely contributing to exceedences of Washington State water quality standards for temperature (USDA – Forest Service 1999).

Figures 1 and 2. Cedar Creek Dam before (top) and after removal (bottom) in October 2005.

The project area is located at River Mile 1.5 of Cedar Creek, a tributary to the Pend Oreille River within the Columbia River basin in northeastern Washington State. The Pend Oreille River originates at the surface outflow of Lake Pend Oreille, Idaho, which is fed by waters of the larger Clark Fork drainage of Idaho and Montana. The Columbia River Distinct Population Segment of bull trout, which includes the Pend Oreille sub-basin populations, was listed under the Endangered Species Act as "Threatened" on June 10, 1998 (63 FR 31647). Bull trout were once abundant in the Pend Oreille River (Gilbert and Evermann 1895) and have been documented as occurring historically throughout much of its 155-mi length (Andonaegui 2003). Removal of the Cedar Creek Dam restored fish passage to approximately 12 mi of stream in the Cedar Creek drainage, including about 3 mi of designated bull trout critical habitat (70 FR 56212). Cedar Creek has been described as representing the "best habitat condition of all streams" in the Box Canyon Reach of the Pend Oreille River (KNRD and WDFW 1997).

The Town of Ione was dependent on Cedar Creek for its water supply from the early 1900s to 1988. Initially, several log crib dams were constructed along the lower reaches of Cedar Creek, each of which was either washed out in high flow or removed and replaced. In 1950 Ione constructed a more modern, permanent concrete arch-type dam. The dam was constructed without fish passage facilities. In 1988, Ione converted to groundwater wells and the surface diversion has been inactive since then. The dam fell into disrepair in recent years and was at risk of failure at high flow due to overtopping and abutment erosion. In April 2002, the Washington State Department of Ecology (Ecology) Dam Safety Office issued Administrative Orders to Ione requiring that safety deficiencies at the dam be corrected by October 2004. Emergency, temporary repairs to the dam were done in the fall of 2004, but Ione decided that removing the dam was the most cost-effective and long-term solution for restoring fish passage, improving water quality, and eliminating safety hazards.

The primary objective of this project was to support bull trout recovery and watershed restoration within the Pend Oreille watershed by

- Restoring channel processes to allow and support passage of all fish species and life stages historically present in the stream;
- Restoring stream form and function, including watershed hydrology, sediment, and wood transport;
- Reducing water temperatures to improve spawning and rearing conditions for bull trout and other native salmonids;
- Restoring riparian and floodplain cover and function; and,
- Eliminating risks to public health and safety from potential dam failure.

Concepts provided by Washington's Aquatic Habitat Guidelines were used to guide design and implementation.

Funding for the project was provided by Washington's Salmon Recovery Funding Board, Ecology, and the U.S. Fish and Wildlife Service. Donations of in-kind labor, materials, and equipment were provided by WDFW, Ecology, Washington Department of Natural Resources, Washington State Department of Transportation, Pend Oreille County, Kalispel Tribe, Colville National Forest, Federal Highway Administration, Curlew Job Corps, Fairchild Airforce Base, and Ron Lundberg, a private citizen.

This paper summarizes the design approach and construction methods of the dam removal. Additionally, we discuss the impacts of a sustained high-flow event, which occurred less than 8 months post-construction, had on the project site.

Methods

Project Design

The approach to project design was based on concepts provided through Washington's Aquatic Habitat Guidelines (http://wdfw.wa.gov/hab/ahg/). The guidelines facilitate the consistent application of good science and practices for project design, construction, and operation affecting aquatic systems in Washington.

In March 2005, the Town of Ione commissioned Inter-fluve, Inc., a river restoration firm from Hood River, Oregon, to design and implement the dam removal project, including oversight during stream reconstruction. Design specifications included (1) removal of up to 26,000 yd^3 of sediment from the dam forebay; (2) off-site sediment disposal; (3) reconstruction of 1,200-1,500 ft of stream channel, including large wood (LW) installation and pool riffle sequence construction; (4) biotechnical bank stabilization; and, (4) riparian restoration including salvaged, on-site native materials such as topsoil, sedge mats, and hardwood cuttings.

Inter-fluve, Inc. collected the following information to develop a comprehensive basis for design:

- Topographic survey, including profile and cross sections to be used for hydraulic model input, earthwork volume calculations, and base mapping in AutoCad;

- Sediment characterization using Wolman pebble counts and bulk sediment sampling;

Hydrologic analysis to identify channel stability flows and fish passage flows; and

- Reference reach channel and habitat data.

Channel design would provide a natural process-based solution for restoration of Cedar Creek in the reach influenced by the dam. The channel stability objective was to construct a somewhat deformable channel, but provide enough stability for floodplain vegetation to become well established over time. Modeling using the HEC-RAS steady state hydraulic model was employed to develop appropriate biotechnical bank designs, evaluate the need for streambed grade control, and design specific components of the streambed, banks, and other flood-prone surfaces. Design criteria required by WDFW included streambed stability up to a 5-year recurrence flood and floodplain stability up to a 10-year recurrence flood. Streambed stability was based on sizing bed material in riffles to withstand the 5-year recurrence design flow. Designed channel bankfull widths and depths were 30-35 ft and 1 ft, respectively, and overall channel slope was 2.2%. Bedrock outcrops and relatively confining valley walls largely defined the channel sinuosity.

Bank stability was a challenge, because bank material was sand and silt deposited in the reservoir pool. Bioengineering treatments were identified that incorporated native and commercial plants appropriate for the watershed and to the predicted hydraulic conditions. Stabilization techniques included fabric encapsulated soil lifts (FESLs), large wood (LW) revetments and logjams, gravel and cobble point bars, and LW scattered on the floodplain and point bars. Shear stress and scour calculations were used when developing appropriate bioengineering treatments. Soil lifts were stabilized using a layer of woven coir mat to provide strength, and a layer of non-woven coir mat to retain fine sediments. Large wood and boulders also provided fish habitat elements in the new channel.

Conceptual and preliminary design documents, including drawings, specifications, engineer's cost estimate, and construction schedule, were developed for review and approval by a multi-agency, interdisciplinary team lead by WDFW.

Construction

In July 2005, the Town of Ione commissioned B&W Excavating and Construction of Valley, Washington, to implement project design. Engineering staff from Inter-fluve, Inc. was retained to oversee the construction contract and implementation.

A significant issue for construction was dewatering the entire construction zone. The contractor installed a 4,000-gpm (8.9 cfs) turbine pump to bypass the entire stream around the construction zone. The pump, powered by a diesel generator, operated 24 h a day for about 8 weeks. One thousand feet of 12-in diameter high-density polyethylene pipe (HDPE) were welded on site and attached to the pump. The flexibility of the pipe allowed for maneuvering around the construction site as necessary to facilitate excavation and streambed reconstruction. The pipe was moved several times during construction without shutting down the pump or disconnecting the pipe. The pipe withstood several episodes of severe bending without breaking or significant leakage (Figure 3). Prior to dewatering, fish located in the project reach (approximately 1,200 ft) were removed from the stream and relocated to other suitable habitat outside of the project area. Block nets were installed at the upstream end of the project site to keep fish from entering the work area. Sediment control dams at the lower end of the project site provided a barrier to upstream migration. Additional screening was installed around the turbine pump to prevent entrainment.

Excavation equipment included two tracked excavators, a large dozer, three 20-yd^3 articulating dump trucks and two 10-yd^3 dump trucks for backup. Excavation of 20,000 yd^3 of sediment took less than 3 weeks with two, five to six person crews working 7 d per week (Figure 4). Sediment was hauled approximately 0.1 mi to a private field.

Channel reconstruction and bank stabilization included the placement of approximately 120 pieces of large wood (10-26 in diameter) and 2,800 ft of fabric encapsulated soil lifts (Figure 5). The majority of the LW was placed along the margins or partially spanning the new channel. To maintain grade control, two channel spanning logs were buried as sills at the upstream end of two of the riffles. Riparian and upland plantings included 750 shrubs, 200 hardwood trees, 1,460 conifers, and 80 pounds of native grass seed mix. Native materials salvaged from the project site, such as forbs, woody and herbaceous

Figure 3. Flexible HDPE pipe used for dewatering was moved several times without breaking or significant leakage

Figure 4. Excavation of sediment stored behind Cedar Creek Dam (Inter-fluve, Inc. photo)

Figure 5. Fabric encapsulated soil lifts installed to stabilize stream banks (Inter-fluve, Inc. photo)

plantings, alluvial sediments, and dead wood of various sizes, were incorporated into the floodplain to provide roughness and stability. Grass seed was planted under coir fabric and hardwood cuttings were planting between layers in the FESLs. Large wood was "passively" anchored; cable anchoring was only used on one log complex.

The total project cost to date is US$976,023, which includes in-kind donations of labor, materials, and equipment from partnering entities valued at $64,538. Approximately 23% of the budget was used for administration and engineering, including on-site construction management services provided by the engineering contractor. Construction costs, including permitting and riparian restoration, were approximately 77% of the budget. A breakdown of the budget is provided in Table 1.

Discussion

The finished channel met the design requirements for slope, number of pools, and bank-full widths and depths. The location of pools was at or slightly downstream of the locations in the design drawings. The total length of soil lifts was less than designed, because it was decided they were not necessary at several of the point bars. Design documents specified use of a liner of streambed materials of appropriate size based upon channel stability analysis. However, after excavation unearthed the original stream channel, an in-the-field decision was made to leave that material in place instead of hauling in off-site streambed material.

The region experienced a higher than average snow pack the winter of 2005-2006, and a moderately high run-off. The nearest gauged stream (Colville River) experienced a flow with about a 10-year recurrence interval. It is probable that Cedar Creek also experienced flows higher than the 5-year recurrence, if not the 10-year. A July 2006 channel profile survey showed that the project experienced varying degrees of incision and deposition during the runoff, with incision dominating (Figure 6). The thalweg at the downstream logjam dropped about 1.5 ft (Sta. 5+00).

Table 1. Summary of administrative, engineering, and construction costs for the Cedar Creek Dam removal project

Administration and Engineering		**$ 222,963**
Administration	$ 1,614	
Engineering technical assistance (in-kind)	$ 10,442	
Engineering contract, inc. on-site construction management services	$ 208,236	
Construction		**$ 753,060**
Construction contract	$ 651,447	
Riparian restoration materials	$ 6,828	
Permits and legal notices	$ 686	
Technical assistance, material, and equipment donations (in-kind)	$ 51,426	
Miscellaneous construction expenses, site maintenance, etc.	$ 42,673	
Total project cost		**$976,023**

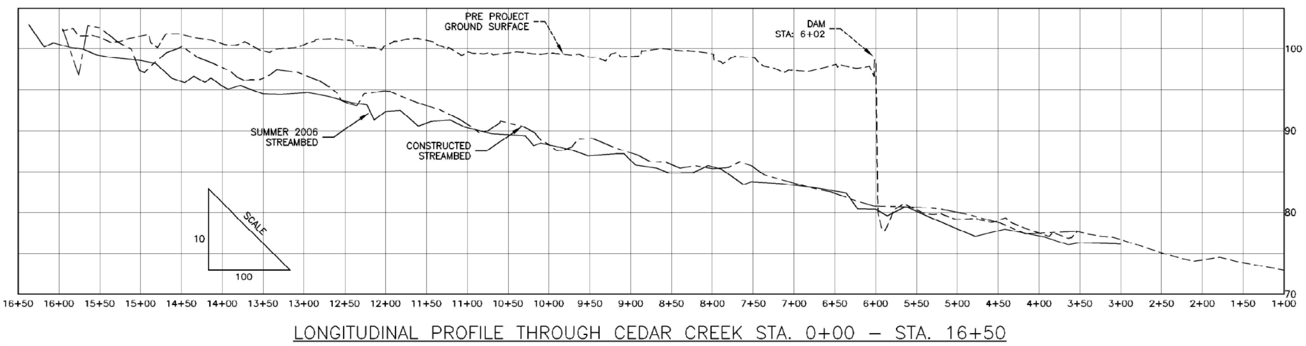

Figure 6. Longitudinal profile of project site showing pre-project ground surface, constructed streambed (November 2005), and adjusted streambed following high flow event (July 2006).

The riffle from there to the log jam installed at the previous dam site (Sta. 6+00) lowered about 6 in. The lower end of the riffle above that logjam stayed at grade (Sta. 6+50), but the upper end of that riffle dropped about 2 ft (Sta. 7+50). From there on to the upper end of the project the bed was generally 1.5 to 3 ft lower than the constructed profile (Figure 7). There are several places where the new bed is at the same elevation as the constructed profile (Sta. 10+00, 10+90, and 12+50), but those are now riffles at the elevation of the old bottoms of pools. In many places the channel scoured to bedrock. The only places with any filling were at the de-watering pump pool and the pool just downstream (between Sta. 16+50 and 15+00), which are now both riffles.

The FESLs generally adjusted to the new streambed elevation without failing. The only significant bank erosion was at two full-span log sills, which were both undermined. At these logs, low flow now goes entirely under the logs and high flows go over, creating downstream scour (Figure 8). The downstream banks eroded at both of those logs.

An inventory of revegetation plantings was conducted in the spring of 2007, approximately 1 year following installation. Only plants on the left (i.e., north-east) bank were inventoried owing to high water preventing access to right bank plantings. Fifty-eight percent of total plants installed in 2006 were inventoried to determine percent survival by species. Of plants inventoried, survival ranged from 38% to 100% (mean = 61%). Failure of some plantings is attributed to poor or improper planting technique. Overall, native materials salvaged from the project site pre-construction and replanted on site show good success. Sedges, herbs, and some deciduous shrubs have returned to the site from these salvaged materials. The Washington State Hydraulic Project Approval permit requires 80% survival of plantings over 3 years post-project. If necessary, additional plants may be installed in the future to help meet this objective.

Several lessons were learned from the adjustments caused by high flows. One was the importance of design criteria that included an assessment of acceptable level of risk. Despite the incision that occurred, the project was considered a success. Relatively high-frequency flow events (5 and 10-year recurrence) were chosen for hydraulic calculations so that the channel would be less rigid than typical engineered channels, which are often designed for 25- to100-year events. The level of risk to the project was considered acceptable since the majority of the stored sediments were removed from the reservoir, and because fish passage was not likely to be at risk from erosion processes. There was no significant infrastructure nearby in either direction. The banks and floodplain surfaces generally remained intact and the revegetation success was acceptable.

Figure 7. Channel incision occurred during a high flow event eight months following project completion

Figure 8. Significant bank erosion occurred at full span log sill, undermining the structure

The second lesson is the difficulty of designing constructed riffles. Since constructed riffles have not experienced the bed armoring process that occurs at natural riffles, it may be wise to slightly oversize the rock in the constructed riffle. Because the flows exceeded the design flows for the project, this conclusion may not seem clearly supported. However, lack of similar levels of incision in the unaltered upstream channel indicates that naturally armored riffles are more resilient.

An adaptive management strategy was employed in late summer 2006 to try to reduce incision in the long term. Using part of the remaining project budget, six LW complexes were built in the lower 600 ft of channel that was still reasonably accessible. Each LW complex included one or more full-spanning pieces of wood that are intended to collect additional wood during high flows (Figure 9). The expectation is that these complexes will cause gravel deposition as they create hydraulic resistance during high flows. This deposition should increase the backwater depth in upstream pools, reduce the bank-full depth in riffles, and reconnect the channel to the floodplain.

Monitoring to date has consisted of an inventory of revegetation plantings to assess survival, photo points, inventory of pre- and post-project on-site fish abundance and composition, and channel profile surveys. Monitoring was not an eligible expense of the funding sources used for the dam removal and stream restoration. All monitoring has, therefore, been done through "in-kind" donations of labor and equipment from WDFW, other natural resource agencies, and local volunteers.

Figure 9. Channel spanning log jams were installed to increase gravel deposition.

As discussed previously, prior to dewatering in 2005, fish located in the project area were removed from the stream and relocated to suitable downstream habitat. A standard three-pass electrofishing protocol was used for removal and to estimate population numbers. In 2006 and 2007, the same reach was surveyed using the same protocol, except that fish were not relocated. Results show a reduction in the percentage of brook trout *Salvelinus fontinalis* in total species composition and an increase in cutthroat trout x rainbow trout *Oncorhynchus mykiss* hybrids following project completion (Table 2). Removal

Table 2. Fish abundance and composition pre- and post-removal of Cedar Creek Dam near Ione

	Pre-construction		Post-Construction			
	2005		2006		2007	
Species	Number	Percent	Number	Percent	Number	Percent
Rainbow trout[1]	1	0.1	36	11.0	107	25.2
Slimy sculpin	228	23.6	95	29.1	141	33.3
Eastern brook trout[1]	729	75.3	147	45.1	127	30.0
Westslope cutthroat trout	9	0.9	45	13.8	3	0.7
Rainbow trout[1] x cutthroat trout hybrid	1	0.1	3	0.9	16	3.8
Brown trout[1]	0	0.0	0	0.0	1	0.2
Young-of-year salmonid[2]	0	0.0	0	0.0	29	6.8
Total fish	968		326		424	

[1] *These fish are not native to the project area*

[2] *Presumed to be rainbow trout, westslope cutthroat trout, or hybrids as young-of-year eastern brook trout were large enough to identify*

of the dam has sifted the habitat in the project reach from reservoir to riffle-pool, which tends to favor cutthroat trout, rainbow trout and slimy sculpins *Cottus cognatus*. Maturation of the channel and habitat features is anticipated to show a future shift in species composition toward native dominance as time progresses.

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Providing Habitat for the Wild and Rare in the Riparian Area

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Abstract

Each year federal, state, and county conservation agencies spend millions of dollars to stabilize streambanks and create habitat for trout. However, past stream restoration projects in the upper Midwest have often failed to incorporate habitat for nongame species such as snakes, frogs, turtles, and birds, primarily because of a lack of knowledge about those species' habitat needs. Most recently every state has prepared a Wildlife Action Plan as a prerequisite to receive federal funding to implement habitat projects for nongame species. Developing habitat for other nongame species at the same time that construction equipment is being used for trout stream projects is efficient and cost-effective. Not combining habitat for these species is a missed opportunity. In the Driftless Area of the upper Midwest, conservationists are planning projects that improve water quality and riparian habitat while implementing these projects in a way that benefits multiple nongame species.

Introduction

The Driftless Area is identified in all four State Wildlife Action Plans (Minnesota, Illinois, Wisconsin and Iowa) as the highest priority area for number of Species in Greatest Conservation Need, and all four plans have identified water quality, hydrology, geomorphology, and riparian habitat as priorities within the Driftless Area. The streams and riparian areas of the Driftless Area suffer from a history of erosion as a result of agricultural land use. Across the region, hundreds of miles of spring creeks have been inundated with soils and fine sediment, which has degraded water quality, increased stream temperatures, damaged aquatic habitat, and altered watershed hydrology. For over 50 years conservationists and conservation organizations have been working to improve Driftless Area streams by stabilizing the streambanks and incorporating habitat for trout. Trout Unlimited has recently completed a survey of the Driftless streams and has identified more than 450 mi of various stream segments that have been improved (Thrall 2007). Unfortunately, little if any effort was made to specifically target nongame species habitat for the past 50 years. In fact, habitat such as woody debris that provides refuge for a number of nongame species is often removed in the process of stabilizing the streambanks. By improving knowledge about habitat for nongame species and providing additional dollars targeted for these species, the carrying capacity of game and nongame species in the riparian corridor can be increased. Also, because conservationists are already working with large equipment in the riparian corridor to complete their projects, with a little additional work, habitat for nongame species could be incorporated into the project for a fraction of the overall cost of the project.

Study Site

Located in the heart of the Upper Mississippi River basin, the geographically distinct 24,000-mi2 Driftless Area of southwest Wisconsin, southeast Minnesota, northeast Iowa, and northwest Illinois is interlaced with more than 1,200 streams (more than 4,000 river miles) that spring from the underlying limestone-bedrock (Figure 1).

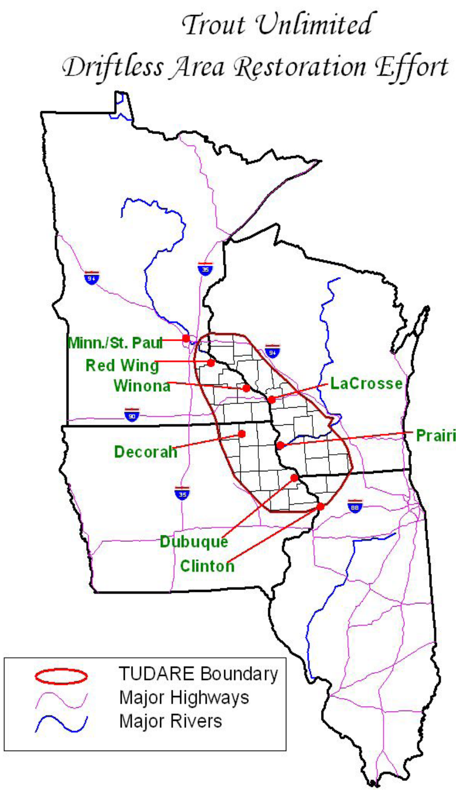


Figure 1. Driftless Area – covering four states

Methods

In 2005 the Vernon County Land and Water Conservation Department working with Robert Hay, a Cold-blooded Species Program Manager with the Wisconsin Department of Natural Resources, explored various instream projects to improve the habitat for turtles, frogs, and snakes on the West Fork of the Kickapoo River in Vernon County Wisconsin. Then, in 2006 the Wisconsin Department of Natural Resources Western Area Fisheries, working with nongame biologist Armund Bartz, developed a series of projects on the Bad Axe River in Vernon County, Wisconsin. These two pilot projects were designed and constructed to experiment with cost-effective practices for nongame species at the same time other construction was occurring for bank stabilization and trout habitat.

Turtles - Wisconsin has 11 species of turtles. Ten of the 11 turtle species spend their winter under water. A turtle is able to spend time under water by taking water into its mouth and cloaca (the termination of the urinary and digestive systems). Here, the skin lining the throat and cloaca is capable of exchanging enough oxygen and carbon dioxide to sustain the low metabolism. To protect themselves from freezing, several of the species bury themselves in the substrate while others simply lie on top of the substrate and remain fairly immobile during the winter. Several radio-tracking surveys have shown that many turtles do not actually hibernate, but instead remain semi-active, moving about during the winter. Two of Wisconsin's threatened turtles the Wood Turtle *Clemmys insculpta* and Blanding's Turtle *Emydoidea blandingii* have been observed mating under ice (Christoffel et al. 2002). Conservationists working with herpetologists several practices were identified that created permanent pools that could help turtles over winter underwater.

One instream structure used to create permanent pools is a "Vortex Weir", constructed by placing large rocks in the shape of a "V", with the point of the "V" pointed upstream (Figure 2). As water flows over the rock, it is directed to the center

Figure 2. Example of a Vortex Weir

of the stream and the action of the water falling over the rock scours out a deep pool below. This practice originally designed for trout to create a deep pool also benefits turtles. Large boulders that are placed below the weirs create pockets that reduce stream flow and reduce the amount of energy needed by trout and turtles to feed.

Another goal was to design habitat that replicates the natural habitat created when large trees lodge themselves adjacent to streambanks during flooding events. These trees are often removed to allow shaping and stabilization of an eroding bank. The large trunk or roots of a tree slow the water down and allow silt to settle and accumulate. Turtles locate these deposited fine silts and bury themselves in the fall. Unfortunately, some of the worst streambank erosion occurs adjacent to these unstable tree roots, and often what is good habitat one year is frequently gone the next year with the spring floods. However, constructing practices that create pockets of fine silt can be designed so that there is no erosion, and they remain permanent. Working with contractors and a large excavator, woody debris can be anchored and placed below the water line so that debris does not accumulate and cause erosion (Figure 3).

In 2006 and 2007, both state and county projects developed areas where silt was allowed to build up and provide over wintering habitat. Wooden structures originally developed to provide overhead cover for trout and placed in conjunction with rock riprap were also installed in a way to collect silt. The state Wisconsin Fisheries crew also experimented with woody debris for turtles by stacking large branches into the bank where fine silts would collect. Both practices were designed to accumulate silt and do so without causing further erosion of the banks.

Walk any stream or pond and you can often find turtles basking on floating logs. Basking helps turtles regulate their body temperature and aids in digestion. Vitamin D is important for the uptake of calcium from their food and promotes shell development in the younger turtles. Basking in the sun not only helps regulate their body temperature, but the warmth of the sun allows the shell to dry, inhibiting bacterial and fungal growth (Christoffel et al. 2002). Creating permanent basking logs, or escape logs (Figure 4.), was a simple task with an excavator. Logs were anchored into the bank and placed just off the surface of the water where they would not obstruct water flow and turtles could escape predators by sliding off into a deep pool.

SNAKES – Some snakes, like turtles, also overwinter underwater. The Eastern Milk Snake *Lampropeltis triangulum*, the Western Fox snake *Elaphe vulpine,* and the common garter snake *Thamnophis sirtailis* all must find a suitable hibernaculum in the vicinity of their summer habitat. They require a secure den with low temperatures that remain above freezing. Since they are susceptible to loss of body water, their hibernation site must also be close to the water table (but not flooded). A number of studies have shown the lack of adequate hibernacula is a limiting factor in the success of snake populations (Christoffel et al. 2002).

Figure 3. Anchoring woody debris

Figure 4. Installed basking log

Constructing hibernacula for snakes is not an uncommon practice. The first hibernaculum of the Vernon County project was created by excavating down to 2 ft of saturated soils, a width of approximately 36 in and an overall depth of 10 ft. What was unusual about our second hibernaculum was that it was placed in conjunction with the bank stabilization project (Figure 5.). Shaping the bank and anchoring the toe of the bank with rock is standard operating procedure when installing rock riprap. But, by placing 6 to 12 in of clean rock 2 ft under water, running the rock up the slope, wrapping the rock in a fabric and providing an entrance to the rock, we were able to construct a hibernaculum as part of the streambank stabilization project for less than $1,000. Water temperature was monitored in both hibernacula every hour, 24 h a day, 7 d a week for a year. The temperature of the water in both hibernacula never reached freezing, and rapid fluctuations were never observed. Sloughing of the banks was a common problem of the hibernaculum next to the stream; however, it was concluded that by constructing the trench in phases, instead of opening it all at once, would have helped to reduce the collapsing sides of the hibernaculum.

FROGS – A few frogs native to Wisconsin have the ability to withstand freezing. In the Driftless Area, the Wood Frog *Rana sylvatica*, Western and Boreal Chorus Frog *Pseudacris triseriata*, Northern Spring Peeper *Pseudacris crucifer*, and the Copes Gray Treefrog *Hyla chrysoscelis*, can freeze solid during the winter. Frogs are able to do this by generating an "antifreeze", consisting of high levels of sugars and sugar alcohols in their tissues that keep their cells from freezing (Premo 2005). Projects targeting amphibians were aimed at creating shallow back water areas (Figure 6), and constructing point bars that allowed for the deposition of sediment and created shallow flats. These shallow gradient mud or sand flats below the eddies, which typically support low and sparse vegetation, are ideal for a number of frogs, but are particularly ideal for Wisconsin's only endangered amphibian the Blanchard's Cricket Frog *Acris crepitans Blanchardi*. Creating side channels that connect to the stream but are slightly warmer in temperature will also provide additional refuge for frogs and forage fish.

BIRDS – Stream projects for bank stabilization and trout are sometimes at odds with the needs of a variety of birds. Removing the trees lining the streambank provides nesting habitat and the shaping of eroding vertical banks can destroy nesting bank swallows. Efforts are being made to prohibit nesting in banks prior to construction and

Figure 5. Hibernaculum placed in streambank under rock riprap.

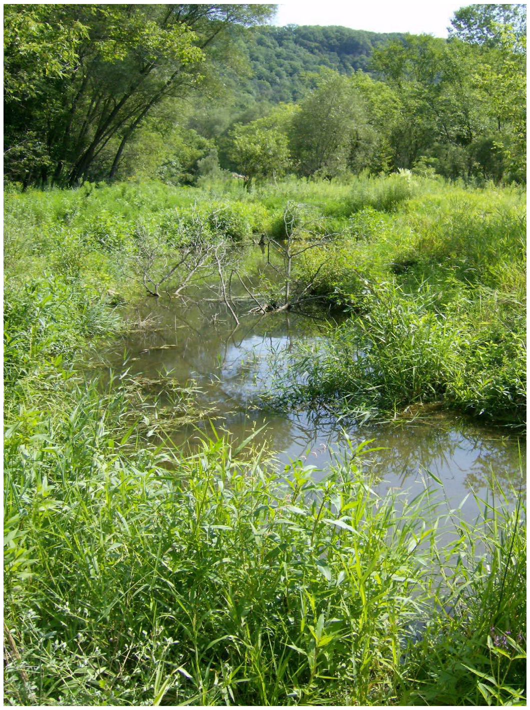


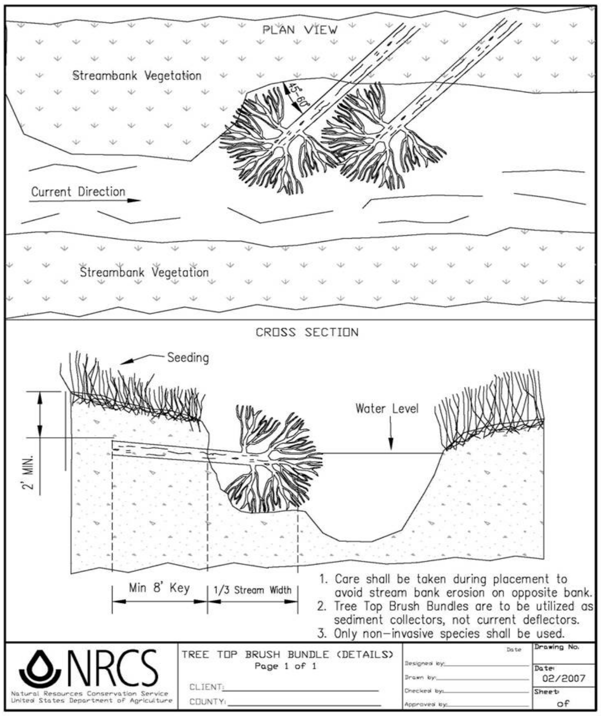
Figure 6. Back water area created with an excavator during project.

replacing trees and cool season grasses that existed prior to construction with warm season grasses. If stream restoration specialists are knowledgeable, they can even add additional habitat that did not exist before. For example, the Louisiana Waterthrush *Seiurus motacilla*, feeds on aquatic insects living among rocks in riffles. Feeding boulders could be placed with minimal cost and effort during the construction process, where appropriate.

Discussion

Because of the interest shown in the two Vernon County pilot projects by conservationists and fish biologists, Trout Unlimited has organized the “Wild and Rare” committee. Members of this committee have agreed to meet twice each year to educate each other; develop standard drawings (Figure 7) of various nongame habitat; tour and critique stream restoration projects; review and distribute information about funding opportunities for nongame habitat; and discuss ways of disseminating lessons learned. Currently, the committee is made up of representatives from The Nature Conservancy, U.S. Fish and Wildlife Service, Trout Unlimited, U.S. Geological Survey, Natural Resources Conservation Service, and Department of Natural Resources (including nongame specialists from Minnesota, Wisconsin, and Iowa). The committee would eventually like to develop a guide for professionals and landowners involved in stream restoration projects. The guide will include standard designs and general discussions as to where and when it would be appropriate to provide additional habitat for nongame species.

Although funds have not been available for monitoring it is apparent that the diversity of habitats for nongame species has been greatly enhanced. The Wild and Rare Committee will continue to seek resources for monitoring, implementation, and the dissemination of its conclusions. Conservationists doing streambank stabilization and trout habitat projects have expressed strong interest in learning how to incorporate habitat for other nongame species. Thus far, several standard drawings for nongame habitat have been created and members from the Wild and Rare Committee have made presentations about the two pilot projects.



1. Care shall be taken during placement to avoid stream bank erosion on opposite bank.
2. Tree Top Brush Bundles are to be utilized as sediment collectors, not current deflectors.
3. Only non-invasive species shall be used.

Figure 7. Standard drawing created for “root wads”.

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Improvement of a Weir for Sakhalin Taimen Migration in the Sarukotsu River, Northern Japan

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Abstract

Dams and weirs disrupt upstream and downstream passage of salmonid fishes, resulting in reduction or local extinction of their populations worldwide. Sakhalin taimen *Hucho perryi* is one of the largest stream salmonid species in the world, which has a record of exceeding over 120 cm in length, and is indigenous to the eastern Eurasian continent and Hokkaido Island, the northern most island of Japanese archipelago. This piscivorous species has lost many populations in Hokkaido and is nearly extinct due to the overharvesting, poaching, and habitat destructions such as the construction of impassable weirs that prevent their spawning migration. As a result, it has been listed as a “threatened” by IUCN and “endangered 1B” species by Ministry of the Environment of Japan. In Hokkaido, the taimen generally inhabits downstream reaches of rivers with occasional coastal life and migrates upstream for spawning in spring. The Sarukotsu River, one of a few remaining natal streams, had an impassable weir for the taimen, and we recently improved it to allow the fish to migrate for spawning. In this presentation, we report the effectiveness of this habitat restoration effort by a local citizen group and our future restoration measures for this unique salmonid.

Introduction

Crossing constructions (e.g. dams and weirs) in the river disrupt upstream and downstream passage of stream fishes, resulting in a reduction or local extinction of their populations (Morita and Yamamoto, 2002). Most studies focused on the effects of the large hydroelectric, power dams on aquatic biota, but little attention has been paid to the effects of weirs on fishes. In Japan, there are numerous small agricultural weirs (30 - 150 cm high) in rivers, which disrupt upstream and downstream passage of stream fishes.

The Sakhalin taimen *Hucho perryi* is one of the largest stream salmonid species in the world, which has a record of exceeding over 120 cm long in Japan (Figure 1). The genus *Hucho* is composed of five species distributed on the Eurasian continent (Berg 1962, Grtsenko et al. 1974, Holčik et al. 1988, Edo et al. 2000). The distribution of Sakhalin taimen is limited to the far northeast of Asia, from the Primorye region of Siberia (south

FIGURE 1.-Photograph of Saklalin taimen (*Hucho perri*).

of Amur River) to Sakhalin Island, southern Kurile Islands and the northernmost island of Japan, Hokkaidl (Figure 2A: Kimura 1966, Holčik et al. 1988). Unlike the other species of the genus, which are strict residents in fresh water without migrating to the sea, only the Sakhalin taimen is considered as an anadromous species (Gritsenko et al. 1974, Holčik et al. 1988, Edo et al. 2005). This piscivorous species has lost many populations in Hokkaido and is nearly extinct due to the past overharvesting, poaching, and habitat destructions such as the construction of impassable weirs that prevent the ir spawning migration. As a result, it has been listed as a "threatened" by IUCN and "endangered 1B" species by Ministry of the Environment of Japan. The objective of this study is to show the effect of improvement of a weir for Sakhalin taimen migration in a small stream of Hokkaido.

Methods

The study was conducted in the upper reach of the Sarukotu River that runs through a small town, Sarufutsu (45° 17' N, 142° 3' E), in northern Hokkaido (Figure 2B). This small stream (20 km long, 2-6 m wide) flows directly into the Sea of Okhotsk. This highly sinuous, low gradient stream is primarily dominated by coniferous riparian forests. Other stream salmonids inhabiting this stream include white-spotted charr *Salvelinus leucomaenis* and masu salmon *Oncorhynchus masou*.

In 1986, an agricultural weir was installed in the upper reach of a tributary of Sarukotsu River (Figure 3A). After the installation of the weir, white-spotted charr and masu salmon (i.e., resident stream salmonids) have been able to migrate upstream over this weir, but Sakhalin taimen had never been observed to do so. Most of the reaches below the weir have concrete-block bottoms that are not suitable as spawning grounds for stream salmonids. We have observed only a few cases in which smaller taimen (50-60 cmtotal length, TL) successfully went over the weir. However, larger taimen individuals (>80 cm in TL) have never been observed above the weir and they have been often trapped in the downstream reaches of the weir. We observed that the large taimen individuals attempted to migrate up the weir many times, but their challenges were never successful. Moreover, those taimen downstream of the weir were often poached illegally. We have observed eggs of taimen spread on the wall of the weir that suggested a female taimen was poached and taken out of water (Figure 3C).

In an attempt to solve the problem of the weir, the Sarufutsu Sakhalin Taimen Conservation Group struggled and consulted with the Sarufutsu

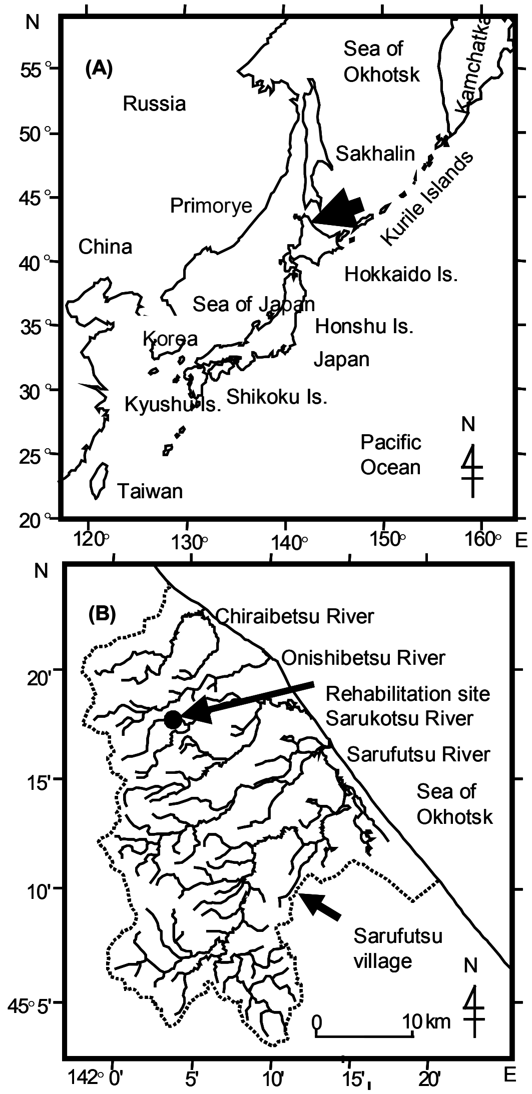

FIGURE 2.-(A) Map of the Hokkaido, northern Japan and Sarufutsu village which is marked by an arrow. (B) Map of Sarufutsu villagge and location of the rehabilitation site in the Sarukotsu River.

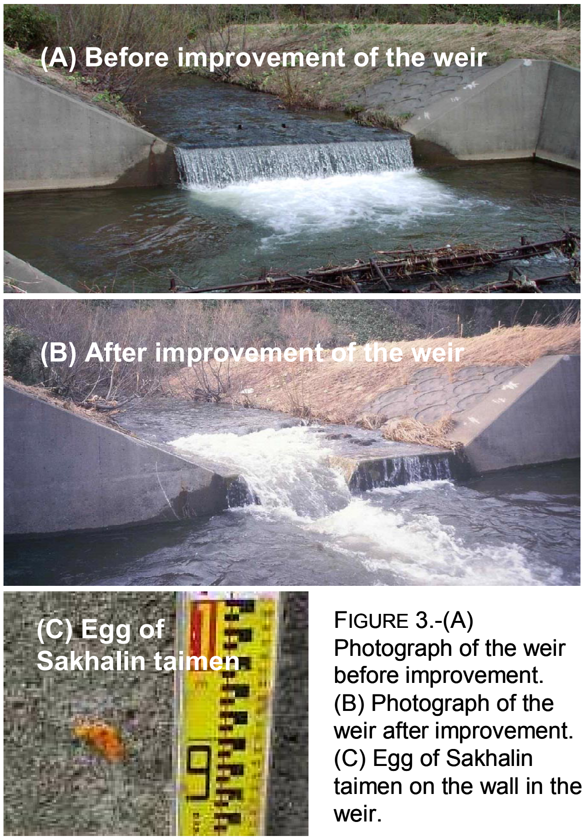

FIGURE 3.-(A) Photograph of the weir before improvement. (B) Photograph of the weir after improvement. (C) Egg of Sakhalin taimen on the wall in the weir.

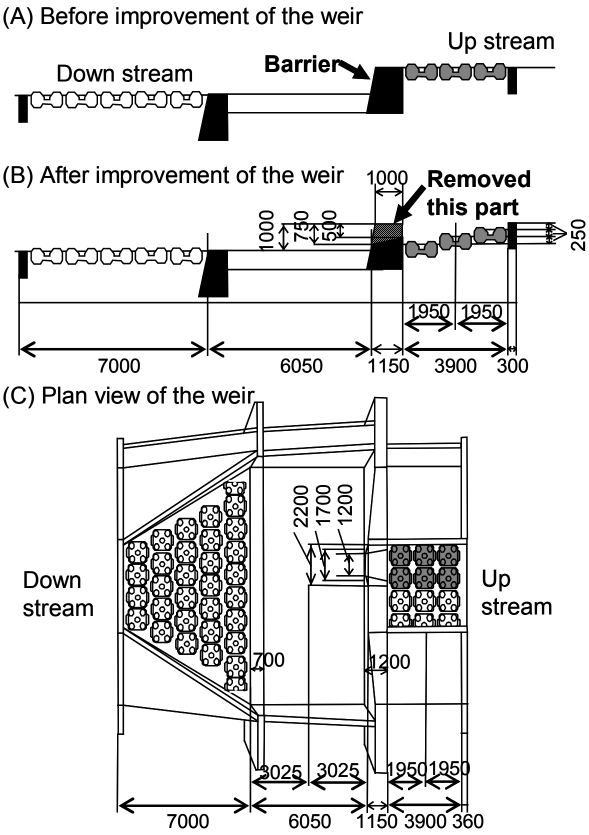

FIGURE 4.-(A) Longitudinal profile of the weir before improvement. (B) Longitudinal profile of the weir after improvement. (C) Plan view of the weir.

municipal office to modify the weir for Sakhalin taimen to be able to migrate upstream. Finally, the weir was modified in winter 2004 and a simple and low-cost method was implemented (Figure 3. 4). Six blocks of river bed protection were lowered in the weir (Figure 4A. B) and a part of the weir was removed (Figure 4B). This engineering work was conducted during winter to minimize the impact on the resident stream fishes.

In the research site, the spawning period of Sakhalin taimen ranged from the middle of April to early May in 2004. After improvement of the weir in 2004, we observed the taimen migration downstream of the weir and in upstream reaches for about 3 km of the weir every day during the spawning period in 2004. We also surveyed taimen fry using hand nets in early July.

Results and Discussion

The effect of improvement of the weir was evident; although we observed some numbers of Sakhalin taimen that could not go over the weir before the improvement, few individuals were observed being trapped in the pool below the weir after the improvement. On April 25th, we observed five pairs of Sakhalin taimen that passed through the improved weir. Their estimated total lengths ranged from 40 cm to 80 cm. Moreover, in early July, fry were observed in the upstream reaches of the weir (Figure 5). As a result of the weir improvement, we considered that most of the Sakhalin taimen migrated and spawned successfully that year.

Before the improvement of the weir, although there were only a few cases, smaller taimen (50-60 cm TL) successfully went over the weir but larger taimen individuals (>80cm TL) were never observed above the weir. It appears that the number of redds of Sakhalin taimen increased after the weir improvement. However, after the present habitat rehabilitation, the number of redds of the Sakhalin taimen observed in the present study

FIGURE 5.-Photograph of fry of Saklalin taimen in the upstream reach of the weir after improvement.

reaches was still smaller than that found in the main stem of Sarukotsu River (Edo, unpublished data). Considering the mature age being > 5-6 years and longevity being long (>10 years) in the taimen as well as their semelparity (Edo 2001), it should take longer time to confirm the effects of the habitat rehabilitation because the number of taimen spawners had continued to decrease for the last 16 years after the weir was constructed. So, it is important that we continue to monitor the Sakhalin taimen migration in the present study site in the future.

The improvement of the weir in the present study was successful for Sakhalin taimen migration; however, riparian forest was clear-cut near the spawning habitat after this rehabilitation work (Figure 6). It is necessary to minimize the human impact (e.g., deforestation, river channelization and dam construction) in the whole area of Sakhalin taimen habitat. On the other hand, we feel that it is important for forest and river managers to understand the ecology of Sakhalin taimen and their habitat. In Sarufutsu, a conservation program of taimen for the local residents, the local government, and anglers was established by the Sarufutsu Sakhalin Taimen Conservation Group. For example, their programs include symposia for exchanging information regarding the ecology and present condition of taimen, advocating catch and release and refraining from fishing for the spawners in the spawning reaches, cleaning the river, and environmental education for children and adults including the anglers. The goal of this citizen group is to keep vital environments for Sakhalin taimen populations and to establish well balanced relationships between taimen conservation and human activity such as fishing.

FIGURE 6.-Photograph of deforestation near spawning habitat of Sakhalin taimen.

Acknowledgments

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Effects of Wildfire on Stream Temperatures in the Bitterroot River Basin, Montana

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Extended Abstract

Wildfire can influence a variety of stream characteristics including channel morphology, habitat complexity and structure, nutrient availability, temperature, and stream biota (Burton et al. 1995, Spencer et al. 2003, Dunham et al. 2007). Although the effects of wildfire can be diverse, the magnitude in space and time of the initial impacts and recovery of streams from these disturbances are not well understood. Temperature is an important abiotic factor for aquatic systems, because it influences the growth, distribution, and behavior of fish. In western Montana, maintaining coldwater habitats is a critical component of conservation of native trout species of concern, westslope cutthroat trout *Oncorhynchus clarkii lewisi* and bull trout *Salvelinus confluentus*. Wildfire can initially increase stream temperature, but when to expect a response, the extent of the response in the watershed, and the recovery of the stream temperature to reference conditions are uncertain.

Recovery of stream temperatures after a wildfire and the subsequent effects on fish populations have been examined in only a few areas. For example, a Montana study found increases in post-fire stream temperatures. In addition, populations of westslope cutthroat trout often recovered, whereas brook trout Salvelinus fontinalis remained less abundant than in control streams (Sestrich 2005). In Idaho, physical stream habitat characteristics, including temperature, remained altered for several years after a fire, but native aquatic vertebrates appear resilient to these changes (Dunham et al. 2007). Minimum and maximum temperatures in first- and second-order streams in Yellowstone National Park were greater than in reference streams and often exceeded salmonid temperature tolerances for 5 years after the 1988 wildfires. However, in third- and fourth-order streams in burned watersheds, temperatures were comparable to those in reference streams (Minshall et al. 1997). Thus, understanding how wildfire affects water temperature across different types of systems is important as we predict the impacts of wildfire on the landscape. In 2000, several large wildfires burned large portions of the Bitterroot River basin in Montana. The objectives of this paper are to evaluate post-fire changes in summertime stream temperature and determine whether stream temperatures in burned watersheds are returning to pre-fire values.

We used a Before-After-Control-Impact design to address immediate effects of wildfires on stream temperature and how summertime stream temperatures responded in ensuing years. We examined temperature data from 33, 3rd- to 4th-order streams in three treatment groups: reference streams (<6% watershed burned), streams with temperature

loggers located downstream of a burn, and streams with temperature loggers located within a burn. We did not have water temperature data for all streams in any year except 2001, so we used temperatures in that year as a reference for gauging trends. Temperature data for July, August, and September were analyzed separately to assess seasonal effects. We selected average maximum temperature as a metric, because maximum temperature is strongly associated with the distribution of native fish.

For sites located within riparian burns, we detected an increase in maximum water temperature in all months (July 1.2˚C ±0.3, August 1.7˚C ±0.3, and September 2.3˚C ±0.2) relative to temperatures in control streams. An increase in absolute summertime maximum temperature was also evident at sites in riparian area burns; temperatures exceeded 20˚C in 8 of 16 stream sites. Stream sites located downstream of a burn did not have significantly higher temperatures (July 0.1˚C ±1.0, August -0.4˚C ±1.2, and September -0.2˚C ±0.8) than did control streams. Furthermore, maximum summertime stream temperatures exceeded 20˚C in only two of nine stream sites.

At stream sites within riparian burns, an increase in stream temperature was seen the first year post-fire in all months examined. During the second to fifth years after the fire, stream temperature appeared to decrease slightly, but there was not complete recovery. Temperatures at these sites often exceeded salmonid thermal limits, which implies that salmonid populations in watersheds with stand-replacing riparian burns may decline. In sites downstream of a riparian burn, there was no detectable fire effect. These sites may provide a thermal refuge for fish during times of high temperatures. Many native aquatic vertebrates appear to be resilient to many of these longer-term changes in stream habitat characteristics including increased stream temperatures (Dunham et al. 2007). If stream temperature is not recovering, but the biota is returning, sublethal effects of these water temperature changes on stream biota should be examined to understand the impacts of wildfire over the long term.

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Genetic Analysis of Bull Trout Populations on the Flathead Indian Reservation, Montana

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Abstract

Bull trout *Salvelinus confluentus* are found in two drainages within the lower Flathead River system of Montana: the Jocko River and Mission Creek. The hydrology of the lower Flathead River system has been extensively modified for irrigation purposes resulting in reduced connectivity and isolation among local bull trout populations. We quantified levels of genetic diversity within and among four bull trout populations in the lower Flathead River system to determine how genetic relationships among populations have been affected by contemporary factors (e.g. dams, irrigation canals). Genetic diversity was relatively low in Dry Lake Creek, a small isolated population, compared to larger populations with some degree of connectivity among them. Although the populations surveyed were all in close geographic proximity, significant levels of genetic variation were observed among all populations. Data suggest that a population in Dry Lake Creek represents individuals diverted through a canal in the Jocko River and not a remnant endemic population. Estimates of effective population size in three of the four populations we examined were low (N_e = 3.3 to 12.6), which may be attributed to small population sizes and low levels of connectivity among populations.

Introduction

Bull trout *Salvelinus confluentus* are native to northwestern North America and once ranged from northern California to the Yukon Territory and from the Pacific Coast as far inland as western Alberta and Montana (Haas and McPhail 1991). Bull trout have declined throughout their range and are currently listed as a threatened species by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 1999). Introductions of nonnative species, habitat degradation, and habitat fragmentation have all contributed to these declines (Rieman et al. 1997). Information regarding the levels of genetic variation within and among local bull trout populations has been identified as an important conservation need to facilitate bull trout recovery (U.S. Fish and Wildlife Service 2002).

Historically Lake Pend Oreille and the Clark Fork River system in Idaho and Montana supported a large meta-population of bull trout (Pratt and Huston 1993). The Flathead River is one of the main tributaries to the Clark Fork River and is located approximately 165 km upstream from Lake Pend Oreille. Presently, bull trout are found in two lower Flathead River tributaries: Mission Creek and the Jocko River. Within the Jocko River system, bull trout populations occur in the North Fork Jocko and the South Fork Jocko (Figure 1). In the Mission Creek drainage, bull trout are present in Dry Lake Creek and Post Creek and in associated lakes, which were modified for irrigation purposes (Figure 1). The hydrology of the Jocko River and Mission Creek drainages is complex due to alterations including the construction of dams and irrigation diversions and canals. Presently the North and South Fork Jocko rivers have limited connectivity with the Flathead River. The other two populations have no connectivity with the Flathead River. Although Dry Lake Creek was formerly a tributary to Mission Creek, the connection was eliminated when the stream was modified for irrigation delivery. Presently a trans-basin canal is used to divert water from the upper Jocko River drainage to St. Marys Lake in the Dry Creek drainage (Figure 1). Bull trout in Post Creek are also isolated by a dam that prevents upstream passage of fish into McDonald Lake and Post Creek; however, fish may still travel downstream over the dam. These modifications make it difficult to determine the evolutionary history of bull trout in the lower Flathead system. For example, it is unknown if bull trout in Dry Lake Creek represent an isolated population from the Mission Creek drainage, or if they originated from the Jocko River after being entrained in the irrigation canal.

The objective of this study was to characterize levels of genetic diversity within and among bull trout populations in the lower Flathead River system to aid ongoing conservation and recovery efforts currently being conducted on the Flathead Indian Reservation by the Confederated Salish and Kootenai Tribes (CS&KT). Given the complex hydrology among the streams in the lower Flathead River system, we were also interested in the genetic relationship among bull

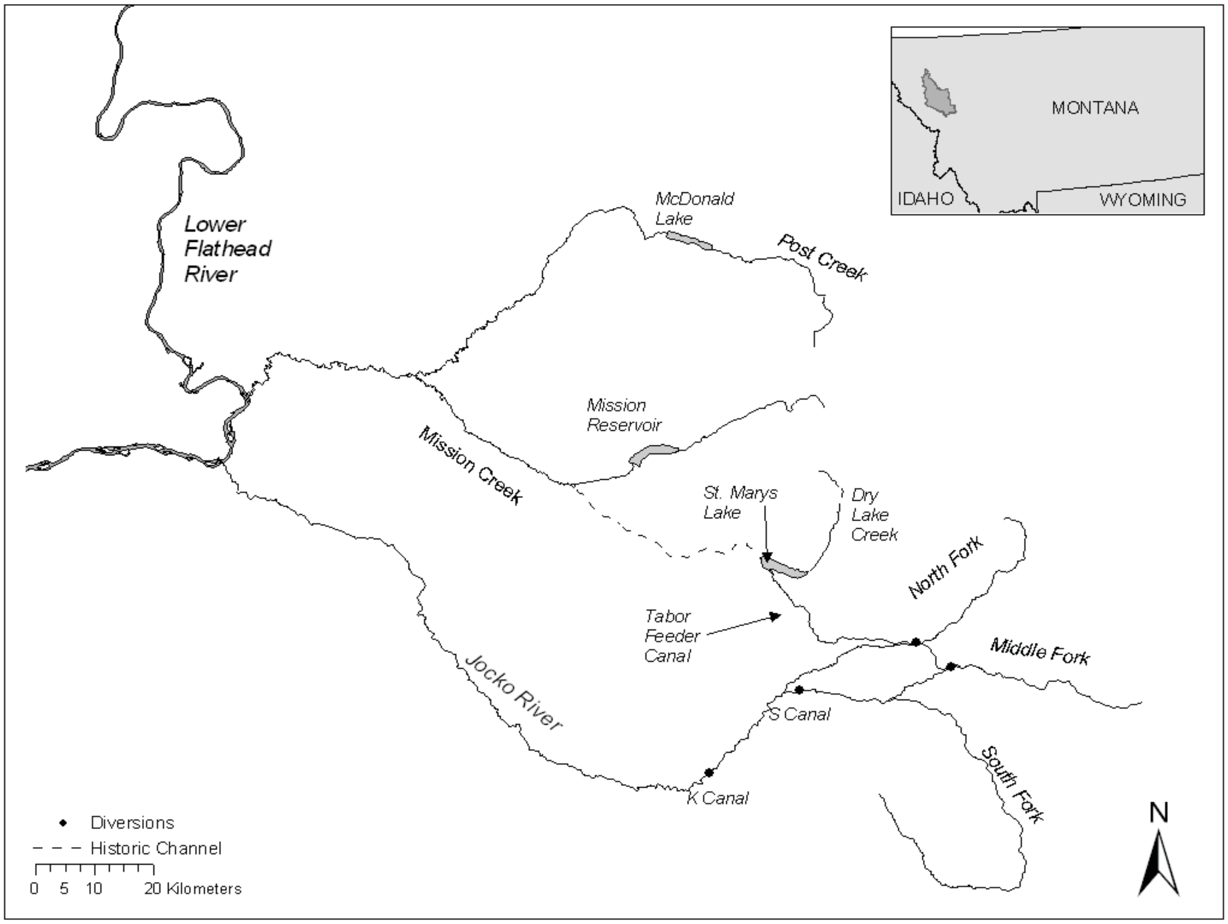

Figure 1. Study location within the lower Flathead River system. From its confluence with the Jocko River, the Flathead River enters the Clark Fork River approximately 41 km to the west.

trout populations and how contemporary factors (e.g., diversions, irrigation canals, dams) have affected these relationships. Additionally, several adult bull trout were also collected in the main stem Jocko River and in the Flathead River to conduct genetic assignments for these individuals to determine their population of origin within the lower Flathead drainage.

Materials and Methods

Sample Collection

Genetic samples were collected from juvenile and adult bull trout that were captured by electrofishing from four streams within the lower Flathead River drainage: the North Fork Jocko River (NFJ), the South Fork Jocko River (SFJ), Post Creek (PC) and Dry Lake Creek (DLC). Sampling was conducted over multiple years for NFJ and SFJ. Genetic samples for population assignment were also collected from 21 adult bull trout captured in the main stem Jocko River (n=18), the lower Flathead River (n=2), and Dry Lake Creek Canal downstream of St. Marys Lake (n=1).

Laboratory Methods

DNA was extracted from all samples using a modified chelex extraction protocol (Miller and Kapuscinski 1996). Individuals were genotyped at 12 microsatellite loci: Omm1070, Omm1128, Omm1130 (Rexroad et al. 2001), Sco104, Sco105, Sco106, Sco107 (Washington Dept. of Fish and Wildlife unpublished), Sco200, Sco212, Sco216, Sco218 (DeHaan and Ardren 2005) and Smm22 (Crane et al. 2004) following the methods outlined in DeHaan and Ardren (2005). Several of these loci exhibit fixed allelic differences between bull trout and brook trout *Salvelinus fontinalis* and were used to identify bull trout x brook trout hybrids.

Statistical Methods

Populations were tested for conformance to Hardy-Weinberg equilibrium (HWE) using the program Genepop v3.4 (Raymond and Rousset 1995). For NFJ and SFJ, where populations had been sampled over multiple years, HWE tests were first performed by treating sampling years separately (2004, 2005 and 2006) and then by combining all samples from each stream. Significance values for HWE tests were adjusted for multiple comparisons using a sequential Bonferroni adjustment (Rice 1989). Because many of the 2006 NFJ and SFJ samples were collected in a single location within each stream, we used the program Kinship v1.3.1 (Goodnight and Queller 1999) to identify groups of related individuals (i.e. full siblings). In cases where family groups were identified, all but one of the individuals were removed from further analyses. For purposes of estimating levels of genetic variation within and among populations and performing population assignments, temporal replicates from NFJ and SFJ were combined. Given the mean generation time for bull trout (5 to 7 years; Fraley and Shepard 1989), we feel that combining temporal replicates is an effective means of estimating the overall genetic variation in these populations.

We used the program GDA (Lewis and Zaykin 2001) to estimate measures of genetic diversity including mean numbers of alleles per locus and observed and expected heterozygosity. The program HP-Rare v1.0 (Kalinowski 2005) was used to provide estimates of allelic richness that had been corrected for differences in sample size. Populations were tested for evidence of recent genetic bottlenecks using the program Bottleneck (Cornuet and Luikart 1996) assuming a two-phased model of mutation. We estimated effective population size (N_e) based on linkage disequilibrium (Waples 2006) using the program LDNe (R. Waples, personal communication).

We used Fstat v2.9.3 (Goudet 2001) to estimate the overall level of genetic variation among all populations (F_{st}) and the associated confidence level based on 1,000 bootstrap replicates. The program Fstat was also used to estimate pairwise levels of genetic variation (F_{st}) among all populations and test pairwise estimates for significance. We also examined the multidimensional genetic relationship among populations by conducting a correspondence analysis (FCA) using the program Genetix

(Belkhir et al. 2004). This method provides an unbiased graphical approach to examining the genetic relationships among populations. The program Phylipv3.6 (Felsenstein 1993) was used to estimate Cavalli-Sforza and Edwards (CSE; 1967) chord distance between all population pairs.

Several adult bull trout were collected in the main stem Jocko River as well as other locations in the lower Flathead River drainage for population assignment. To assess our ability to correctly assign unknown fish to their population of origin, we performed a jackknife analysis of our lower Flathead baseline dataset using the program WhichRun v4.1 (Banks and Eichert 2000). In this procedure individuals are removed from the baseline dataset one at a time and treated as unknowns and then assigned to the most likely population of origin based on a maximum likelihood algorithm. The number of individuals correctly assigned to their population of origin provides a means of estimating the statistical power of the baseline dataset to assign unknown individuals. Following jackknife analysis, we used WhichRun to assign the unknown adults to their most likely population of origin within the lower Flathead River system.

Results

We had difficulty amplifying DNA from a number of samples that we believe was due to the methods used to preserve these samples. Subsequently, individuals missing genotypes at five or more loci were omitted from analysis. Ten individuals genetically identified as F1 hybrids, and three individuals genetically identified as brook trout were also omitted from statistical analysis.

The samples from DLC and PC deviated from HWE at a single locus: Omm1130 and Sco218, respectively. The NFJ sample from 2006 deviated from HWE at 5 loci, Omm1128, Omm1130, Sco104, Sco218 and Smm22. These deviations were the result of an excess of heterozygotes, often an indication that several related individuals have been sampled (Balloux 2004). Kinship analysis identified several related individuals collected from NFJ in 2006, and all but one of these fish were removed from further analysis. The SFJ samples collected in 2004 deviated from HWE at a single locus, Sco104, and the samples from 2006 deviated at two loci, Sco105 and Omm1128, due to heterozygote excess. Kinship analysis also identified a group of related individuals from SFJ, and all but one of these individuals were removed as well. Once related individuals had been removed and temporal samples combined, NFJ deviated from HWE at a single locus, Omm1128, and SFJ deviated from HWE at four loci: Omm1130, Sco104, Sco107, and Smm22.

The mean number of alleles per locus ranged from 4.417 for DLC to 8.500 for SFJ (Table 1). Allelic richness was lowest in DLC (4.355) and highest in NFJ (6.489) (Table 1). Observed heterozygosity was lowest in PC (0.656) and highest in NFJ (0.766) (Table 1). Results of the genetic bottleneck tests showed that only DLC has experienced a recent genetic bottleneck ($p < 0.001$). Estimates of N_e and the associated 95% confidence values were as follows: NFJ N_e = 12.6 (10.5-15.2), SFJ N_e = 8.6 (7.6-9.7), PC N_e = 58.2 (38.0-107.5), DLC N_e = 3.3 (2.6-6.5).

Table 1. Estimates of genetic diversity for bull trout populations in the lower Flathead River system based on 12 microsatellite loci.

Population	N	A	A_R	H_e	H_o	N_e
NFJ	33	7.75	6.489	0.734	0.766	12.6
SFJ	64	8.5	6.572	0.75	0.729	8.6
PC	35	6.833	5.586	0.686	0.656	58.2
DLC	17	4.417	4.355	0.639	0.673	3.3
Mean		6.875	5.75	0.702	0.706	

N=sample size, A=mean number of alleles per locus, A_R=allelic richness, H_e=expected heterozygosity, H_o=observed heterozygosity, N_e = effective population size

The overall level of genetic variation among populations (F_{st}) was 0.136 and was significantly different from 0 (95% C.I. = 0.109 to 0.164). Pairwise estimates of F_{st} ranged from 0.073 between NFJ and SFJ to 0.248 between PC and DLC (Table 2). All pairwise comparisons were found to be significant ($\alpha<0.05$) following Bonferroni correction. Cavalli-Sforza and Edwards Chord distance (CSE) ranged from 0.061 for NFJ and SFJ to 0.151 for PC and DLC (Table 2). The CSE chord distances showed that DLC was most closely related to NFJ. The correspondence analysis showed distinction among all of the populations, with NFJ and SFJ being the most closely related and PC most closely related to the Jocko River populations (Figure 2).

Jackknife analysis of our baseline dataset assigned 146 of the 149 individuals (98%) to the correct population of origin. Of the three mis-assigned fish, one from NFJ was mis-assigned to SFJ and two from SFJ were mis-assigned to NFJ. These results suggest that we have a high degree of power to assign bull trout to the correct population of origin within the lower Flathead River system. We then used our genetic baseline to perform population assignments for adults of unknown origin collected in the main stem Jocko River and other areas within the lower Flathead River system. Of the 21 individuals assigned to population, 10 were assigned to NFJ, nine were assigned to SFJ and two were assigned to DLC.

Table 2. Pairwise estimates of genetic variation among populations (Fst; above diagonal) and Cavalli-Sforza and Edwards chord distance (below diagonal) for bull trout populations in the lower Flathead River system. Estimates are based on 12 microsatellite loci.

	NFJ	SFJ	PC	DLC
NFJ	---	0.073	0.190	0.150
SFJ	0.061	---	0.127	0.133
PC	0.128	0.091	---	0.248
DLC	0.105	0.106	0.151	---

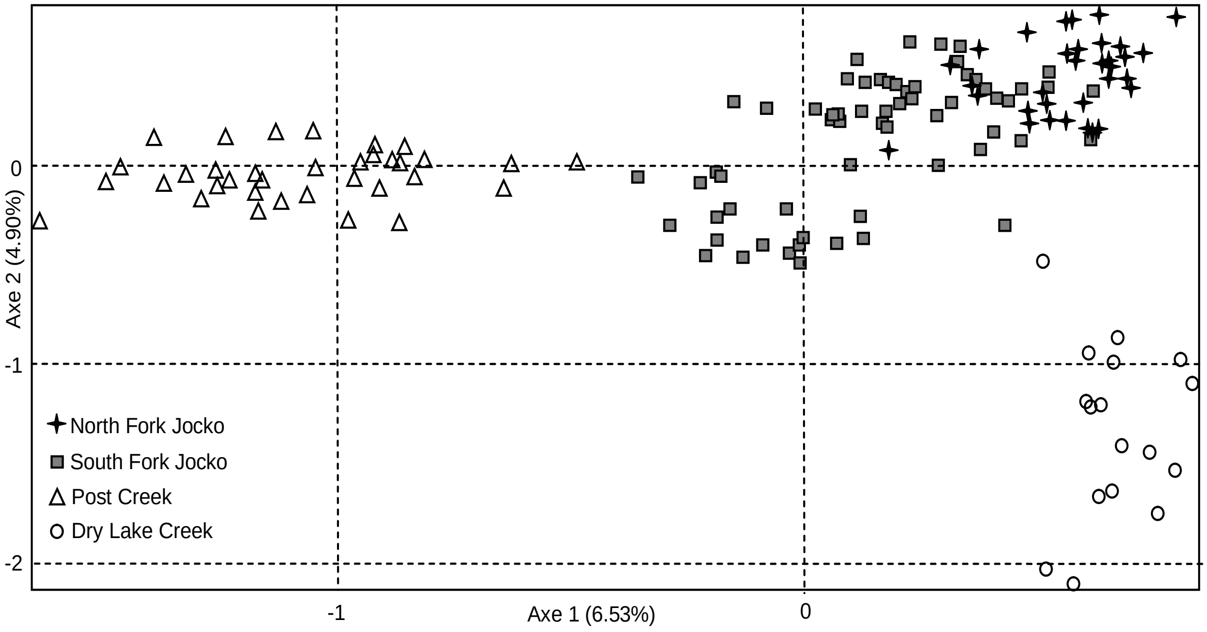

Figure 2. Correspondence analysis (FCA) of bull trout from the lower Flathead River system based on 12 microsatellite loci.

Discussion

Overall levels of genetic diversity (numbers of alleles per locus, allelic richness, heterozygosity) we observed for lower Flathead River bull trout populations were similar to those we have observed for populations throughout the Clark Fork River and Lake Pend Oreille Basins using these same microsatellite loci (Ardren et al. 2005). However, the levels of genetic variation among the four populations varied considerably. For example, in DLC the mean number of alleles per locus was approximately one-half of what we observed in SFJ, and allelic richness (which was corrected for differences in sample size) was also considerably lower in DLC. Reductions in genetic diversity and evidence of a recent bottleneck in DLC may be attributed to the fact that this is an isolated population. While DLC was historically connected to the Mission Creek system, it has been isolated by a dam for over 75 years. Estimates of genetic diversity were also relatively low for PC, another isolated population. Reductions in genetic diversity resulting from isolation above barriers have been observed for other freshwater fishes as well (Yamamoto et al. 2004; Wofford et al. 2005).

We observed low estimates of effective population size (N_e) for three of the four populations we surveyed. Effective population size was lowest in DLC ($N_e = 3.3$), where an isolated bull trout population persists above St. Marys Lake. Redd counts in DLC since 1980 have observed between zero and three redds suggesting there are very few adult bull trout in this population. Reductions in genetic diversity and N_e in DLC can likely be attributed to genetic drift given the extremely low size and isolated nature of this population. Although PC is also isolated above a dam, this population had a greater effective size than DLC ($N_e = 58.2$). Post Creek contains a much larger bull trout population than DLC and the larger size of this population may have buffered it against such a severe reduction in N_e.

Estimates of N_e were low for NFJ and SFJ as well (12.6 and 8.6 respectively). Historically, irrigation diversions in the upper main stem Jocko River restricted or eliminated upstream passage of migratory bull trout attempting to return to these systems. The 'K' canal, a seasonal barrier on the Jocko River since the early 1900s, was opened to selective passage in 1996. The 'S' canal, 10 km farther upstream, has been a complete barrier to migration since the early 1900s, but was recently modified for selective fish passage (bull trout only) in 2002. Although migratory fish have access to the North and South Fork Jocko rivers, these barriers have limited the number of fish that have been able to access habitat in these systems in recent years. The reductions we observed in N_e in these two populations likely result from the small number of migratory fish that are able to access spawning habitat in these tributaries in any given year. The excess number of heterozygotes we observed in NFJ and SFJ suggests that these samples were composed of several related individuals and provides further evidence that low numbers of adults spawn in NFJ and SFJ. Low estimates of N_e raise concern for these populations because populations that have experienced losses of genetic diversity and have low effective size are more susceptible to extinction (Newman and Pilson 1997).

In general bull trout show high levels of genetic differentiation among populations throughout their range (Costello et al. 2003; Spruell et al. 2003) including populations in close geographic proximity (Whitely et al. 2006). The populations in this study also followed this pattern as all four of the local populations that we examined were significantly differentiated from one another. The overall level of genetic variation we observed among the four populations in this study was similar to that observed by Nerass and Spruell (2001) in a study of 17 bull trout populations in Lake Pend Oreille and the Clark Fork River. These data suggest that although these populations lie in close geographic proximity (e.g., North and South Fork Jocko rivers), levels of gene flow among these local populations are relatively low.

The genetic data presented in this study help to clarify the evolutionary relationship among bull trout populations in the lower Flathead River.

Due to the extensive hydrological modifications made in the lower Flathead River system, it was unclear if the population in DLC was a remnant from the Mission Creek system, if it was made up of Jocko River individuals entrained through the irrigation diversion and canal, or if this population was a mixture of both Mission Creek and Jocko River fish. The results of HWE tests suggest that the population in DLC does not represent an admixture. Furthermore, all of the DLC individuals were correctly assigned in the jackknife analysis, providing additional evidence that this is a distinct spawning population. Low estimates of genetic diversity and low N_e suggest this population has undergone substantial genetic drift, however. We observed the greatest amount of genetic variation (F_{st}) between DLC and PC (a Mission Creek tributary). Additionally, the CSE chord distances, and the correspondence analysis showed that DLC is more closely related to the Jocko River populations than PC. We hypothesize that that if a bull trout population existed in DLC before the connection with Mission Creek was lost, that population was extirpated following construction of the dam and individuals entrained through the irrigation canal from the Jocko River colonized habitat above St. Mary's Lake. Subsequent genetic drift has caused this population to diverge from the populations in the Jocko River system.

The majority (19 of 21) of the adult bull trout captured in the main stem Jocko River and the lower Flathead River were assigned to NFJ and SFJ. These results suggest that bull trout in these rivers maintain a migratory life history and that the main stem Jocko River provides important habitat for migratory individuals. In the upper Flathead River (upstream of Flathead Lake), bull trout migrate long distances (Fraley and Shepard 1989). Adults in the Jocko and lower Flathead rivers may represent fluvial individuals migrating between the Flathead and Clark Fork rivers or even adfluvial fish migrating farther downstream to Lake Pend Oreille. Analysis of bull trout captured at main stem dams on the Clark Fork River suggests that individuals from the lower Flathead River system are in fact migrating downstream through main stem Clark Fork dams (DeHaan and Ardren unpublished data). It is important to note that unknown adults could only be assigned to one of the four baseline populations; however, there are no barriers between several other bull trout populations in the Clark Fork River and the lower Flathead-Jocko River system. Given that bull trout are capable of migrating large distances, it is possible that adult bull trout originated from populations that were not included in our baseline dataset, and were incorrectly assigned to one of the populations in the baseline dataset.

Conclusions

The hydrology of the lower Flathead and Jocko River system has been extensively modified and these modifications appear to have had an effect on local bull trout populations within this drainage. We found that measures of genetic diversity were lower for bull trout populations that were isolated above dams and effective population size was reduced in populations that had limited migratory connectivity for adults. Maintaining connectivity among local populations and habitat types is important for the persistence of local bull trout populations (Dunham and Rieman 1999). Conservation strategies for bull trout populations in the lower Flathead River system therefore, should focus on reducing isolation among local populations.

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Evaluating Genetic Diversity and Genetic Structure of Interior Redband Trout in the Environmental Extremes of Idaho

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Extended Abstract

Columbia River redband trout *Oncorhynchus mykiss gairdneri* are widely distributed throughout the Fraser and Columbia rivers east of the Cascade Mountains, up to barrier falls on the Kootenai, Pend Oreille, Spokane, and Snake rivers (Behnke 1992). In Idaho, redband trout reside in a variety of habitat types and stream conditions, and can be divided into those found in montane streams and those found in desert streams. In the desert streams, elevation ranges from 750 to 2,560 m and the habitat is predominantly vegetated with sagebrush *Artemesia spp.* in the lower elevations and juniper *Juniperus spp.* and Douglas fir *Pseudotsuga menziesii* in the higher elevations (Zoellick et al. 2005). Maximum water temperatures usually fluctuate from 18°C to 26°C during the summer. Montane streams typically have larger substrate, higher gradient, more canopy covering from conifers, and exist at higher elevations; water temperatures are usually several degrees cooler during the summer.

Management and conservation of native, redband trout is an important priority for many state and federal agencies due to dramatic population declines throughout the historical range of the species. Redband trout have experienced declines due to habitat alterations from agricultural and grazing land uses and hybridization with nonnative fishes (Behnke 1992). In the desert drainages, ephemeral water flows during drought years and high water temperatures that exceed lethal levels may be prominent isolating factors Zoellick et al. (2005) indicated that redband trout populations in the lower elevation streams were less productive and had slower recruitment following drought years, while the higher-elevation streams were less impacted by these factors.

This study investigates how genetic diversity is partitioned among redband trout in 70 tributaries and eight watersheds throughout the montane and desert habitats in Idaho. In total, 2,271 samples were collected from eight watersheds and analyzed with 13 microsatellite loci. Polymerase Chain Reaction (PCR) conditions and cycling profiles for the 13 microsatelite loci are available from the authors upon request as well as a complete list of sample locations. Genetic diversity was measured by the number of alleles per locus (A) and expected heterozygosity (H_e). The number of “private” alleles within all of the 70 populations and eight watersheds are also reported.

We predicted significant spatial structuring at a hierarchical stream network scale, with populations in desert streams being more structured and having lower levels of genetic diversity than those in montane streams. This was based upon the assumption that populations in desert streams would be more fragmented by low stream flows and high water temperatures, while those in montane streams would be less impacted. A permutation test of Fst (measure of genetic differentiation) was performed in FSTAT to test this prediction and the following guidelines were used to interpret Fst values:

F_{ST} = 0.00 to 0.05 indicates little genetic differentiation.

F_{ST} = 0.05 to 0.15 indicates moderate genetic differentiation.

F_{ST} = 0.15 to 0.25 indicates great genetic differentiation.

F_{ST} >0.25 indicates very great genetic differentiation.

Analyses of molecular variance (AMOVA) were performed to determine how genetic diversity was partitioned at different hierarchical scales. The first analysis evaluated how genetic variation was partitioned among desert and mountain groups, among populations within these groups, and within populations. The second analysis evaluated how genetic variation was partitioned among the eight watersheds, among populations within these watersheds, and within populations.

Our results indicate strong spatial structuring at multiple scales. The AMOVA analyses revealed a greater amount of variance explained by population (87%) rather than environmental grouping (0.6%) or watershed (1.6%) differences (Table 1). However, all geographic scales were significant. Contrary to our predictions, we did not find greater degrees of genetic differentiation in the desert populations compared to the mountain populations. Average Fst among mountain populations was 0.12 and average Fst among desert populations was 0.13 - a nonsignificant difference (p-value 0.53). Genetic diversity was also not significantly different among mountain and desert populations (mean allelic richness = 3.31 and 3.24, respectively; mean He = 0.67 and 0.67; respectively). There were 18 private alleles detected in 13 of the 70 populations and 23 private alleles detected in seven of the eight watersheds. No private alleles were detected within the Snake River watershed. These results indicate that both the population and watershed scales are important for management.

Our pattern of watershed-level differentiation is consistent with other studies that have investigated *O. mykiss* population genetic structure. Knudsen et al. (2002) also found significant differences among redband trout in watersheds in Montana and British Columbia as well as differences among populations within watersheds. However, greater degrees of genetic differentiation were observed in this study at small spatial scales, unlike other *O. mykiss* (primarily steelhead) populations. In the Clearwater River basin, low to moderate levels of genetic differentiation were reported (F_{ST} >0.05) for steelhead populations sampled within an entire watershed (Moran et al., unpublished data). In contrast, we observed significantly higher F_{ST} estimates (averaging 0.13) within a sampled watershed and high Fst values for population comparisons, indicating that watersheds consisted of multiple, isolated populations of redband trout.

The results of this study provided essential information on how genetic variation is partitioned and can be used to guide managers in the future prioritization and restoration of redband trout throughout its range. Our results revealed that redband trout are structured at both the population and watershed levels. At a minimum, populations within all watersheds should be prioritized for conservation and management to ensure adequate representative of genetic variation. Future work exploring intraspecific hybridization with hatchery rainbow trout, barriers to movement, fluvial distance, and anadromous-resident relationships will provide additional information regarding the distribution of genetic variation throughout the range of the species.

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Genetic Investigations of Bonneville Cutthroat Trout in the Bear River Drainage, Idaho: Intra- and Interspecific Hybridization-Introgression and Distribution of Mitochondrial DNA Diversity

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Extended Abstract (do not cite)

Introduction and Methods

Due to substantial reductions in the distribution and abundance of Bonneville cutthroat trout *Oncorhynchus clarkii utah* in the Bear River drainage in Idaho, considerable attention has focused on a better understanding of the species' demographic, life history, and genetic characteristics to assist with conservation and restoration purposes. This study focused on two areas of population genetics. To assess the impacts from past nonnative hatchery trout stocking on intraspecific and interspecific hybridization and introgression, we screened samples with six diagnostic nuclear DNA (nDNA) markers (Ostberg and Rodriguez 2002, 2004) and a diagnostic mitochondrial DNA (mtDNA) marker (Toline et al. 1999). To assess genetic population structure and to specifically test the appropriateness of five previously defined management unit designations (Pegram, Nounan, Gentile, Riverdale, and Malad), we sequenced a highly variable mtDNA gene region that had previously revealed genetic variation within and among populations of cutthroat trout in the Snake River and Bear River drainages (Toline et al. 1999). These management units reflect groups of populations that are believed to be isolated from one another as a result of major drainage divides, dams, or both (Teuscher and Capurso 2007). Partitioning of genetic variation among and within management units was assessed using analysis of molecular variance (AMOVA) in Arlequin 2000 (Weir and Cockerham 1984), exact tests of population differentiation (Raymond and Rousset 1995), and pairwise F_{ST} estimates. Cutthroat trout, rainbow trout *Oncorhynchus mykiss* or hybrids between the two species, were sampled (nonlethal fin clip) from 54 sites (44 tributaries) in the Bear River drainage in Idaho and Wyoming. An attempt was made to sample fish at multiple sites within each tributary (low, medium, and high in the drainage), and a sample size goal of 30 per tributary was attempted, although many sites had less than 30 due to low population densities. Trout were sampled regardless of phenotypic identification and size. Fin tissue was stored in 100%, non-denatured ethanol until DNA extraction.

Results and Conclusions

Based on comparisons to hatchery reference populations, we found little evidence of intraspecific hybridization. Only three nonnative mtDNA haplotypes were found among the 750 samples analyzed. Evidence of interspecific hybridization was more prevalent, with 18 of the 54 (33.3%) sites examined containing rainbow trout x cutthroat trout hybrids (Table 1). Hybridization (number of hybrids observed/total) ranged as high as 33.3% (3 sites). First-generation (F_1) hybrids were identified in seven sample locations, indicating recent hybridization. Five of these seven sites also contained samples with genotypes indicative of both rainbow trout and cutthroat trout. Despite evidence of recent hybridization in some areas, more than one-half of the sites in which hybridization was detected contained only fish with genotypes indicative of cutthroat trout and greater than F_1 ($>F_1$) hybrids. Introgression within these sites (number of rainbow trout alleles observed/total) was low (<3.0%). Of the 20 F_1 hybrids detected, four possessed rainbow trout mtDNA and 16 possessed cutthroat trout mtDNA. Of the 47 $>F_1$ hybrids detected, 14 had rainbow trout mtDNA and 33 possessed cutthroat trout mtDNA. The confirmation of naturally reproducing rainbow trout populations and the identification of F_1 hybrids indicates hybridization is an ongoing problem. Management policies implemented to stock only sterile rainbow trout and to remove existing nonnative rainbow trout populations should continue to prevent the further spread and increase of introgression throughout the drainage.

Patterns of genetic structuring generally supported previously defined management units. All pairwise F_{ST} estimates and exact tests among management units were significant ($P < 0.05$), and AMOVA analyses partitioned 55.98% of the observed genetic variation among management units. Our results were consistent with previous studies that have demonstrated that cutthroat trout in the Bear River drainage share a more recent common ancestor with Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri* in Idaho than with populations of Bonneville cutthroat trout in the central and southern portions of their range in Utah. Managers will have to carefully consider these findings when considering taxonomic assessments, prioritizing populations for conservation and management purposes, and identifying suitable populations for translocations, reintroductions, and brood-stock development programs.

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Table 1. Site number, sample site, sample size (N), number identified as cutthroat trout-like, rainbow trout-like, F_1 hybrid, mtDNA lineage of F_1 hybrids, >F_1 hybrids, mtDNA lineage of >F_1 hybrids, total number of hybrids detected, and percentage rainbow trout (RBT) introgression. Introgression calculated as the number of RBT alleles observed in samples identified as cutthroat trout-like and hybrid divided by total alleles examined.

Site #	Sample Sites	N	Cutthroat trout-like	Rainbow trout-like	F_1 Hybrid	mtDNA lineage	>F_1 Hybrid	mtDNA lineage	Hybrids detected	RBT introgression (%)
1	SecondCreek	4	3	0	1	CUT	0		1 (25.0%)	0.0
2	ThirdCreek	3	3	0	0		0		0	0.0
3	MillCanyonCreek01	15	5	5	1	RBT	4	RBT	5 (33.3%)	9.2
4	CottonwoodCreek03	22	18	0	0		4	CUT	4 (18.2%)	1.9
5	CottonwoodCreek05	21	16	0	0		5	CUT	5 (23.8%)	1.9
6	NHoopsCreek05	7	7	0	0		0		0	0.0
7	SouthHoopsCreek	9	9	0	0		0		0	0.0
8	MinkCreek05	28	24	0	0		4	CUT	4 (14.3%)	1.2
9	DryCreek00	20	19	0	0		1		1 (5.0%)	0.4
10	FosterCreek	2	2	0	0		0		0	0.0
11	BirchCreek01	3	3	0	0		0		0	0.0
12	BirchCreek03	6	5	0	0		1	CUT	1 (16.7%)	1.4
13	SugarCreek01	26	22	0	0		4	CUT	4 (15.4%)	1.1
14	MapleCreek01	26	25	0	0		1	CUT	1 (3.9%)	0.3
15	MapleCreek03	30	30	0	0		0		0	0.6
16	UMapleCreek03	10	10	0	0		0		0	0.0
17	CubCreek03	35	35	0	0		0		0	0.0
18	LoganRiver01	23	23	0	0		0		0	0.0
19	EightmileCreek01	22	3	19	0		0		0	0.0
20	EightmileCreek03	5	5	0	0		0		0	0.0
21	EightmileCreek05	2	2	0	0		0		0	0.0
22	NPearlCreek01	6	6	0	0		0		0	0.0
23	PearlCreek01	5	4	0	0		1	CUT	1 (20.0%)	1.7
24	PearlCreek03	7	7	0	0		0		0	0.0
25	SSkinnerCreek03	5	5	0	0		0		0	0.0
26	N.SkinnerCreek01	2	2	0	0		0		0	0.0
27	SkinnerCreek01	5	5	0	0		0		0	0.0
28	S.SkinnerCreek03	11	11	0	0		0		0	0.0
29	StauferCreek01	1	1	0	0		0		0	0.0
30	CanyonCreek01	9	6	0	0		3	CUT	3 (33.3%)	2.8
31	CoopCreek01	10	10	0	0		0		0	0.0
32	BearRiverN	12	11	1	0		0		0	0.0
33	Geotown03	11	0	11	0		0		0	0.0
34	MontpeilerCreek05	30	25	1	0		4	CUT	4 (13.3%	2.0
35	BearRiverP	24	24	0	0		0		0	0.0
36	BearRiver06	49	49	0	0		0		0	0.0
37	BearRiver05	63	62	1	0		0		0	0.0
38	ThomasFrk99	16	16	0	0		0		0	0.0
39	ThomasFrk04	40	40	0	0		0		0	0.0
40	PruessCreek03	5	5	0	0		0		0	0.0
41	GiraffeCreek03	9	9	0	0		0		0	0.0
42	CoantagCreek	39	39	0	0		0		0	0.0
43	HobbleCreek	75	75	0	0		0		0	0.0
44	BearLake03	30	28	0	2		0		2 (3.1%)	0.0
45	BearLake98	35	35	0	0	CUT	0		0	0.0
46	SwanCreek04	24	16	3	1	CUT	4	CUT	5 (20.8%)	N/A
47	Swan 04S	127	119	1	6	CUT	1	CUT	7 (5.5%)	0.001
48	Beaver Cr 03	13	13	0	0		0		0	0.0
49	St. Charles 03	39	22	4	4	2,2[1]	9	RBT	13 (33.3%)	63.3
50	Williams 01	13	0	12	0		1	RBT	1 (7.7%)	N/A
51	Williams 03	28	0	23	5	1,4[1]	0		5 (17.9%)	0.0
	Total	**1063**	**915**	**81**	**20**		**47**		**67**	

[1] *Number with RBT mtDNA listed first, number with CUT mtDNA listed second.*


WILD TROUT
SYMPOSIUM

The Role of Catch and Release in Wild Atlantic Salmon Conservation in Europe—Possibilities and Pitfalls

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Abstract

The Atlantic Salmon *Salmo salar*, which may be the “noblest” of all “trout” gamefish, is experiencing multiple threats around its North Atlantic range of distribution, and its abundance has shown a long–term reduction. This species represents an interesting case to use in an evaluation of successes and failures in “trout” management and conservation worldwide. Threats ranging from those of large-scale salmon farming, dam building, diseases and invasive species, pollution and habitat loss to those of overharvesting, represent a complex picture well known also for other trout species. For Atlantic salmon, much focus the last decades has been on reduced marine survival. However, in-river management varies significantly among and within countries, and there are interesting differences in the status of and production of wild salmon among and within countries such as Norway, Russia, Iceland, and Scotland. There are similarly interesting differences in management traditions among these countries. This paper will present and discuss Atlantic salmon management and conservation in Europe in general, and the application of catch and release more specifically, pointing at lessons learned that might be useful for the future management and conservation of Atlantic salmon and other trout facing similar challenges.

Introduction

The Atlantic salmon *Salmo salar* is often considered as the King of all game fishes, and may be the noblest of all trout species, be it in the *Salmo* or *Oncorhynchus* genus. Its mysterious journeys, its perfect look and taste, and its fighting spirit made it special very early on in the history of angling. But the complex life history and the way humans valued it made it especially vulnerable to different impacts. The Atlantic salmon conservation history is not very different to that of other regions and other trout species – except that this species may have experienced these problems more severely than most other trouts. Problems with loss of stocks, overharvest, and severely reduced production have been a theme for the last 150 years: overfishing, hydropower development, acid rain, habitat degradation, diseases, genetic interference, and pollution all are problems experienced across regions and subspecies (Lynch et al. 2002).

The Atlantic salmon conservation discourse in Europe was traditionally an allocation debate (Berg 1986). First, it was between fishers in the lower parts of the rivers against fishers in the upper parts, and later, escalating in the 1800s, a conflict between coastal and river fishing, and then, as commercial fishers discovered the feeding grounds off the coasts of the Faro islands, Greenland, and Norway during the 1950s, it became a conflict between ocean fisheries and inshore fisheries. As fishing techniques became even more efficient, the debate about possible overfishing became more prominent. At the same time, during the 1900s, a range of external threats to salmon also emerged. This initiated a more diverse conservation discourse, where first pollution, then hydropower development (HPD), and later problems arising from aquaculture and the spread of alien species became important themes and challenges for sustaining Atlantic salmon.

Today, the abundance of Atlantic salmon is more limited than ever before, and numerous international, national, regional, and local authorities as well as private non-governmental organizations (NGOs) and individuals work to conserve and strengthen wild Atlantic salmon around the North Atlantic Ocean. Yet, the stock status and the mitigating measures vary significantly among the countries with wild Atlantic salmon. For instance, some regions seem to sustain salmon better than other regions. The number and type of threats differ as well, as do management approaches to dealing with these.

In this paper I will examine the practice of and attitude toward catch and release (C&R) in wild salmon management in some countries in Europe, contrast this to Canada, and assess and discuss this measure against the multiple threats that Atlantic salmon faces. Further, I use cases from Norway to assess C&R more specifically. Catch and release was introduced into Atlantic salmon recreational fisheries later than in brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss* fisheries (Policansky 2002; 2007). The first C&R regulations were introduced in eastern Canada in 1981 (Tufts *et al*. 2000). Since 1984 in eastern Canada, anglers have been required by law to release all Atlantic salmon ≥ 63 cm long. However, there exist older recommendations to release salmon both from Canada and Norway, for instance. In Norway, the forest manager Torleif Solberg as early as in 1948 wrote a charming story about the benefits of the release of the female salmon named "Yellow Sandy" in river Åbjøra, Northern Norway.

Methods

This paper is based on existing and extracted data about fishery management and harvest regulations from North Atlantic Salmon Conservation Organisation (NASCO) and Statistics Norway, supplemented with a few interviews with managers and anecdotal information and knowledge of salmon angling in Iceland, Norway, Scotland, Spain, and Russia.

Results

The approach to harvest regulation in sport fisheries varies significantly across NASCO member countries. Traditionally, regulation is done by a combination of effort restrictions and gear restrictions - what we can call indirect regulations (Table 1). Effort restrictions are mostly season limitations, and sometimes, week and day restrictions as well. For instance, Scotland does not allow angling on Sundays, while Iceland has a 12-h daily limit in fishing time. A few countries have effort restrictions also in number of rods allowed on a river, such as Iceland. Gear restrictions might be on type of bait, weight, and number and size of hook(s) allowed. For instance,

Table 1. Main approaches to harvest and catch regulations in Atlantic salmon angling in different countries. Effort is designated as restrictions on season length (S), days per week (W), hours per day (D), and restrictions on number of rods allowed (R). Directed fishing indicates that harvest is regulated by fish gender, size, and/or origin.

	Effort (season/ week/day/rods)	Gear restrictions	Quota	Directed fishing (gender/size/ wild-farmed)	Spawning targets
Iceland	Yes (S/D/R)	Fly and worm only	No	No	No
Norway	Yes (S)	No prawns	No	Yes, locally	No
Finland	Yes (S)	No	No	No	No
Russia	Yes (S)	Fly only	No	No	Yes
Scotland	Yes (S/W)	Locally	Yes	Yes	No
England & Wales	Yes (S)	Locally	Yes	Yes	Yes
Spain	Yes (S)	No	No	No	No
Canada	Yes (S)	Fly only	Yes	Yes	Yes

Norway has banned use of prawns and shrimp, something England and Wales have not done. In Canada, most fishing is fly-fishing only, a trend that seems to spread more and more to other countries, specifically Russia, but also to Iceland, Scotland, and several rivers in Norway.

Few countries have a quota-based management approach or what we can call directed fishing, where specific groups of salmon (for instance grilse) can be taken while others should be released. The latter practice is most prevalent in Canada. Recently, NASCO recommended the move towards establishing Minimum Spawning Targets (MST) or Conservation Limits (CL) for specific rivers. Thus far, it is mostly Canada and Russia that have established such targets and use these actively in managing river fisheries. More recently, Ireland and England and Wales have established such targets or limits. Ireland used them actively in their 2007 evaluation of their fisheries, which led to significant reduction in fishing, particularly drift netting. Norway and Scotland for instance are just underway in establishing such targets, planning to implement them from the 2008 season and onwards.

The practice of C&R has been a part of salmon angling for decades and is well documented in the angling literature. Important angling role models and angling and conservation organizations have spoken in favor of C&R. The last couple of decades have seen research documenting what anglers said; mortality is mostly low to very low on Atlantic salmon, unless in temperatures above 18 degrees C (Thorstad et al. 2007). Interestingly, the adoption of the practice varies significantly among and within countries. First, let us look at differences among countries (Table 2), before I discuss differences within a country, using examples from Norway.

Only three countries, Canada, Russia, and England and Wales use C&R as a compulsory, official harvest regulation measure in their fishing regulations (Table 2). Canada was the first country, with Russia following closely. Interestingly, sport fishing on the Kola Peninsula has been near 100% C&R since this fishery opened around 1990. The other countries, all of Scandinavia, Iceland, Scotland, and mainland Europe so far have a voluntary approach to C&R, meaning that C&R is mostly applied in private regulations or just as encouragements. However, it is interesting to see that the number of fish released varies significantly among the countries which have taken a voluntary approach. Scotland's spring salmon and parts of Iceland's salmon fishing have just in recent years quickly reached a significant level of releases. Norway, Finland, and Spain have the lowest release rate of the countries included in this evaluation.

Table 2. Application of catch and release (C&R) in selected European countries and Canada. Source: NASCO.

	Compulsory/ voluntarily	First year with systematic C&R	Official C&R rate (2005)	Unofficial C&R rate	Trend
Iceland	V		17 – 26 %[a]	25 – 30 %	Increase
Norway	V	-	0 %	2 – 5 %	Unknown
Finland	V	-	0 %	0 %	Unknown
Russia	C&V	1990	87 %		Increase
Scotland	V (some C)	1994	55 %		Increase
England & Wales	C&V	1999	55 %		Increase
Spain	V		0	1 – 5 %	Unknown
Canada	C&V	1984	58 %		Stable

[a] *If the sea ranching river Ranga is taken out the figure is 26 %. If Ranga is included it is 17 %.*

Canada, Russia, and the European Union account for the largest number of released salmon (Table 3, in this reporting, there were made no distinction between EU countries). Interestingly, C&R is clearly increasing from 2000 to 2006, owing mostly to European Union and the Russian Federation. The slight decrease in Canada is assumed to reflect stock changes and not regulation changes. It is also worth noting that some countries do not record releases, despite they in fact occur, such as in Norway (see later). The government and its management agency are still considering how to record these statistics.

Cases from Norway

Norway is among the countries with most of the remaining stocks of wild Atlantic salmon. However, about one-third of Norway's approximately 500 rivers with salmon are considered negatively affected or threatened in one way or another. Major threats are low ocean survival, parasites (sea lice and *Gyrodactylus salaris*), hydropower plants, problems with acidification, escaped farmed salmon (ecological and genetic threats), and overharvest.

The situation for the salmon in Norway is complex and multifaceted, and some stocks are healthy and even increasing, while others are at the rim of extinction. Harvest of salmon has for decades been high in Norway. During the 1970s and 1980s a number of fisheries from ocean to river operated, causing an estimated harvest rate up to 95% on some stocks. Norway closed down the drift net fishing off the coast in 1989, and beginning in 1992 a private buy-out agreement arranged by the North Atlantic Salmon Fund (NASF) has closed down the line fisheries off the Faro Islands, which harvested almost 40 % Norwegian salmon. Recently, fishing has consisted of fixed-net fishing in the sea and angling in rivers. In addition, three major rivers have had subsistence net fisheries. Exact harvest rates the last decade is not well known, but is probably in the 50 to 80 % range for the most productive stocks (Fiske and Aas 2001). River angling harvests 20 to 80 % of the fish entering the river, with 30 to 50% being most common (Mills 1991; Fiske and Aas 2001).

Many foreign anglers and salmon conservationists are furious at the catch-and-kill practice in Norway, and this is probably one of several reasons why few American fly anglers do not visit Norway, while angling segments from Japan and Germany, as well as most Scandinavian anglers seem to prefer the dominating catch and kill practice. What is the eventual potential of C&R in Norway under the current regime given the challenges we are facing? Let us evaluate a couple of situations.

Case 1: The reestablishment of salmon in the acid rivers of the south coast

The south coast of Norway has, due to the bedrock and nearness to the industrial areas of Europe and the British Isles, suffered from acidified

Table 3. Official figures of catch and release among the NASCO parties. Source: NASCO 2007

Year	2000	2001	2002	2003	2004	2005	2006
Canada	62,106	58,961	54,425	51,442	57,005	45,886	49,279
Denmark (Faroe Islands and Greenland)	0	0	0	0	0	0	0
European Union*	27,346	33,504	32,984	34,968	55,064	60,145	62,812
Iceland	2,918	3,607	5,576	5,357	7,294	9,150	8,261
Norway	0	0	0	0	0	0	0
Russian Federation	12,624	16,410	25,248	33,862	24,679	23,592	33,380
USA	0	0	0	0	0	0	425
Total	104,994	112,482	118,233	125,629	144,042	138,773	154,157

**Includes river fisheries in Scotland, England and Wales, Spain and Finland.*

waters since the start of the 1900s. Rivers like the Mandal, which was one of the many rivers that British anglers favoured in the 1800s, lost its stock completely between 1910 and 1920. During the mid-1990s, liming techniques for use in rivers was developed and full-scale liming of the Mandal started in 1997. A stocking program based on nearby rivers was established to reintroduce the salmon to the river. No harvest regulations except for those for "normal" and "healthy" rivers in Norway were established. This implied a 3-month season and no bag limit. Allowed baits were flies, worms, and spoons.

After liming and stocking, there was a rapid establishment of salmon with a significant harvest surplus (Figure 1). It is safe to assume that C&R or a strict quota regulation would not improve the establishment and growth of this stock; hence, eventual implementation of C&R would mostly be based on angling quality, because the spawning stock was very healthy. This region does not have problems with escaped farmed salmon, which could demand a stronger spawning stock, because escapees do not compete too well with wild salmon.

Case 2: The mighty rivers of the north: Alta and Tana

Two of the most famous salmon rivers of Norway are the Tana and the Alta in the far north. Tana is, together with the Miramichi in Canada, one of the two biggest salmon river systems in the world. Alta is among many rated as the world's best river for salmon angling, due to large catches and a very high average weight (close to 25 lb). Both rivers are located in the north of Norway, and the distance between the two is only about 300 mi. The Alta is subject to hydropower development (HPD), and there is significant salmon farming in the fjord outside the river. The Tana has no HPD and little farming. Both fjords have significant netting for wild salmon. The Alta has a strictly regulated sport fishery, and is the only river in Norway with a systematic C&R program. The Tana is heavily fished with rods from shore and

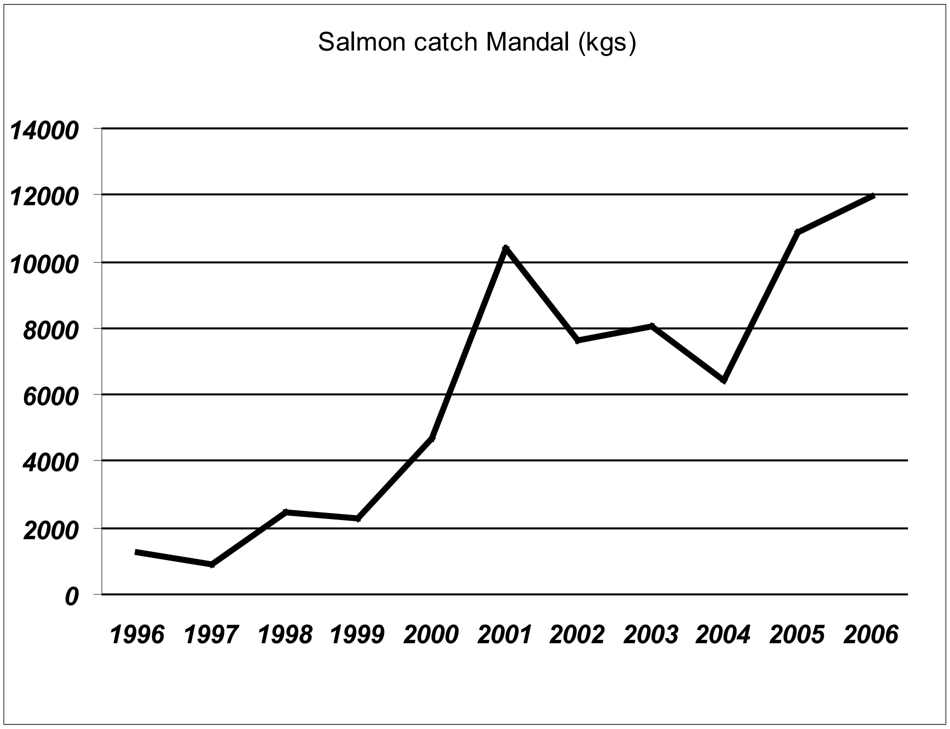

Figure 1. Growth of Atlantic salmon harvest in river Mandal, Norway after full scale liming from 1997 and restocking based on salmon from nearby rivers and without any specific harvest regulations.

boats, and there is a significant subsistence fishery with nets and traps done by the native Saami people. Tana is also a border river with Finland for major parts, which complicate management further.

The two rivers show significantly different trends in harvest and catch the last 7 years (Figure 2). The Alta has had a significant increase, and the Tana has had a serious decline. While the external threats to salmon in Alta are more serious than in the Tana, it is likely that there is a significantly higher harvest rate in Tana. Now, even conservative managers and stakeholders consider that the Tana system most likely lacks many spawners, while the Alta stock seems to be resilient enough to overcome problems caused by HPD as well as farming.

Discussion: Challenges for Atlantic salmon conservation and the role of C&R

The current situation for the Atlantic salmon is characterized by several and increasing number of threats caused by other sectors. In addition, ocean survival of salmon is far less than some decades ago. Despite that current harvest rates are considerably lower than in the 1970s and 1980s, harvest is still significant, caused by angling as well as by remaining subsistence and commercial net fisheries. It is important to take into account that the general production potential of salmon today is far less than in historic times, due to loss of habitat and reduced oceanic survival.

Catch and release represents a way to sustain spawning stocks at almost the same level as they would have been without any river harvest, and at the same time, upholds a very valuable and treasured sport fishery. However, we have seen that the practice is very unevenly distributed among countries with Atlantic salmon. Russia and Canada have the highest rates of C&R, but also Scotland, England and Wales, and Iceland have had a significant growth in C&R fishing, especially the last five years. Even though there is no documentation that there is a causal relationship between C&R and stock status in different regions, it is worth noting the very good situation for the salmon in Russia and Iceland, and the improvements for the spring salmon in Scotland paralleling the growth in C&R. Catch and Release sometimes leads to specialized tourism and management regimes, just as increasing tourism to formerly remote and seldom-visited places leads to C&R.

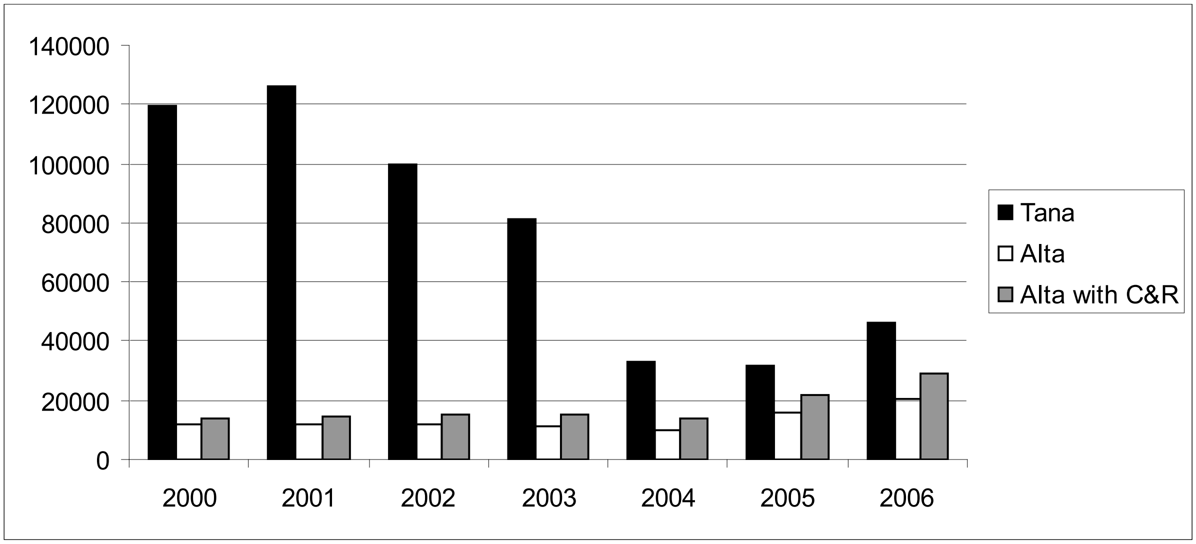

Figure 2. Catch and harvest of salmon in rivers Alta and Tana (Norwegian part) 2000 – 2006.

Also, there are clear differences within countries. This is well known in Canada, where there is far less C&R in some regions and rivers than in others (Thorstad et al. 2007). In Norway, it is worth noting the very different harvest strategies applied in the two rivers Alta and Tana and the different run sizes they produce. While the Alta has a restrictive harvest strategy and the only well-established C&R program in Norway, the Tana has the opposite, a very heavy fishing pressure with a much higher harvest rate. Stocks seem to develop very different in these rivers.

It is obvious that the distribution of C&R is related to the overall approach taken in angling regulations in the different countries. Traditionally, effort and gear restrictions, or indirect regulations dominated. Countries that have moved most in the direction of a more quota-oriented approach or who have developed spawning targets and conservation limits have also been those with the most use of C&R.

There are other interesting aspects of the different distribution of C&R practices, notably the cultural differences attached to this. North America seems to be most favorable towards C&R, while Scandinavian countries and mainland Europe seem to be most negative. In a previous paper (Aas et al. 2002), we examined and compared the debate about C&R in Europe and North America. Animal welfare arguments are more prevalent in the European discourse, for instance in Norway and in Germany (Arlinghaus 2007), and opposite, conservation arguments dominate the North American discourse. Also, consumptive aspects of angling seem to play a bigger role in Norwegian angling than in North America (Aas et al. 1995). However, Iceland has much of the same harvest and subsistence culture as Norway (for instance regarding whaling), and it is interesting to see the rapid growth of C&R in Iceland in recent years, which might question the relevance of cultural differences to explain differences in application of C&R.

Managers in many countries often focus on the serious challenges to salmon conservation caused by external sectors, such as energy production and aquaculture. Resilient stocks, with the largest possible buffer and as many fish as possible in different life stages, are important whether we want to meet challenges from low and varying ocean survival or the threats from escaped farmed salmon. In Norway there is a lot of focus on how to reduce the percentage of escapees in the rivers. Of course, the farms have the main responsibility to prevent escapement. But on a short-term basis, reduced harvest is probably the most ecologically and economically efficient measure to reduce the percentage of escapees in the rivers during spawning, and their spawning success.

Conclusion

Among eager anglers, especially fly anglers, one can get the impression that C&R helps against anything and that it is the panacea of sport fish conservation. Catch-and-Release angling might be a successful management strategy to protect declining populations, but it cannot replace other mitigations often needed more. However, C&R often can assist and work together with more long term efforts to reduce threats against salmon and help uphold valuable fisheries in times and on places with high fishing pressure and reduced stocks.

Ethical issues with C&R represent a challenge in several jurisdictions. Because C&R anglers clearly are not fishing for food or for any other utilitarian purpose, C&R in some places has focused attention on ethical issues more than on recreational angling in general. This debate is further linked to an assumption that there is a clear and fixed conservation limit, and that when the stock is above this level, harvest is acceptable, while when it is below, it is unacceptable with any fishing at all. Reality is different, and in addition, factors such as escaped farmed fish, spatial distribution of spawners, and differing conservation limits due to seasonal variations in environmental factors makes the below or above Conservation Limit debate theoretical at best. I expect that C&R will become a more common management tool in European salmon angling, but think it should still be applied with a basis in local conditions and challenges, not replacing other often more needed mitigations. When the C&R practice grow, it is a need to continue to develop the practice in a wise manner, so that C&R really becomes "live release". The establishment of threshold temperature values when fishing should be stopped rather than operate on a C&R basis is one such step, an approach so far only Canada has taken.

Acknowledgment

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Catch and Release of Large, Piscivorous Ferox Trout in Loch Rannoch, Scotland

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Abstract

Ferox trout are large, piscivorous brown trout *Salmo trutta*. Between 1994 and 2007, 60 ferox trout (fork length >40 cm long) were caught by trolling in Loch Rannoch. The fish were tagged, and released. Ten individuals were re-caught, at least once, up to 7 years later. Analysis of the recaptures indicates that ferox trout survive catch and release and continue to grow with no long-term effect on their condition. Back-calculations of fork lengths from scales indicate that some individuals are consistently slow- or fast-growing, and that brown trout in Loch Rannoch can attain a fork length of 40 cm between their 5th and 13th year. The spatial distribution of recaptures suggests that individual fish have home ranges associated with a particular shore that they occupy from one year to the next. Mark-recapture models indicate that the population of ferox trout exploited by anglers may be substantially less than 200 individuals and may be in decline. Wide-scale adoption of catch and release is recommended.

Introduction

Ferox trout is a term commonly used to describe large, piscivorous brown trout *Salmo trutta*, which are the top fish predators in many Scottish lochs (Campbell 1979). In some lochs, ferox trout are reproductively isolated and genetically distinct from the other sympatric brown trout (Duguid *et al*. 2006). Indeed, ferox trout were previously considered a separate species –*Salmo ferox*. Currently, however, most fisheries biologists consider ferox trout to be members of the brown trout species complex that have adopted a life-history strategy of delayed maturation, extended longevity, piscivory, and rapid growth (Mangel and Abrahams 2001). Nevertheless, the species status of ferox trout may require reassessment (Duguid *et al*. 2006).

Based on a study of 141 ferox trout from 22 Scottish lochs, Campbell (1971, 1979) concluded that typically ferox trout grow slowly until they reach a critical length of 35-40 cm, whereupon they undergo a rapid increase in size associated with a switch to piscivory (Campbell 1971, 1979). Although ferox trout do eat smaller brown trout (Grey *et al*. 2002), examination of stomach contents has revealed a preference for Arctic charr *Salvelinus alpinus,* which abound in most lochs where ferox trout occur (Campbell 1971, 1979). Ferox trout live for many years and can grow to over a meter in length. The current United Kingdom (UK) rod-caught record stands at 14.4 kg (31 lb-12 oz) with the oldest fish recorded in the UK being 23 years of age.

Angling for ferox trout has increased in popularity in recent years (Greer 1995), often in the form of catch and release, yet remarkably little data exist regarding population abundance and home range size, as well as the effects of catch and release on survival and growth. Consequently, in 1994, a long-term mark-recapture catch-and-release study was initiated on Loch Rannoch, in the Scottish highlands. The objectives of the study were (1) to establish whether ferox trout survive catch and release and if so, whether there are any effects on their condition; (2) to determine if individuals have home ranges; and (3) to estimate the number of ferox trout in Loch Rannoch

Methods

Field Site

Loch Rannoch (National Grid Ref. NN600580), which is situated in the Grampian Mountains in central Scotland, is one of the largest lochs in the UK (Figure 1). Its main physical features are summarized by Murray and Pullar (1910). The loch, which has an area of 19 km^2 and lies at an altitude of 204 m, has a maximum depth of 134 m, and length of 16.7 km. Approximately 75% of the loch's area is characterized by water deeper than 15 m. The loch is orientated west to east and is fed, at its western end, by the River Gaur. The loch is oligotrophic with a stony shoreline and lies in a setting dominated by mixed relict deciduous and coniferous woodlands with areas of rough grazing and marginal cultivation.

The loch contains at least eight species of fish: brown trout, Atlantic salmon *Salmo salar*, pike *Esox lucius,* perch *Perca fluviatilis,* eels *Anguilla anguilla*, three-spined sticklebacks *Gasterosteus aculeatus*, minnows *Phoxinus phoxinus*, and Arctic charr.

Loch Rannoch is part of the Tummel Valley Hydro Electric generation complex and has been a hydroelectric reservoir since 1928, when Rannoch Power Station began to receive water from Loch Ericht. A low barrage at Kinloch Rannoch limits the change in water level to a maximum of 2.74 m.

Fish Tagging

In July 1994, the Ferox85 angling group began tagging and releasing all ferox trout with a fork length ≥40 cm caught by its members on Loch Rannoch. The Ferox85 group was formed in 1985 to improve understanding of the biology and behavior of ferox trout and to facilitate the management of sustainable rod fisheries for this important resource. In the intervening 14 years (1994-2007), the Ferox85 group has tagged 60 different ferox trout in Loch Rannoch, of which 10 have been re-caught by Ferox85 members at least once.

All the fish were caught by angling during the fishing season (March 15th to October 6th). Ferox trout angling differs greatly from conventional

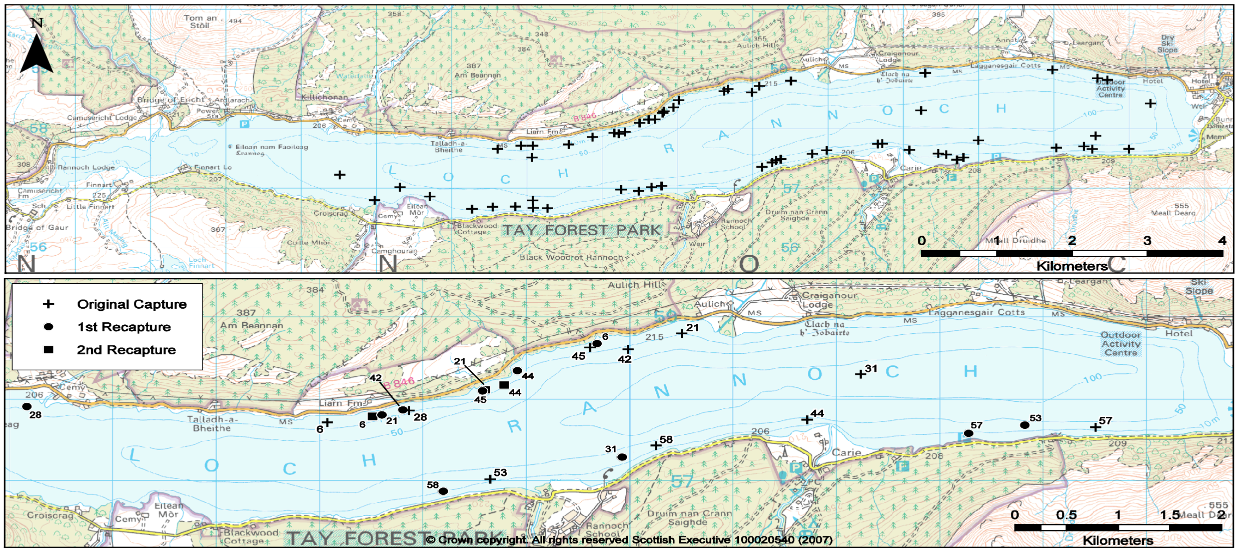

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Figure 1. A map of Loch Rannoch with the 60 original captures marked by a cross and the 13 recaptures marked by a circle or square.

brown trout fishing methods (Greer 1995). Mounted dead baits and lures were trolled behind a boat at differing depths and speeds. The dead baits (usually brown trout or Arctic charr) were mounted to impart fish-like movement. An echo sounder was used to search the contours of the loch bottom for drop-offs and likely fish holding areas and to ascertain fishing depth. Typically, one entire circuit of the loch's shoreline excluding the shallow west end was undertaken on each visit.

Hooked fish were played with care and netted directly into a large tank of water before being carefully unhooked. For the purposes of the study, a ferox trout was considered to be any brown trout with a fork length $\geq$40 cm. Upon unhooking, the capture position of a ferox trout was marked on a map (Figure 1). The fish was then transferred into a large fine-mesh keep net, on the shore closest to the point of capture, where it was allowed to recover before processing. After recovering, the fish was removed from the keep net and placed in a tank containing water and an anesthetic (0.05 % aqueous solution of 2-pheoxyethanol). When the fish was sufficiently sedated its fork length and weight were obtained. Photographs were taken as a record of melanophore constellations (Figure 2), which have been shown to provide a reliable method of individual identification in Atlantic salmon (Donaghy *et al*. 2005). A sample of scales was removed for aging and back-calculation of lengths. The adipose fin was then clipped to aid in the identification of previously tagged fish and preserved in alcohol. Each individual was tagged using a Carlin, dart or Floy tag. After tagging, the fish was returned to the keep net to recover and then released from the shore. The entire procedure usually took less than 30 min.

Statistical Analyses

All analyses were performed using R 2.5.2 (R Development Core Team), WinBUGS 1.4.2 (Gilks *et al*. 1994) and MARK (White and Burnham 1999).

A total of 60 ferox trout were marked and released between 1994 and 2007 and on 15 occasions a previously marked fish was re-caught by a Ferox85 member. Two recaptures, which were in the same year as the previous encounter, were excluded from the analysis to remove any non-independence within years for individual fish. Remarkably, both recaptures involved the same individual (fish 31),which was re-caught three times. After exclusion of the first and third recaptures for fish 31, the data set contained information on 73 encounters involving 60 different ferox trout . The age of each fish was determined from the number of annuli on its scales. The fork length of each fish at the end of each growing season was then back-calculated from its scales using the Dahl-Lea equation (Francis 1990). The age at which each

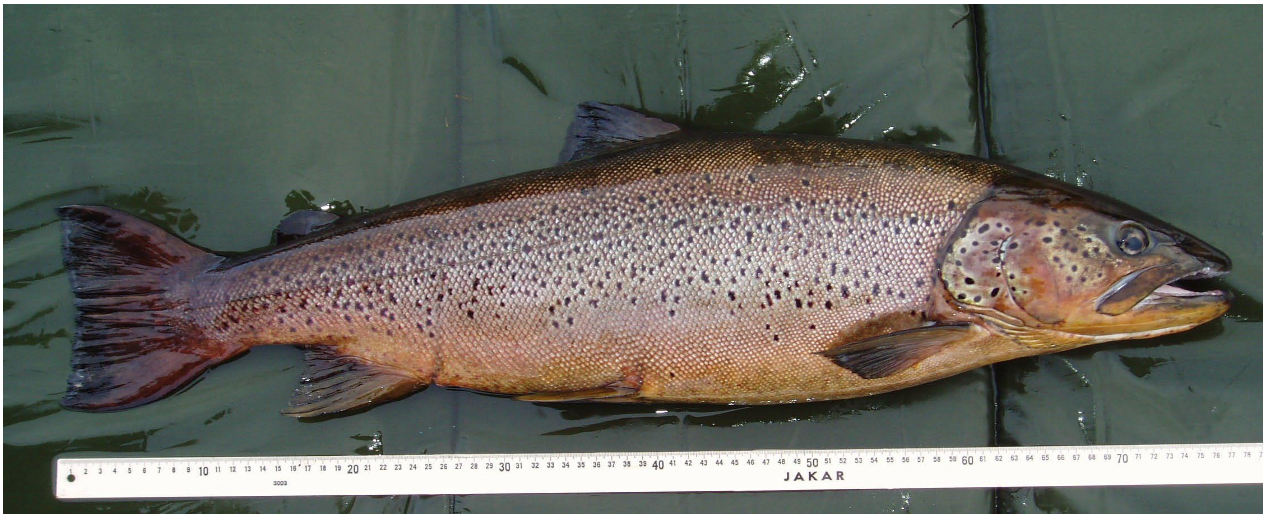

Figure 2. The largest ferox trout tagged in the study (fish 56, 75.5 cm, 7.39 kg, 18 years).

trout became a ferox was defined to be the age at which its back-calculated fork-length attained or exceeded 40 cm and its *ferox-age* was defined to be its age minus the age at which it became a ferox trout.

The relationship Weight = αLength$^{\beta}$ where β is the allometric growth parameter and α is a scaling constant was estimated by fitting a linear regression of $\log_e$(weight) versus $\log_e$(fork length) for all 73 encounters. Since the 13 recaptures represent 'repeated measures', a mixed (hierarchical) model was used with fish identification as a random effect on α (Pinheiro and Bates 2000). To test the effect of capture, age and ferox-age on condition, the same model was fitted with capture versus recapture, age or ferox-age as an additional fixed explanatory variable.

The mean growth trajectory of brown trout in Loch Rannoch with a fork length $\geq$40 cm was estimated by fitting a von Bertalanffy growth curve to the fork length against ferox-age for all 73 captures (Piling *et al*. 2002). The data were too sparse to permit the fitting of a mixed (hierarchical) model (Piling *et al*. 2002). The annual instantaneous growth rate by weight since the previous encounter was calculated for each of the 13 recaptures.

Two hypotheses of the movement of ferox trout in Loch Rannoch were assessed using permutation tests (Manly 1997). The first hypothesis was that ferox trout tend to be re-caught closer to their previous encounter site than expected by chance and the second that ferox trout tend to be re-caught on the same shore (north or south) as their previous encounter. In both cases the chance expectation was generated by randomly permuting the fish identification numbers 10,000 times with respect to the sites and dates of capture. The test statistic for the first hypothesis was the mean of the distance between successive encounters, and the test statistic for the second was the number of recaptures in the same half (north or south) of the loch.

The annual abundance, survival rate, and recruitment of ferox trout in Loch Rannoch was estimated using the POPAN mark-recapture model which also estimates the annual probability of (re)capture (Schwarz and Arnason 1996; Williams *et al*. 2002). The term (re)capture is here used to refer to capture and recapture. The survival rate and recruitment were assumed to be constant through time. Three competing models were fitted with (1) a constant annual probability of (re)capture; (2) an annual probability of (re)capture that varied linearly across the course of the study; and (3) an annual probability of (re)capture that varied independently between years. The three competing models were compared using Akaike's Information Criterion adjusted for small sample sizes (Burnham and Anderson 2002). A mixed (hierarchical) Bayesian mark-recapture model with constant abundance and survival and the annual probability of (re)capture modeled as a random effect with a beta distribution was also fitted to the data (Gelman *et al*. 2004). Two alternative models were fitted with the annual survival fixed at 0.9 and 0.5, respectively. The prior distribution for the number of ferox trout in Loch Rannoch was a gamma distribution with a shape of 1.75 and a rate of 0.005.

Results

The annual back-calculated fork lengths for the 60 individuals indicate that brown trout in Loch Rannoch can reach a fork length of 40 cm in their 5th to 13th year (Figure 3). The growth trajectories of three individuals (fish 16, 18, and 52) are in bold to highlight the different types of growth pattern. Fish 16 shows the typical ferox trout pattern described by Campbell (1979): slow growth to about 35-40 cm followed by a rapid increase in size. However, neither fish 18 nor fish 52, which were fast- and slow-growing respectively, exhibit an obvious growth spurt. The length-weight relationship was best described by an allometric growth parameter of 3.00 (2.79-3.21 95% CI) and a scaling constant of -11.39 (-12.17 - -10.61 95% CI) (Figure 4). Neither capture, age, nor ferox-age had a significant effect on the condition of a fish (in all cases $P > 0.25$).

The von Bertalanffy growth curve (Figure 5) had an average maximum fork length (L_{∞}) of 89 cm (76-327 95% CI), fork length at ferox-age 0

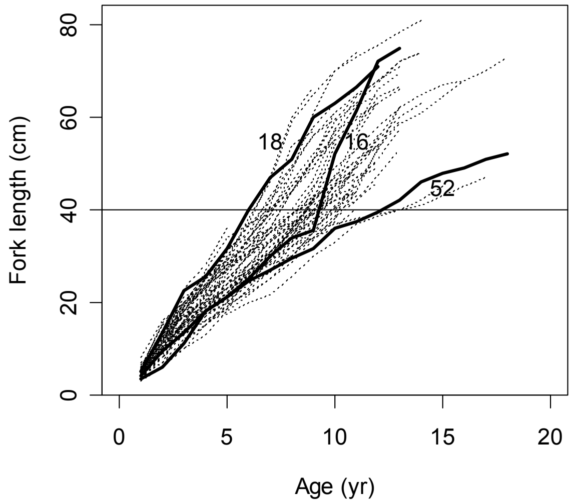

Figure 3. Back-calculated fork length (cm) at the end of growing season against age (year) for all 60 initial captures of ferox trout.

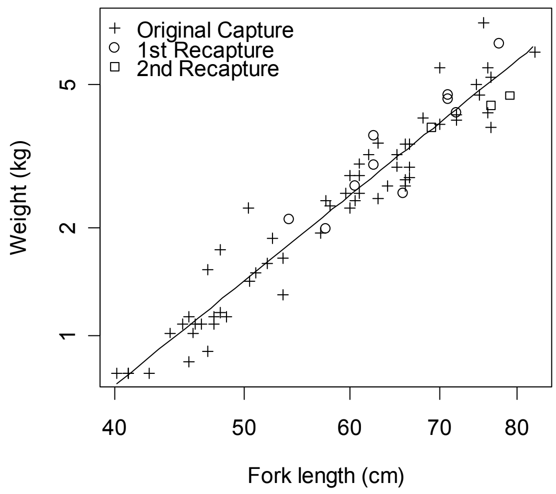

Figure 4. Length-weight relationship for 73 ferox trout encounters.

(L_0) of 41 cm (36-45 95% CI) and a growth rate coefficient (k) of 0.15 year^{-1} (0.02-0.29 95% CI). The mean annual instantaneous growth rate by weight for the 13 recaptures was 18% and the maximum was 50%.

The mean distance between subsequent encounters was 2.3 km and 11 of the 13 recaptures (85%) were in the same half of the loch as the previous encounter. The permutation tests revealed that ferox trout tended to be re-caught closer to the site of the previous encounter ($P < 0.05$) and tended to be re-caught on the same shore more often ($P < 0.015$) than expected by chance.

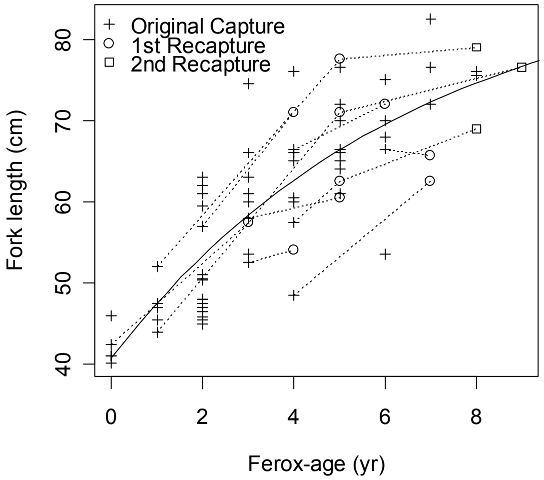

Figure 5. Von Bertalanffy growth curve for 73 ferox trout encounters. Subsequent encounters are indicated by a dotted line.

The best supported POPAN model estimated the annual survival rate to be 0.76 (0.53-0.90 95% CI), the number of brown trout attaining a fork length of 40 cm to be 12 individuals year^{-1} (5-23 95% CI), and the probability of capture by a Ferox85 member to be constant at 0.09 year^{-1} (0.03-0.20 95% CI). The model also estimated that the number of ferox in Loch Rannoch has declined from 82 (0-170 95% CI) in 1994 to 52 (9-95 95% CI) in 2007. The hierarchical Bayesian mark-recapture model estimated the abundance to be 31 (19-52 95% CI), when the annual survival was fixed at 0.5 and 129 (79-221 95% CI) when it was fixed at 0.9.

Discussion

The study has established that if carefully handled, ferox trout can survive catch and release with no detectable long-term effect on condition. Of the 60 ferox tagged over 14 years, 10 were re-caught at least once up to 7 years after tagging. Given the size of Loch Rannoch (19 km^2) and the limited fishing effort – the Ferox85 group fished the loch using a single boat on average 10 to 15 times a year – the probability of recapture of 0.17 (10/60) is remarkably high. In addition, rod capture and tagging did not prevent fast growth. One individual (fish 45) achieved an instantaneous annual increase in its weight of 50% (an increase from 1.93 kg to 4.65 kg in less than two years) and the average instantaneous increase was 18%·year^{-1}.

From the back-calculated lengths of brown trout from throughout Scotland, Campbell (1979 p.17) concluded that "there are populations of slow- or fast-growing, relatively short-lived trout and populations of initially slow-growing trout in which, for a small proportion, the potential for growth and longevity is considerable." With respect to the small proportion, which he considered to be ferox, Campbell (1971 p.19) also concluded that "at about 7 to 9 years of age, when their length is around 35 to 40 cm, a sudden rapid increase in growth takes place, often resulting in a doubling of weight within the annual growth period." The results of this study suggest that Campbell's (1971, 1979) conclusions may require reassessment. Although some ferox trout exhibited the classic growth pattern, others were consistently fast- or slow-growing throughout their life and achieved a fork length of 40 cm from anywhere between their 5th to 13th year.

The reason for the individual differences in growth trajectory is unclear. One possible explanation is that individuals differ in the size at which, and extent to which, they become piscivorous. Indeed, analysis of brown trout stomach contents from 13 Norwegian lakes indicates that brown trout can start feeding on sticklebacks at 13-15 cm and Arctic charr at 20-23 cm (L'Abée-Lund *et al*. 1992). In addition, using nitrogen isotopes Grey *et al*. (2002) found that ferox trout in Loch Ness, Scotland, exhibited a lower trophic level (4.3) than predicted if ferox preyed exclusively on Arctic charr. They attributed the discrepancy to the moderate levels of cannibalism on insectivorous brown trout. The possibility that not all large long-lived brown trout are exclusively piscivorous should also be considered. Nevertheless, given that all 60 individual were caught using a trolled deadbait (58 fish) or lure (2 fish), it is reasonable to conclude that all the fish in the current study were exhibiting some degree of piscivory.

Tagged ferox tended to be re-caught closer to the site of the previous encounter than expected by chance, given the spatial and temporal distribution of all the encounters, suggesting that individual ferox tend to occupy particular areas of the loch season after season, i.e., have home ranges. Further analysis of the data suggests that the home ranges tend to be situated along a particular shore. A similar behavior has been described in adult brown trout in Loch Leven, a shallow, eutrophic loch in southern Scotland (Thorpe 1974).

The mark-recapture models suggest that there may be substantially less than 200 brown trout with a fork length $\geq$40 cm in Loch Rannoch. Furthermore, the data suggest that the population may have declined since 1994. As in any analysis, the validity of the parameter estimates depends upon the extent to which the model assumptions are satisfied.

The POPAN model makes six assumptions (Williams *et al*. 2002). It assumes that (1) all recapture are correctly identified; (2) there is no emigration; (3) the fate of each ferox trout is independent of every other ferox trout; (4) sampling periods are instantaneous; (5) every marked ferox trout has the same survival probability between sampling period i and i+1; and (6) every marked and unmarked ferox trout has the same probability of (re)capture at sampling period i.

Since all ferox trout captured by Ferox85 members during the study were photographed, adipose clipped, and tagged, the first assumption was certainly met. Similarly, it seems reasonable to assume that the emigration of large brown trout out of Loch Rannoch is unlikely (assumption 2), and that since ferox trout are thought to be solitary, individual fates are probably largely independent (assumption 3).

The fourth assumption, in contrast, is certainly violated as the angling season is almost 7 months in duration. Because fish released earlier in the year have longer to survive until the next season, than those released later, the extended sampling period creates heterogeneity of survival among released animals and thus violates the fifth assumption. In addition, senescence may result in a decrease in survival with age. Although heterogeneous survival probabilities tend to result in a positive bias in survival estimates, the bias tends to be small (Williams *et al*. 2002). Furthermore, a higher survival parameter is associated with a larger population estimate. Consequently, the violations of the fourth and fifth assumptions are conservative in the sense that they will tend to inflate the abundance estimate.

The sixth assumption is more problematic. If, for whatever reason, ferox trout vary in their individual propensity to be captured by trolling, then the population abundance will be an underestimate. For example, as discussed above it is possible that ferox trout differ in their degree of piscivory. It is also possible that some individuals might specialize on the benthivorous morph of Arctic charr in Loch Rannoch (Adams *et al*. 1998) - although as far as we are aware an individual of this morphologically distinct ecotype has never been reported from the stomach content analysis of a ferox trout. Irrespective of whether or not the abundance estimates include all brown trout with a fork length of ≥40 cm in Loch Rannoch, the population to which it refers is the population of interest to anglers and fishery managers, i.e., those ferox trout that are caught by trolling. Finally, given the broad confidence intervals around the abundance estimates the question of whether the population has declined since 1994 cannot be answered with certainty. Nevertheless, the precautionary principle argues that until additional information becomes available, managers should assume that the total number of brown trout with a fork length ≥40 cm in Loch Rannoch is substantially less than 200 and in decline.

The study has demonstrated the importance of catch and release for the management of ferox trout in Loch Rannoch. Not only do ferox trout survive catch and release and continue to grow with no apparent long-term effect on their condition, but the population is small, readily exploited by anglers and may be in decline. Wide-scale adoption of catch and release is recommended.

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Long-term Evaluation of Trophy Trout Regulations on Two Pennsylvania Limestone Streams

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Abstract

Special angling regulations are commonly established in an attempt to enhance sport fish populations to meet both biological and social objectives. We evaluated the effects of trophy trout regulations (356-mm minimum length limit and 2-fish/d creel limit) on the wild brown trout *Salmo trutta* populations in Penns Creek and Fishing Creek, two formerly stocked limestone streams in central Pennsylvania that receive high angling pressure. An 11.3-km reach of Penns Creek is managed under all-tackle trophy trout regulations and was evaluated for a 17-year period while a 5.3-km reach of Fishing Creek is managed under artificial-lures-only, trophy trout regulations and was evaluated for an 18-year period. The estimated total wild brown trout biomass increased significantly in both streams under the regulations, while estimates of total wild brown trout abundance remained relatively consistent through time, indicating an increase in the proportion of larger individuals. The estimated biomass and abundance of 350 to 424-mm-long wild brown trout increased significantly in both streams under the regulations, but the abundance of 425 mm and larger individuals did not change. Similar results were documented in two other formerly stocked limestone streams monitored during this same time period (one managed under catch-and-release regulations and one managed under general statewide regulations). These results suggest that while the wild brown trout populations in Penns Creek and Fishing Creek responded positively to the trophy trout regulations, with an overall increase in the abundance of larger brown trout in both streams, it is likely that factors such as wild trout management and shifts in angler sentiment played important roles in the improvements, rather than more restrictive angling regulations alone. Angler opinion surveys conducted on Penns Creek and Fishing Creek during the same period indicated that most anglers had favorable experiences and supported the trophy trout regulations.

Introduction

The use of special angling regulations to reduce or eliminate the sport harvest of salmonids has increased markedly during the past few decades (e.g., Anderson and Nehring 1984; Graff 1987; Carline et al. 1991; Bailey and Hubert 2003; Parker et al. 2007). These regulations have been established on both stocked and unstocked waters in an attempt to increase trout density, improve population size structure, and ultimately improve fishing quality. When special angling regulations are successful, hooking mortality is usually low and the probability of recapture is high (Gresswell 2004). Where some harvest is permitted, creel limits are often small and the length of fish that may be harvested is restricted (Carline et al. 1991). Additionally, terminal tackle is usually restricted to artificial lures and flies. The use of live bait is typically prohibited to minimize hooking mortality, which is typically less than 10% for salmonids caught on artificial lures and flies and up to 50% for those caught with bait (Wydoski 1977; Mongillo 1984; Nuhfer and Alexander 1992; Taylor and White 1992; Schill 1996; Schisler and Bergersen 1996; DuBois and Dubielzig 2004). However, DuBois and Kuklinski (2004) reported substantially lower post release mortality levels of brook and brown trout (2–7%) when bait was actively fished. Additionally, Carline et al. (1991) reported that hooking mortality of wild brown trout associated with bait angling in Spring Creek, a heavily-fished limestone stream in central Pennsylvania, had to be considerably less than 25% based on the high catch rates and trout densities that were maintained throughout the study period, even though large numbers of trout were caught and released by bait anglers. The restriction of bait may limit the participation of and angling opportunities for individuals that prefer to fish with bait. Greene et al. (2006b) reported that 43% of anglers used bait during a 2004 angler use and harvest survey conducted on 200 unstocked, wild trout stream sections in Pennsylvania. Additionally, Greene et al. (2006a) reported that 68% of anglers used bait during a 2005 angler use and harvest survey conducted on 30 stocked trout stream sections throughout Pennsylvania.

The objective of this study was to evaluate the long-term effects of trophy trout regulations on the wild brown trout *Salmo trutta* populations inhabiting Fishing Creek and Penns Creek, two popular, heavily fished, limestone streams located in central Pennsylvania. Formerly, both fisheries were maintained by stocking large numbers of catchable-size trout. Fishing Creek, Clinton County, was stocked with catchable trout until 1982 and Penns Creek, Centre County, was stocked with catchable trout until 1992. Due to the presence of robust, Class A (≥40 kg/ha) wild brown trout populations, sections of both streams were removed from the Pennsylvania Fish and Boat Commission's (PFBC) stocked trout program in favor of wild trout management. Fishing Creek was added to the trophy trout regulation program in 1983, while Penns Creek was added in 1995. A 5.3-km section of Fishing Creek is currently managed under artificial-lures-only trophy trout regulations, which limits terminal tackle to artificial lures and flies, while an 11.3-km section of Penns Creek is managed under all-tackle trophy trout regulations, which allows the use of bait. Both stream sections are open to angling year-round with a 356-mm minimum length limit and 2-fish/d creel limit from the opening day of trout season (second Saturday in April) to Labor Day, with no harvest for the remainder of the year. For the purposes of this study, 350 mm and larger trout were considered legal-size under the trophy trout regulations because trout were tallied by 25-mm size groups and exact lengths were not recorded for all fish.

Study Area

Penns Creek and Fishing Creek are located in the Valley and Ridge physiographic province of central Pennsylvania. Large springs from the underlying limestone aquifers maintain the base flow and productivity of the middle portions of both streams, where the trophy trout regulation sections are located.

Penns Creek

Penns Creek is a true limestone stream, originating from a large spring at Penns Cave. It flows 131 km from its source to its confluence with the Susquehanna River and drains a 793-km^2 watershed. The upper 67 km of this stream harbors a robust wild brown trout population, which includes the 11.3-km reach that is managed under all-tackle trophy trout regulations. The trophy trout section can be characterized as a relatively wide stream (mean wetted channel width: 30 m) of moderate gradient (0.9%) that meanders through a broad valley with mixed land use, predominated by agriculture and forest land. Typical ranges of water quality measurements were pH 8.0–8.4, and total alkalinity 108–138 mg/l as $CaCO_3$. Angling access is good, with about 32% of the riparian zone of the trophy trout section publicly owned and 44% of the section is within 100 m of a public road. A rail trail also provides good walking and bicycling access to the stream.

Fishing Creek

Fishing Creek is a limestone-influenced stream that originates as a freestone stream due to the dominant sandstone geology in the mountainous region of its upper watershed. When the stream reaches the valley floor, it sinks and rises due to the karst limestone geology. As the stream emerges, it becomes more characteristic of a limestone stream, with higher pH and alkalinity, more stable flows, and a considerable increase in fishery productivity. Fishing Creek flows 69 km from its headwaters to its confluence with Bald Eagle Creek and drains a 469-km^2 watershed. The lower 35 km of this stream harbors a robust wild brown trout population, which includes the 5.3-

km reach that is managed under artificial-lures-only trophy trout regulations. Wild brook trout *Salvelinus fontinalis* also inhabit the trophy trout section, but at much lower densities than brown trout. The trophy trout section can be characterized as a moderate-size stream (mean wetted channel width: 14 m) of moderate-high gradient (2.2%) that flows adjacent to a PFBC trout production hatchery and then through a narrow, forested gorge and ends adjacent to a U.S. Fish and Wildlife Service research and production hatchery. Typical ranges of water quality measurements were pH 7.7–7.8 and total alkalinity 82–103 mg/l as $CaCO_3$. Angling access is very good, with about 55% of the riparian zone of the trophy trout section publicly owned and 84% of the section is within 100 m of a public road.

Methods

Penns Creek

The Penns Creek brown trout population was sampled during June or July on eight occasions from 1991 to 2007. The same 425-m site was sampled during each survey. Two 250-V, DC electrofishing towed boats were used side-by-side to survey the site each year. Each boat was equipped with two probes that served as the anodes and either stainless steel droppers or a stainless steel sheet attached to the hull of the boat served as the cathode.

Three-pass depletion estimates were used to estimate abundance during the first three surveys. Confidence intervals (95%) were calculated based on the formulas described by Armour et al. (1983). All three electrofishing passes were conducted during the same day. All trout captured were measured (total length; nearest mm) and tallied by 25-mm size groups. A subsample of 10 trout per 25-mm size group was weighed to the nearest gram. Because recapture efficiencies varied with total length, separate population estimates were computed for age-0 brown trout (<125 mm) and for age-1 and older fish. Mean weights were computed for fish in each 25-mm size group, and these were multiplied by the estimated number of fish per size group to estimate biomass. Stocked brown trout were distinguished from wild individuals on the basis of fin condition. Individuals with fin deformities or excessive wear were recorded as hatchery origin and were not used for abundance or biomass calculations.

Petersen mark-recapture population estimates were used to estimate abundance during the last five surveys. The sample reach was surveyed at 1 to 3d intervals. During the first electrofishing pass, all trout captured were given a temporary caudal fin clip and measured (total length; nearest mm) and tallied by 25-mm size groups. A subsample of 10 trout per 25-mm size group was weighed to the nearest gram. All trout collected during the second electrofishing pass were measured and the presence of caudal fin clips was recorded. The Chapman modification of the Petersen mark-recapture formula was used to compute estimated abundance and a binomial distribution was used in computing 95% confidence intervals (Krebs 1989). Because recapture efficiency varied with total length, separate population estimates were computed for age-0 brown trout (<125 mm) and for age-1 and older fish. When fewer than three individuals were recaptured in a 25-mm size group, the first pass catch and second pass catch (minus recaptures) were summed to obtain the abundance estimate (Ricker 1975). Mean weights were computed for fish in each 25-mm size group, and these were multiplied by the estimated number of fish per size group to estimate biomass.

Fishing Creek

The Fishing Creek brown trout population was sampled during July or August on 14 occasions from 1982 to 2000. A 391 to 488-m site was sampled during each survey. The starting point of the site remained consistent each year. One 250-V, DC electrofishing towed boat was used to survey the site each year. Petersen mark-recapture population estimates were used to estimate abundance during all surveys, following the same methods as described for Penns Creek. All other methods were consistent with those used for Penns Creek.

Results

Penns Creek

Because too few marked age-0 fish were recaptured during some surveys, their abundance could not be estimated. Instead, the total catch of these individuals during the first electrofishing pass was used as an index of abundance. The catch of age-0 fish fluctuated considerably through time, with no strong trends.

The estimated biomass of age-1 and older brown trout (hereafter referred to as adults) increased significantly from 67 kg/ha in 1991 to 103 kg/ha in 2007 (r^2=0.75; P<0.01), but there was not a significant increase in the overall abundance of these individuals (r^2=0.12; P=0.39), indicating a shift in the size structure of the population to more larger individuals. The abundance of intermediate-size (275–325 mm) brown trout increased significantly from 184/km in 1991 to 485/km in 2007 (r^2 = 0.58; P=0.03). Additionally, the abundance of legal-size (≥350 mm) brown trout increased from 38/km in 1991 to 174/km in 2007 (r^2=0.76; P<0.01; Figure 1). The increased abundance and biomass of legal-size individuals was due to an increase in 350 to 400-mm fish. There was no change in the abundance of 425 mm and larger brown trout (r^2=0.16; P=0.32). Estimated abundance of 425 mm and larger brown trout was low and ranged from 0 to 9 fish/km. Overall, there was over a twofold increase in the abundance of intermediate-size and over a fourfold increase in the abundance of legal-size brown trout through time.

Fishing Creek

We documented similar trends in the Fishing Creek brown trout population as in Penns Creek.

Again, the catch of age-0 fish varied considerably through time, with no strong trends. The estimated biomass of adult brown trout increased significantly from 76 kg/ha in 1982 to 289 kg/ha in 2000 (r^2=0.61; P<0.01), and there was also a significant increase in the overall abundance of these individuals (r^2=0.31; P=0.04), especially in the larger size classes. The abundance of intermediate-size (275–325 mm) brown trout increased significantly from 90/km in 1982 to 637/km in 2000 (r^2=0.45; P<0.01). Additionally, the abundance of legal-size (≥350 mm) brown trout increased significantly from 80/km in 1982 to 235/km in 2000 (r^2=0.42; P=0.01; Figure 2). It is unclear as to why the abundance of legal-size brown trout decreased considerably in 1994 and 1996, but the population quickly rebounded by 1998 and 2000 (Figure 2). The increased abundance and biomass of legal-size fish was due to an increase in 350 to 400-mm individuals. There

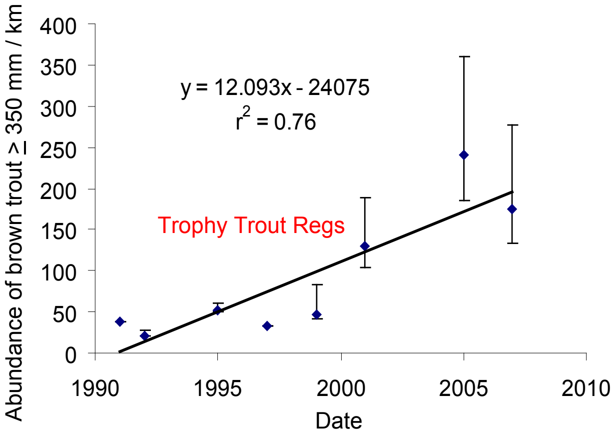

Figure 1. Estimated abundance of legal-size (>350 mm) brown trout / km in Penns Creek from 1991 to 2007 with 95% CI's. Trophy trout regulations were adopted in 1995.

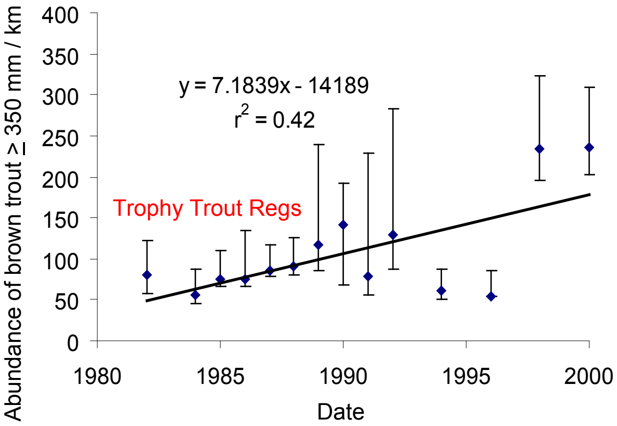

Figure 2. Estimated abundance of legal-size (>350 mm) brown trout / km in Fishing Creek from 1982 to 2000 with 95% CI's. Trophy trout regulations were adopted in 1983.

was no change in the abundance of 425 mm and larger brown trout (r^2=0.05; P=0.46). Estimated abundance of 425 mm and larger brown trout was low and ranged from 0 to 8 fish/km. Overall, there was over a sevenfold increase in the abundance of intermediate size and nearly a threefold increase in the abundance of legal-size brown trout through time. In addition to brown trout, Fishing Creek also continues to support a wild brook trout population. However, as the brown trout population improved through time, the brook trout population declined. The abundance of adult brook trout ($\geq$125 mm) decreased significantly from 338/km in 1984 to 45/km in 2000 (r^2=0.74; P<0.01).

Comparison to Other Limestone Streams

The positive responses of the brown trout populations in Penns Creek and Fishing Creek led us to investigate whether similar trends may have occurred in other wild brown trout populations in limestone streams during the same time period. Two formerly stocked limestone-influenced streams that were sampled regularly during the same time period as Penns Creek and Fishing Creek were Bushkill Creek, Northampton County, and Honey Creek, Mifflin County. Bushkill Creek is currently managed under no-harvest regulations (artificial lures only; open to angling year-round) and Honey Creek is managed under general, statewide regulations (all tackle, 176-mm minimum size limit, 5-fish/d creel limit from the second Saturday in April to Labor Day; 3-fish/d creel limit from Labor Day to February 28; closed to angling March 1 to second Saturday in April). Both streams have been managed for wild trout since 1983. Similar to Fishing Creek and Penns Creek, the brown trout populations inhabiting Bushkill Creek and Honey Creek increased considerably. A comparison of the adult brown trout biomass in these systems indicated that two to four-fold increases occurred in all four populations. The most consistent increase in adult brown trout biomass occurred in the first 6 to 8 years of wild trout management in all four streams, regardless of differences in angling regulations among streams during this time period. After the initial 6 to 8-year jump, adult biomass appeared to apex, year-to-year variability increased, and there was no longer a strong increasing trend. These results suggest that carrying capacity, at least in terms of total brown trout biomass, may have been reached within about 6 to 8 years of wild trout management, regardless of the differences in regulations among streams.

In addition to the trends in total adult brown trout biomass in all four streams, significant improvements in the abundance and biomass of the intermediate-size (275–325 mm) brown trout was also documented. The abundance and biomass of legal-size ($\geq$350 mm) brown trout increased significantly in Penns, Fishing, and Bushkill Creek, but did not change in Honey Creek. Honey Creek is a smaller stream than the other three systems and may not contain as much habitat that is conducive to supporting larger fish. There was no change in the abundance or biomass of 425 mm and larger fish in any of the streams.

Discussion

Penns Creek and Fishing Creek

The brown trout populations inhabiting Penns Creek and Fishing Creek responded positively to wild trout management and trophy trout regulations. Both populations exhibited similar trends including significant increases in total brown trout biomass and significant increases in both the abundance and biomass of intermediate-size (275–325 mm) and legal-size brown trout due to increases in 350 to 400-mm individuals. Both streams harbor low densities of 425 mm and larger fish. Age and growth analyses on wild brown trout from Pennsylvania limestone streams indicate that on average, brown trout reach 350 mm during age 4 but are not reaching 425 mm until age 6 or 7. Annual mortality rates of brown trout age 1 to age 4 in exploited and unexploited limestone streams typically range from 40 to 60%. These data suggest that most individuals succumb to mortality, most of which appears to be of natural causes, well before they reach the larger size classes ($\geq$425 mm) regardless of differences in angling regulations.

Angler Use, Harvest, and Sentiment

Penns Creek and Fishing Creek are both popular, well-renowned streams that receive high angling pressure. Angler effort ranged from 34 h/ha on Penns Creek (Greene and Weber 1995) to 927 h/ha on Fishing Creek (Greene and Weber 1996). In comparison to other limestone streams, angler effort ranged from 26 h/ha on Honey Creek (Weber and Greene 2003) to 569 h/ha on Spring Creek (Carline et al. 1991). The 927 h/ha of effort documented on Fishing Creek is the highest on record for Pennsylvania trout streams.

Angler use and harvest surveys conducted by the PFBC on these streams indicated high levels of catch-and-release. Catch-and-release rates of brown trout ranged from 61% on Penns Creek in 1994 (Greene and Weber 1995) to 99% on Fishing Creek in 1996 (Greene and Weber 1996). The 61% catch-and-release rate reported by Weber and Greene (1995) on Penns Creek was conducted during the period in which the stream was managed for wild trout under general statewide regulations before it entered into the trophy trout program. Even though the 61% catch-and- release rate reported for Penns Creek is relatively high, it was considerably lower than Fishing Creek, likely due to more liberal regulations and the fact that it was stocked heavily with catchable trout up to one year prior to the survey. Conversely, the Fishing Creek survey was conducted while having been managed under trophy trout regulations for 14 years. A 2001 angler use and harvest survey conducted on Honey Creek reported an 88% catch-and-release rate and 3% exploitation rate, which provides additional information that release rates on wild trout stream sections are typically high, even when not managed under special regulations (Weber and Greene 2003). Furthermore, a 2004 angler use and harvest survey conducted on 200 stream sections statewide indicated a 93% catch-and-release rate and a 4% exploitation rate on all wild trout (Greene et al. 2006b).

Stream sections stocked with trout in Pennsylvania typically have considerably higher harvest rates than those managed for wild trout. Greene and Weber (1993) reported an average harvest rate of 60% on stocked trout streams during surveys conducted from 1988 to 1991. A 2005 angler use and harvest survey conducted on 30 stocked trout stream sections statewide reported an average harvest rate of 37% and catch-and-release rate of 63% (Greene et al. 2006a), indicating a considerably increased rate of catch and release as compared to the late 1980's and early 1990's. Thus, as time has progressed catch-and-release rates in both our wild and stocked trout fisheries have also increased, which suggests a shift in angler sentiment has occurred to a more catch-and-release-oriented public. In a nationwide telephone survey, Kellert (1980) reported that the top three reasons people fish were (1) catch food to eat, (2) fishing for sport, and (3) being with family and friends. Duda et al. (1999) conducted a similar survey and reported that the top three reasons people fish were (1) relaxation, (2) being with family and friends, and (3) being close to nature. These results further suggest that the angling public has shifted its focus to the overall experience, rather than simply catching and harvesting large numbers of fish. The high catch-and-release rates documented on Penns Creek and Fishing Creek as well as other wild trout streams in Pennsylvania suggest that angler harvest is currently having a minimal impact on these fisheries.

Bait Angling

Results of this study suggest that bait angling is not having a negative impact on the wild brown trout population in Penns Creek. An attitude and opinion survey conducted on Penns Creek by Hollender et al. (1993) indicated that 65% of anglers and 75% landowners were not supportive of prohibiting bait angling, and most indicated that they would close their land to public angling if bait was restricted. Additionally, bait angling does not appear to have negatively impacted other productive limestone streams, including Honey Creek (Weber and Greene 2003) and Spring Creek (Carline et al. 1991). The restriction of bait may limit the participation of and angling opportunities for individuals that prefer to fish with bait. Weber and Greene (2003) reported that 43% of anglers used bait during the 2001 study on Honey Creek. Carline et al. (1991) reported that 38% of anglers used bait in two sections of Spring Creek. Greene et al. (2006b) reported that 43% of anglers used bait during the 2004 angler use and harvest survey conducted on 200 unstocked, wild trout stream sections in Pennsylvania. Additionally, Greene et al. (2006a) reported that 68% of anglers used bait during the 2005 angler use and harvest survey conducted on 30 stocked trout stream sections throughout Pennsylvania. Based on the high proportion of anglers preferring to fish with bait and the fact that bait does not appear to be negatively impacting the wild trout populations inhabiting the numerous streams where it is has been evaluated, managers should strongly consider the use of all-tackle regulations for future special regulation areas, because restricting bait likely limits angler participation.

Comparison to Other Limestone Streams

The positive responses of the brown trout populations inhabiting Penns Creek and Fishing Creek as well as Bushkill Creek and Honey Creek indicate that special angling regulations may not be the sole factor enhancing wild brown trout populations in Pennsylvania's productive limestone streams. The most consistent increase in adult brown trout biomass occurred in the first 6 to 8 years of wild trout management in all four streams, regardless of differences in angling regulations among streams. The initial improvements in the brown trout populations in Honey Creek and Bushkill Creek occurred while managed under general statewide angling regulations. The 6 to 8-year period reasonably corresponds with the time frame that we expect for one cohort to move through the fishery, which may be an important factor in the positive response. Another interesting aspect is that the significant increase in adult biomass occurred in Penns Creek during the 1990's, while it was documented in the other three streams during the 1980's. This may suggest that changes in the brown trout population may be related to alternate management strategies, rather than just favorable conditions present during the 1980's.

Conclusions

It is likely that trophy trout regulations played an important role in improving the wild brown trout populations inhabiting Penns Creek and Fishing Creek, especially considering the high levels of angler use on these streams. However, it is also likely that stocking cessation, wild trout management, and shifts in angler sentiment to considerably higher levels of voluntary catch and release have also played important roles. During the early 1980's and 1990's when Fishing Creek and Penns Creek were added to the trophy trout program, harvest rates were higher and angler sentiment was more harvest oriented, especially given the fact that both streams were heavily stocked with catchable-size trout and managed as put-and-take stocked trout fisheries before special regulations were established. With the high levels of angler use and catch and release, bait angling does not appear to be negatively impacting the wild brown trout populations in Penns Creek or other limestone streams such as Honey Creek and Spring Creek where it is permitted. It is likely that environmental factors and natural mortality are having a much greater impact on the wild brown trout populations in Pennsylvania's limestone streams, rather than angling, and are currently driving the trends in these streams.

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Angler Effort and Harvest of Sea-run Brook Trout from a Specially Regulated Estuary, Nova Scotia, Canada

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Abstract

Special Trout Management Areas (STMAs) were established to enhance wild, sea-run brook trout *Salvelinus fontinalis* fisheries in Nova Scotia. In 2001, the West River of Antigonish was designated a STMA. New regulations included a delayed opening to 15 May, lure- or fly-only and a reduced daily limit of one trout with a minimum total length of 35 cm. The STMA boundaries extend into the Antigonish Harbour estuary, shared by the West and South rivers. The South River side of the estuary is under general regulations (five trout daily limit, bait permitted, 15 April opening date). During Recreational Fisheries Advisory Council meetings, anglers expressed concerns that increased effort and harvest in the South River was negatively impacting the West River.

Ten years of creel data collected prior to establishing the STMA were compared with data from 2006 and 2007. Angler effort and trout harvest increased dramatically on the South River side of the estuary. Trout longer than 35 cm increased from 23% pre-STMA to 64% in 2006 and 53% in 2007. The percentage of 4- and 5-year-old trout was 10% in previous surveys and 51% in 2006 and 2007. Although the impact of exploitation outside the STMA estuarine border is unknown, size and age changes suggest the West River STMA improved the sea-run brook trout fishery.

Introduction

In Nova Scotia approximately 51,000 licensed anglers participated in a sport fishery that generated approximately Can$53 million to the provincial economy. In terms of annual catch per year by Nova Scotia anglers, brook trout *Salvelinus fontinalis,* are the most popular, followed by introduced smallmouth bass *Micropterus dolomieu* and native anadromous rainbow smelt *Osmerus mordax* (Fisheries and Oceans 2007). Anadromy in brook trout is common and many anglers pursue sea trout because of their large size (Scott and Scott 1988). Wild, sea-run brook trout populations have been deteriorating throughout their range from habitat loss and over exploitation. This decline is especially apparent in the southern half of their North American distribution, which includes Nova Scotia (Ryther 1997).

Interest in changing regulations was fueled by growing public support and publications suggesting that a collapse of many recreational fisheries was related to overfishing (Post et al. 2002). The response of fishery management agencies has often been the use of special regulations on certain rivers and lakes, even when baseline data were minimal or absent (ASF 1999). Nova Scotia Recreational Fisheries Advisory Councils provide anglers the opportunity to offer input into fisheries management decisions regarding regulatory change. Legislative changes enabled the province of Nova Scotia to implement unique regulations on a river specific manner in 2001. The criteria used to select Special Trout Management Areas (STMA) for sea-run brook trout were similar to those outlined for exceptional trout waters by Born et al. (1990). Criteria for riverine STMAs include a high carrying capacity, potential for trophy wild trout, and public access. New regulatory approaches in STMAs justify the need for assessment. Population modeling studies have demonstrated positive impacts of size limits on trout fisheries (Clark et al. 1981; Power and Power 1996; Post et al. 2003); however, relatively few studies have been conducted on severe regulatory changes on heavily exploited anadromous brook trout populations.

Nova Scotia sea-run trout fisheries are characterized by heavy angler pressure, high rates of retention, and the use of bait (LeBlanc 2000). Angling in April and May typically takes place in both tidal areas and lower reaches of rivers making large numbers of migrating brook trout susceptible to heavy angling pressures. With support from the public Recreational Fisheries Advisory Councils, the West River of Antigonish was approved as a Special Trout Management Area in 2001. New regulations were developed based on previous spring creel surveys, which revealed that very few sea run trout lived beyond 3 years of age or had a fork length longer than 35 cm. The new regulations for the West River sea-run trout fishery included a delayed opening to 15 May, gear restriction to lure- or fly-only (no bait), and a reduced daily bag limit of one fish with a minimum total length of 35 cm. The West River STMA includes the main branch of the river system and a portion of the Antigonish Harbour estuary that is shared by both the West and South rivers of Antigonish (Figure 1). The portion of the Antigonish Harbour that is located on the South River side is under general fishery regulations (five trout bag limit, bait permitted, and an open date of 15 April). The Wallace River, located approximately 120 km NW of the West River of Antigonish, has remained under general fishing regulations.

Objectives of the regulations used in Special Trout Management Areas were to improve the size and number of trout caught and to reduce the time required to catch a trout. The purpose of this study is to assess the impact of regulatory change on the stated objectives.

Study Site

The West (N45°37′14.4″ W61°58′50.5″) and South (N45°36′01.0″ W61°54′51.3″) rivers of Antigonish and Wallace River (N45°48′44.4″ W63°30′58.3″) are located on the northern shore of mainland Nova Scotia and flow into the Northumberland Strait. The approximate main river length of the West River is 30.6 km, that of the South River is 31.7 km, and the Wallace River is 30.1 km. These systems are known as productive habitats for brook trout and the geological makeup of their drainage areas includes limestone and gypsum, both of which provide a natural buffering capacity

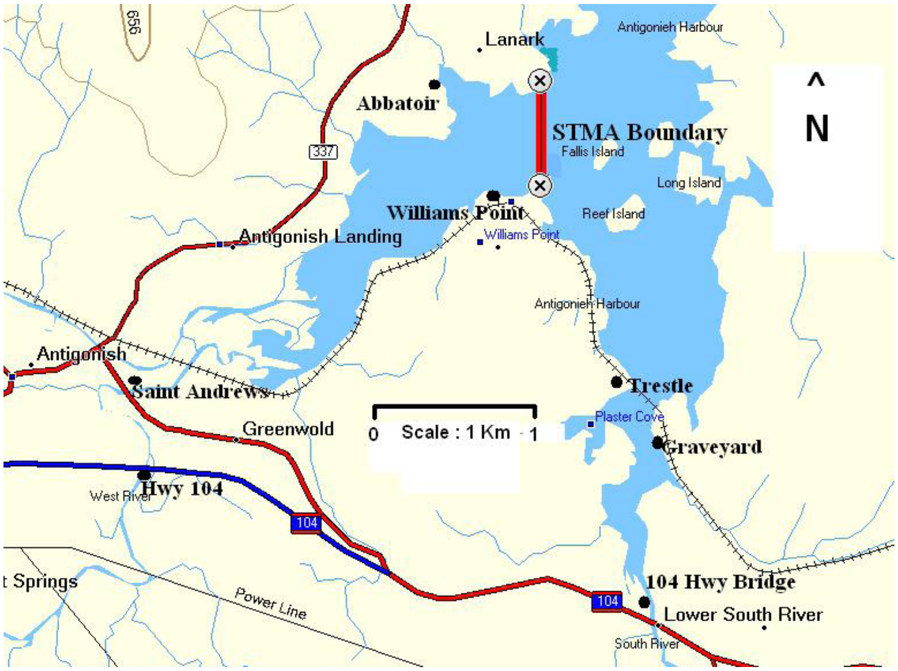

Figure 1. Creel survey sites and West River Special Trout Management Area estuarine boundary.

against acid precipitation. The West River has a pH range of 7.5 to 8.0 while the South and Wallace rivers have a pH range of 6.3 to 6.8 and 6.4 to 7.5, respectively.

Land clearing associated with forestry, agriculture, and other development has impacted these habitats. Few lakes and impoundments are present on the Wallace and West rivers of Antigonish. Although warm water and low flow conditions reduce salmonid habitat in summer, warming is much less relative to many riverine habitats located in more southern regions of the province (MacMillan et al. 2006). Salmonids inhabiting these systems include; native Atlantic salmon *Salmo salar,* brook trout*,* introduced brown trout *Salmo trutta,* and rainbow trout *Oncorhynchus mykiss*. Brown trout have established self-sustaining populations in many rivers whereas the rainbow trout fishery is dependent on escapement from aquacultural sites or direct stock enhancement strategies. Counts of upstream migrating anadromous brook trout from a South River fish counting fence were 351 in 1981 and 1,024 in 1982 (Miles 1985).

Methods

The creel survey sites were selected based on their angling popularity and were located in tidal areas or just above the head of tide on the West and South rivers of Antigonish and Wallace River. Creel survey data for the first week of the angling season between 15 April and 22 April were used to estimate changes in trout catch per hour between 1991 and 2000 and 5 and 6 years after regulatory changes in 2006 and 2007. As a result of a delayed opening of the fishery to 15 May, creel data from West River sites and sites on the West River side of the Antigonish Harbour were available only prior to 2001 (Figure 1). Sites on the South River side of the estuary and on the Wallace River remained under general fishing regulations and had a consistent 15 April opening of the angling season throughout the 17-year study period. The South River shares the same estuary (i.e., Antigonish Harbour) with the West River and sea-run trout are known to migrate throughout their native estuaries. Catches in the South River side of the Antigonish estuary were probably influenced by regulations implemented in 2001 on the West River and estuary. The Wallace River creel survey sites were assessed from 1991 to 2000 and 2007 and included as a control site in this study.

Data collected during the angler interview included the name of the angler, date, time, site of interview, species caught, fork length (FL) of fish caught, hours angled, and gear type used. Total number of anglers, water temperature, air temperature, and weather conditions were recorded from sites each sampling day. Anglers who were interviewed a second time in one day were surveyed regarding the time fished since the first interview.

During week-long creel surveys in 1991-1999, a maximum of 6 of the first 7 d of the angling season were sampled. Hourly survey start times were randomly selected between 0600 and 2000 hours. Results of these surveys indicated that angler activity and catches were variable and trout catch per hour was highly dependent on weather conditions, and an increase in duration of sampling and sampling methodology was required to assess the spring sea-run fishery on an annual basis. Ice cover on estuaries is common during the opening week of the angling season, when effort is heavy and water temperature often remains below 6 ^{o}C. The optimum range for brook trout activity is 10-17^{o} C as summarized by Power (1980). The mean catch per hour, pooled size and age structure data of 1991-1999 and 2000 were compared with that from 2006 and 2007.

The expanded sampling methodology for creel surveys in 2000, 2006, and 2007 followed a two-stage design, where a fishing day was the primary sampling unit, as described in Lester et al. (1991). Mean catch per hour and mean activity (anglers counted) were assessed from two sampling circuits for each day sampled. Mean catch per hour of each species was determined for each angler and then for each day sampled for each system. Daily mean catch per hour was based on samples of more than two angler interviews. Mean catch per hour for each system and year was determined. Daily mean activity was calculated from the two angler counts on each system.

The number of days sampled was determined using the following equation: $N = (1/CV^2) * (1/A + 1/3.4) * (0.5 + 1/m)$, where N = number of days needed to sample with a precision of 0.20, CV= coefficient of variance (precision, 0.20), A = mean estimated number of interviews per day, and m = number of counts (circuits) per day (i.e. 2).

From 15 April to 15 May, the number of sample days was 14 in 2000, 6 in 2006, and 11 in 2007 in South River; and was 14 in 2000 in West River. Limited resources available in 2006 resulted in fewer days sampled compared to other years. Previous surveys have indicated that the high activity on opening day of the angling season was unique from other days. Opening day was, therefore, selected as a sampling day and was treated separately from other days in the survey.

The circuit start time was randomly selected from 10 possibilities for month-long surveys. One circuit required about 2 to 3 h to complete; therefore, a sampling day required approximately 5 to 6 h. The second circuit was started approximately 2 to 3 h after the start of the first circuit. One clerk was required to interview or countanglers. Creel clerks attempted to interview as many anglers as possible and budget time to complete circuits in about 3 h. When angling activity was high (i.e. opening day of season), anglers were subsampled to complete the circuit in approximately 3 h.

Effort, total angler hours spent on each system, was estimated from activity strata from the following equation; $E = TA_1 + TA_2$, where E = effort (number of hours angled), T = duration of the fishing day (hours), and A = mean activity: 1-opening day, 2-other days. The total number of brook trout caught from each system was estimated using the following equation: $C = E * CPUE$, where C = total number of fish caught, E = effort, and CPUE = mean catch per unit effort. The weight of the harvested brook trout was estimated by applying the weight-length equation for anadromous brook trout, Weight in grams = 0.0028 * (FL cm ^ 3.39), in the following equation: Weight in kilograms C = C * (0.0028* (mm FL cm of C) ^ 3.39) / 1000 g).

Standard deviation, standard error, and coefficient of variance were determined for catch per unit effort, activity, and harvest. Coefficient of variance was determined for effort and catch calculated using the following equation: $CV = SE(x) / x$, $CV(E) \overset{\sim}{=} CV^2(A)$, $CV(C) \overset{\sim}{=} CV^2(A) + CV^2(CPUE)$, where CV= coefficient of variance, SE = standard error, x = mean, E = effort, A = activity, and CPUE = catch per unit effort.

The catch per angler hour during the first week of the angling season for the periods 1991-2000 and 2006-2007 was used to detect differences before and after the regulatory change in West River STMA using t-test. Catch per angler hour, effort, and harvest for the first month of the angling season was compared among those for 2000, 2006, and 2007. The mean length of the catch and relative density index of large fish in the population, as defined by the proportion of the fish >35 cm FL, was calculated from pooled 1991-2000 survey data as well as from the 2006 and 2007 data from each system. The mean length of the catch was compared using ANOVA. The relative density index of large fish was compared among years and between systems using a z-test.

Results

During the first week of the angling season between 1991 and 2007, the mean number of brook trout caught per hour on West and South rivers of Antigonish and the Wallace River was 0.10 (0.16, SD) and ranged from 0.00 to 0.80. Water temperatures during this period were between 1.0 and 10.0 ^{o}C. Two creel survey sites, Williams Point, Abattoir and West River Highway 104, were impacted by new regulations in the West River STMA. Prior to West River's delayed opening in 2001, the mean trout catch per hour during the first week of the angling season was 0.05 (0.07, SD) in West River (Table 1). Sites located in the South River side of the estuary, outside the border of the West River STMA, included the Highway Bridge, Railway Trestle and Cove site. The Cove site was a creel survey site assessed during 2006 and 2007 and was located approximately 500 m east of the Railway Trestle site. Angler access to the Cove site was made

Table 1. Annual catch data from the first week of the angler season on South and West Rivers of Antigonish and Wallace River, 15 April - 22 Aprill, 1991 - 2007.

System	Year	Angler hours	Anglers interviews	Brook trout	Trout caught per hour mean
West*	1991-2000	240	90	20	0.05 (0.07, SD)
South	1991-2000	567	207	72	0.14 (0.25, SD)
	2006-2007	179	56	49	0.27 (0.08, SD)
Wallace	1991-2000	1215	417	74	0.06 (0.05, SD)
	2007	99	43	2	0.02

*West River sites were under a delayed opening to 15 May after 2000.

easier because of recent road construction and the close proximity to the Railway Trestle site indicated that fish could easily swim between the sites. Although the mean number of trout caught in South River sites increased from 0.14 (0.25, SD) prior to 2001 to 0.27 (0.08, SD) during 2006-2007, this difference was not significant (T-test, P>0.05). The mean number of trout caught from Wallace River control site was 0.6 (0.05, SD) prior to 2001 and 0.02 in 2007.

From 1991 to 1999, creel surveys were conducted during the first week of the season. In 2000, 2006, and 2007, however, these were expanded to include the first month of the season. Changes in catch per unit effort, activity, and harvest before and after 2001 were used to determine the impact of the West River STMA on the sea-run brook trout fishery. In 2000, prior to the West River STMA, approximately 1,556 h (0.3, CV) were spent angling in various West River sites during the first month of the angling season. The angling effort recorded during 2000 on West River and some of the Antigonish Harbour sites was displaced as a result of the delayed opening. Effort increased dramatically in South River sites; from 2,053 angling hours (0.2, CV) prior to implementation of West River STMA to 6,436 angling hours (0.3, CV) in 2006 and 6,831 angling hours (0.2, CV) in 2007. In South River sites the trout catch per hour was 0.16 (0.6, CV) in 2000, 0.19 (0.4, CV) in 2006 and 0.18 (0.3, CV) in 2007, while the harvest, in terms of number of trout caught, was 275 (0.7, CV) in 2000, 1,008 (0.5, CV) in 2006 and 887 (0.4, CV) in 2007. Increased harvest was mainly attributed to an increased angler effort rather than a change in rate of catch. In South River, total weight of the catch was 61 kg in 2000, 677 kg in 2006 and 507 kg in 2007. The largest change was the estimated weight of the total catch and this was related to a significant increase in the mean size of the catch after the regulation changes (ANOVA, P<0.05). The mean size of the catch was 27.8 cm (7.4, SD) in 2000, 38.5 cm (7.1, SD) in 2006 and 36.7 cm (6.8, SD) in 2007. In West River, the total number of trout caught was 138 (0.5, CV) and had a weight of 31 kg. The levels of angler effort and harvest from South River sites in 2006 and 2007 were greater than the combined estimates of effort and harvest from West and South rivers in 2000 (Table 2).

Table 2. Angler catch per hour, activity per hour, effort, and catch on South and West Rivers of Antigonish, Nova Scotia, 15 April - 15 May, 2000, 2006, and 2007.

Brook trout		Trout caught per hour					Anglers counted per day						Effort		Harvest		
							Opening day	other days					Angler hours		Fish		Wt
System	Year	Days	mn	SD	SE	CV	mn	Days	mn	SD	SE	CV	N	CV	N	CV	Kg
West *	2000	10	0.10	0.14	0.04	0.4	11	13	2.6	2.6	0.7	0.3	1565	0.3	138	0.5	31
South	2000	12	0.16	0.34	0.10	0.6	4	13	3.7	3.0	0.8	0.2	2053	0.2	275	0.7	61
	2006	6	0.19	0.18	0.07	0.4	37	6	10.3	7.9	3.2	0.3	6436	0.3	1008	0.5	677
	2007	11	0.18	0.18	0.05	0.3	55	11	9.1	6.5	2.0	0.2	6831	0.2	887	0.4	507

*West River sites were under a delayed opening to 15 May after 2000.

The increase in size of the catch was demonstrated by changes in the relative proportion of large fish (FL > 35cm) in the catch (Figure 2). A significant change was detected after 2001 when the relative proportion of large trout increased from 0.23 in 1991-2000 to 0.64 in 2006 and 0.53 in 2007 (z-test, $P < 0.05$). A significant increase in the proportion of 4-year-old and 5-year-old trout in the catch was detected after the 2001 West River STMA (z-test, $P < 0.05$). The proportion of 4-year-old trout in the catch was 0.10 in 1991- 2000, 0.35 in 2006 and 0.41 in 2007. The proportion of 5-year-old trout in the catch was zero in 1991- 2000, 0.16 in 2006 and 0.10 in 2007.

Discussion

Angling tends to select larger individuals in the population and can reduce the size of the catch (Jensen 1971). Catch and release, slot limits, and minimum length limits on heavily exploited populations can improve the catches in trout fisheries (Clark et al. 1981; Power and Power 1996). Potential gains from such regulatory changes can, however, be lost as a result of a change in angler behavior (Post et al. 2003). Although only small increases in catch per hour were detected, angler effort on South River was three times greater in 2006 and 2007 compared to 2000 when the entire estuary was open under general angling regulations. This change in angler effort was potentially due to a delay in the season, which displaced anglers from West River sites and a change in the sea run trout population. Anglers were attracted to sites where large fish were captured using terminal gear on the South River side of the estuary. Post et al. (2003) modeled responses of bull trout *Salvelinus confluentus* fisheries under regulatory changes and different levels of angler effort. High angler effort limited the potential gains from regulations as hooking mortality on released fish and illegal harvest can be significant. Bull trout are more susceptible to over-exploitation as they are longer lived and are late maturing (~6 years) compared to other salmonids (Post et al. 2003). Nova Scotia brook trout are fast growing and short-lived species that mature at 2 years of age. West River regulations were designed to protect first and second-time spawning brook trout and are potentially effective in improving the fishery under increased angler effort. However, heavy angler effort outside the estuarine border of the management area could reduce recruitment to the fishery if a large number of West River sea run are harvested from South River sites.

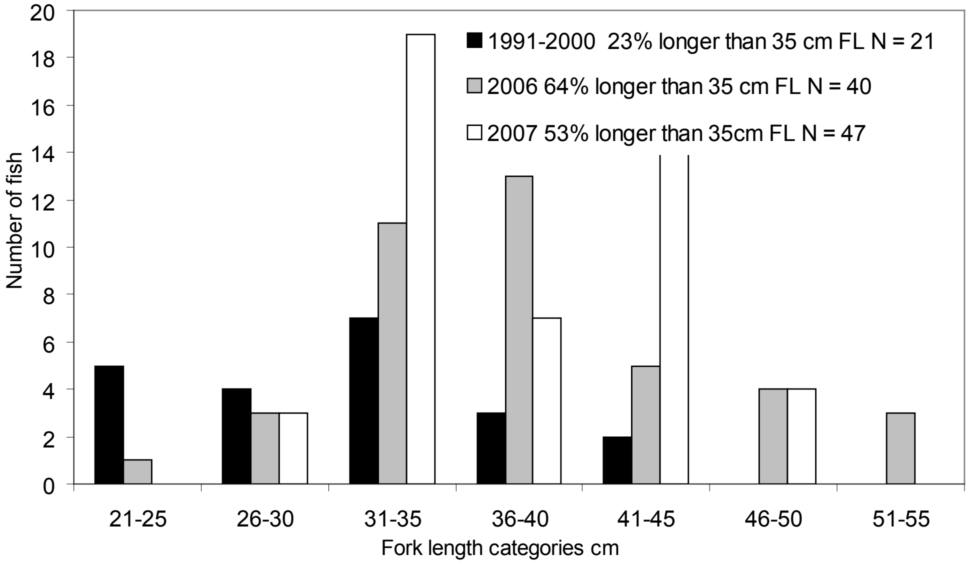

Figure 2. Estimated abundance of legal-size (>350 mm) brown trout / km in Fishing Creek from 1982 to 2000 with 95% CI's. Trophy trout regulations were adopted in 1983.

The number of sea-run brook trout harvested in South River increased more than three times in 2006 and 2007 compared to that in 2000. The creel surveys included only the popular angling sites and do not represent the total harvest of sea trout during the first month of the season. The number of brook trout harvested during the first month of the angling season in South River was close to that (1,024 trout) counted migrating upstream in a 1982 trapping study on South River (Miles 1985). Although tagging studies have demonstrated that sea trout may swim throughout estuaries, the origin of the South River catch remains uncertain. Increased recruitment of trout to the fishery may also relate to additional enforcement presence on the West and South rivers.

One of the objectives of Special Trout Management Areas was to increase the number of larger (>35 cm) FL and older (>3 years) brook trout in the catch. Although anecdotal accounts indicate that the change in the catch from angling in West River STMA has been positive, proper assessment is difficult because this fishery is diffuse in freshwater regions. Previous trapping studies of sea-run populations in South River (Miles 1985) and in other Nova Scotia rivers indicated that 4-year-old brook trout were scarce and 5-year-old brook trout were absent. Results of trapping studies in Moser River, located in Eastern Nova Scotia, indicated that the maximum age of captured sea-run brook trout was 6 years in 1939-1940 (Wilder 1952) and 4 years in 2006. The size structure of captured trout changed from 23% >30cm FL to 3% > 30cm FL over that same time period (MacMillan and Madden 2007). The difference in age and size structure of trout in Moser River was potentially related to flow rates, climate changes, increased acidity, loss of buffering capacity, and to a lesser extent, exploitation. The West River of Antigonish is alkaline, cool, and productive compared to many rivers in Southern and Eastern Nova Scotia.

The potential role of the environment on catches in South River must be considered. Natural variability in environmental conditions can cause dramatic fluctuations in lotic trout populations (Platts and Nelson 1988). Brook trout can quickly repopulate habitat after catastrophic flooding events (Roghair et al. 2002). Over a 70-year period (1934–2004), a variety of regulatory changes were implemented to improve angler catch of rainbow trout in Great Smoky Mountains National Park (Kulp and Moore 2005). Conclusions indicated that abiotic factors such as drought and floods controlled fluctuations in abundance and catch to a much larger degree than diverse regulations. The sea trout catch in Wallace River in 2007, selected as a control in our study, did not demonstrate an improvement in the fishery during the first week of the angling season when angling effort was high. The lack of change in the Wallace River fishery indicated that the catch of South River anglers may relate more to regulation changes than a change in recruitment associated with past environmental conditions; however, the relatively short term duration of our study warrants additional monitoring.

Size, age, and number of sea trout caught in the spring of 2006 and 2007 suggest that West River STMA improved the sea-run brook trout fishery. Concern remains as to the impact of high angler effort and harvest of South River anglers on the West River sea trout population. Initiatives are planned to determine the contribution of West River sea-run trout to the catch of South River anglers.

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The Good, Bad, and Truly Ugly of Catch and Release: What Have We Learned?

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Abstract

Recent international, multidisciplinary collaborative efforts have led to new insights into catch-and-release (C&R) angling by comparing experiences in and synthesizing results from studies in different countries and cultures. These activities have made clear that some biological, management, and social results can be generalized, while for other results, there is no substitute for case- and place-specific studies. As C&R has grown in popularity among managers and anglers, new questions about the biology of fishes, the ethics of angling, the potential societal and economic benefits of C&R, and angler crowding, among others, have arisen. One finding that appears to apply widely is that there is great potential for improving our understanding of C&R, and angler behavior more generally, by making relatively small changes to surveys of anglers that do not yet require information that specifically relates to C&R. Another finding is that management and angling techniques that work well to reduce hooking mortality or to achieve other goals in a particular fishery might not work, or might work differently, in another fishery. These and other findings also lead to suggestions for new research.

Introduction

Catch-and-release (C&R) angling has become widely accepted in managing recreational fisheries (Barnhart and Roelofs 1977, 1987; Lucy and Studholme 2002; Policansky 2002; Radonski 2002; Arlinghaus et al. 2007; Policansky in press). It works—and the term works is discussed in some detail below—particularly for trout. However, as is true for most other aspects of fishery management, C&R has issues. In this paper, I discuss some of those issues, as well as some recent work that sheds light on them. Much of the discussion is based on recent international collaborations (Arlinghaus et al. 2007, Aas in press).

What Is C&R?

Catch and release refers to the release of hooked fish alive. Because at least some unwanted fish must have been released alive since the earliest days of fishing, and because regulatory restrictions on the size, number, or species that may be kept at specific times and places compel C&R, additional definitions are needed (Policansky 2002). Thus, voluntary C&R refers to the live release of fish that could be legally retained; regulatory C&R refers to the live release of fish compelled by or as a consequence of regulations; and total C&R means that all hooked fish are released alive. Voluntary and regulatory C&R can both lead to total C&R, but neither necessarily implies total C&R. Because there is some hooking mortality in all recreational fisheries that have been studied, total C&R is more of a theoretical ideal than a practical reality (Policansky 2002).

What Does “C&R Works” Mean?

Catch and release became widely used in managing recreational fisheries as a method to allow continued angling on fish populations without artificial supplementation (stocking). The theory is that if the fish are released, their populations will not decline in the face of fishing pressure, as had been the case; in addition, many writers argued in favor of C&R on the basis of “sportsmanship” (Schullery 1987; Radonski

2002). To a large degree—especially for trout—the theory has been borne out in practice (Barnhart and Roelofs 1977, 1987; Radonski 2002). In some cases, the hooking mortality is less than 1% (Schill et al. 1986). So in the sense that C&R allows a higher degree of angling pressure than would be possible without C&R, or instead allows angling to continue when the lack of C&R would require restrictive regulations or would permit the decline of the fish populations, it works.

Catch and release has other consequences, though, and for some observers, it does not "work." One consequence is that fishing places can become increasingly crowded as a result of C&R (Policansky 2001). Other consequences include the learning of heavily fished populations to avoid anglers' offerings (Policansky 2002; Arlinghaus et al. 2007), residual hooking mortality that can approach or exceed 40% under some circumstances (e.g., Diodati and Richards 1996; Cox-Rogers et al. 1999; Wilde et al. 2000; Cooke and Philipp 2004), various physiological consequences to the fish (e.g., Cooke et al. 2002a, 2002b), and a variety of ethical questions that become emphasized as compared with catching fish and keeping them for food (e.g., Hersey 1987; De Leeuw 1996; and reviews by Policansky 2002; Arlinghaus et al. 2007; Arlinghaus in press). These matters, as illustrated by several recent papers with an international flavor, constitute the good, the bad, and the truly ugly of C&R.

The Good

The good of C&R is that it has become a widely used tool of managers of recreational fisheries. Catch and release has allowed or helped in the development of tourism (Borch et al. in press), has allowed for the continuation of fisheries that otherwise could not have been continued (Barnhart and Roelofs 1977, 1987; Policansky 2002; Radonski 2002; Arlinghaus et al. 2007; Policansky in press), and arguably has helped to spread a conservation ethic (Schullery 1987). As an example, the Bristol Bay trophy rainbow trout *Oncorhynchus mykiss* fishery that is so justly famous depends explicitly on management that encourages and requires C&R for much of the region and for most of the season (Borch et al. in press, Figure 1). Catch and release did not cause those trout to get so large—they thrive on an

Figure 1. Guide Jeff Pfaender of the Alaska Sportsman's Lodge prepares to release a resident rainbow trout caught by the author in Alaska's Bristol Bay region. Photograph: D. Policansky.

environment enriched by millions of salmon that run up the region's rivers from the sea and provide abundant nourishment, to bears, eagles, and other animals as well as trout—but C&R allowed fishing to occur without reducing the size and number of trout in the region.

Catch and release also has been characterized by increasing research on various fish populations, which it enables by permitting fish to be tagged, released, and recaptured later. Researchers can of course do this without C&R recreational angling, but anglers can provide an enormously expanded research "workforce" for researchers in many cases. This has permitted researchers to learn more about fishes' movements and behavior than would otherwise have been possible. In addition, because of management requirements, researchers have developed angling techniques that enhance the effectiveness of C&R for various species (e.g., Lukacovic and Uphoff in press (striped bass, Morone saxatilis), Schratwieser in press (North American billfishes, family Istiophoridae). Some results with different species confirm each other, while others do not. For example, both Lukacovic and Uphoff's and Schratwieser's papers show that circle hooks decrease hooking mortality, but for billfish, unlike for striped bass (*Monrone saxatilis*), circle hooks increase hooking efficiency (in other words, fewer billfish escape when hooked with circle than with J hooks, while the reverse is true for striped bass). Similarly, Lukacovic and Uphoff (in press) report that high air temperature appears to affect hooking mortality in striped bass more than does high water temperature, while Thorstad et al. (in press) report that high water temperature is most important with respect to Atlantic salmon *Salmo salar* in Norway. Thus, despite the development of information about the effects of C&R on fish, there still needs to be careful study of each case of interest so that all-important details can be understood. Research suggestions are given by Arlinghaus et al. (2007).

Scientific and management questions concerning C&R could have more and better answers, if the surveys that are routinely conducted by many management agencies in many countries throughout the world included questions specific to C&R (Ditton 2002; Policansky in press). In many cases, only small additions would need to be made to surveys that already are conducted. Such surveys already often include questions about angler motivations, expenditures, and catches. It would take relatively little effort and cost to include questions that specifically target C&R, including questions about crowding, motivation, cultural backgrounds and experiences, and so on. Because surveys are conducted in many countries with varying angling and other cultural traditions, they would permit insights into angler behavior across cultural and national boundaries as well as within cultures and countries. Those insights would be of value to managers and decision makers as well as to academic researchers.

The statement about generalization versus the need for case-specific details applies also to the human dimensions of C&R. People's attitudes towards angling and towards C&R vary according to many factors, including the culture they are part of. Thus, Alaska Natives sometimes oppose C&R because to them it represents "playing with food" (e.g., Lyman 2002, in press; Wolfe 2006); in Germany, voluntary C&R is prohibited by law in most cases (Arlinghaus et al. 2007); in Norway (and in many other countries), C&R is not currently a large aspect of the culture of recreational fishing (Borch et al. in press; Thorstad et al. in press); and in many English-speaking countries, C&R increasingly is the norm for many anglers (Schullery 1987; Arlinghaus et al. 2002; Policansky 2002). Similarly, some people see C&R as being kind to fish, while others see it as torturing fish (Policansky 2002; Arlinghaus et al. 2007; Arlinghaus in press). These matters are discussed further below. To complicate things further, attitudes and practices evolve. The growth of C&R and the research interest in it have led to some insights into human and fish behavior (Arlinghaus et al. 2007), which I consider to be a good thing.

The Bad

Some of the "bad" of C&R has been mentioned above. One bad thing is crowding (Policansky 2001). To the degree that C&R allows angling to continue without requiring restrictive regulations or without a consequent decline in the size of fish populations or of individual fish, crowding of productive fishing areas can result, especially in freshwater, where many areas of access are smaller than in saltwater. Places like Moraine and Talarik creeks in Alaska's Bristol Bay region are quite crowded at peak seasons (Figure 2), despite the time and money required to reach those remote locations, because many large rainbow trout can be caught there. Because C&R "works" as described above, there is little concern that fishing in those creeks will lead to diminished trout populations or sizes. In addition to the crowds, the fishing pressure is so high that it is very common to catch trout that have hook scars; some even are missing an eye. Managers, lodge operators, and guides argue that having a robust population of large fish, even with hook scars, is better than having a depleted population of smaller fish. It certainly is better for the lodge, guiding, and tourism business (Borch et al. in press). In addition, angling organizations that favor C&R often favor general environmental conservation as well (see for example the web site of Trout Unlimited, www.tu.org). But the matter of crowding has led some management agencies to spend considerable resources on planning and in some cases implementing plans to limit angler access (Policansky 2001). Although crowding also can occur when anglers keep their catch, in freshwater the greatest crowding usually occurs for short periods when anadromous fish such as salmon return to their natal streams (Figure 3).

Another difficulty associated with C&R is an ethical one. Catch and release is regarded by some as cruel or unethical because the fish are not used for food, but instead are "played with" or tortured for anglers' enjoyment. Other ethical arguments concerning C&R fishing, including approaches to understanding the ethical issues, concerns, and objections, are described by Balon (2000), Olsen (2003), Braithwaite and Huntingford (2004), Schullery (2006), and Arlinghaus (in press). Some writers consider that angling is not ethically permissible at all, a consideration they apply especially to C&R. Others argue that releasing is more ethical than not, given why they fish and what experiences they are seeking. After all, even though some released fish die, most do not, while all retained fish do die. Arlinghaus

Figure 2. Some of the floatplanes crowding a small lake near a creek in Alaska's Bristol Bay region. Each plane holds between 4 and 8 anglers. Photograph: D. Policansky.

Figure 3. Anglers crowding a stream in Alaska during the silver salmon *Oncorhynchus kisutch* run. Photograph: D. Policansky.

(in press) summarized the bases of objections to C&R. One is concern for animal welfare, which permits angling, including C&R, as long as the health of fish populations is not compromised. The animal liberation approach holds that fish can suffer, and therefore they should not be made to suffer by fishing for them, whether they are retained and eaten or released. The approach does not endow them with specific rights, however. The animal rights approach does, holding that all animals possess the moral right to respectful treatment, and not only leads to the end of fishing, as the animal liberation approach does, but also to morally compulsory veganism. Such analyses can help people to think about what they are doing and why. They lead some to stop C&R, while retaining just enough fish for food (Hersey 1987); others stop fishing altogether (Regan 1983; Singer 1990).

Other bads associated with C&R are nonlethal adverse effects, such as loss of hierarchy in social species, loss of reproductive fitness, and other physiological effects (Policansky 2002, Arlinghaus et al. 2007). Finally, an effect of C&R is that in heavily fished areas, such as Armstrong and DePuy spring creeks in southern Montana, fish learn to avoid artificial flies and they change their behavior (e.g., Lewynsky and Bjornn 1987). Some anglers, of course, view this as a challenge, and find it pleasing, while others view it as evidence that the fish have been made to suffer.

The Truly Ugly

For Radonski (2002), the "ugly" of C&R was the discarding by commercial fishing operations of dead fish "with a shovel over the side." Such matters have received extensive treatment in works dealing with commercial fishing (e.g., NRC 1999), but in this paper, I focus on recreational C&R. One matter related to Radonski's "ugly" is highgrading—the discarding of legal but dead fish to replace them with larger ones (Ditton 2002). This topic, however, seems more related to questions of the effectiveness of size and bag restrictions than to C&R as an angling practice and a management tool.

In my judgment, the worst aspects of C&R—and they can be truly ugly—are those involving practitioners of C&R who believe their way is the only moral or ethical way to fish, or who do not recognize that their approach violates the cultural mores of the people in the region they are fishing in. Fishing tourists typically are wealthier than the people where they fish (because fishing tourism is expensive, and only reasonably wealthy people can afford it; Borch et al. in press) and there is a risk that the tourists will trample on the cultures of the locals. Lyman (in press) has described how this has happened to Alaska Natives as well as the Saami of northern Scandinavia and Russia; the long-standing cultural practices of those indigenous peoples were not respected in the face of the opportunity to develop sportfishing, mainly C&R. In addition, those who depend for fish on food can be dismayed and angered by the sight of tourists practicing C&R on fish even though all other fishing—including subsistence fishing—has been prohibited by management agencies to protect depleted populations. Similar conflicts can be observed in sportfishing destinations in many parts of the world.

Finally, the pages of angling magazines often carry diatribes between those who believe C&R is angling's equivalent of beatification and those who believe that C&R is an abomination and that the purpose of angling is to obtain fish to eat. Such conflicts can play out at the water's edge as well.

Conclusions

Recreational angling in general and C&R in particular continue to evolve, as do human cultures and ethics. There is no question that C&R has been and continues to be a useful management tool. Understanding of the ethical issues surrounding C&R continues to develop, as does practical knowledge of C&R to guide management. The topic is likely to remain fruitful for research and barroom conversations for many years to come, and fishery-agency personnel need to be involved in the research and conversations, because their agencies will be profoundly affected by the outcomes.

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WILD TROUT
SYMPOSIUM

The Current Status of Native Dolly Varden in Japan

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Abstract

We investigated population abundance of native Dolly Varden *Salvelinus malma* in mountain streams of northern Japan in relation to several physical habitat characteristics including water temperatures and small dams. Hokkaido Island is the world's southern most distribution margin of native Dolly Varden, and it has been projected that many populations would suffer from severe summer stream temperature warming due to habitat alterations such as construction of erosion- and flood-control dams and potential impacts of global climatic warming. However, there has been little effort in obtaining basic information on the species' population abundance and thermal habitat over successive years. Therefore, in an attempt to initiate long-term research, we began collecting fish data by electrofishing and temperature data by installation of temperature loggers in 37 streams in 2000. We found that several Dolly Varden populations showed signs of recruitment failures among years and less abundance in streams where summer maximum stream temperatures far exceeded the species' thermal tolerance of around 16˚C. In this paper, we will primarily focus on our findings during 1999-2001 field surveys.

Introduction

The Japanese archipelago lies at the far-east margin of the Eurasian Continent, and its climate ranges from subarctic in the north to subtropical in the south, with great variation in temperature and precipitation (Figure 1). The northern-most island, Hokkaido, has a lower average annual air temperature of 8˚C and annual precipitation of 1,100 mm (of which over 30% is snow) than those in southern islands (15-22˚C and 1,500-4,000 mm, respectively). Fish habitats of most rivers in Japan have been severely altered with numerous weirs and dams for city water, agriculture, and industries, particularly during 1960s-1980s (Nakamura et al. 1991). In upstream reaches, many sediment- and flood-control dams as well as hydroelectric power dams have been constructed, and downstream reaches have commonly been concrete-lined and channelized to prevent flooding.

Japanese freshwater fishes, including lampreys, comprise 15 orders, 35 families, and 96 genera, with 211 species and subspecies (Taniguchi et al. 2001). Most belong to the families Cyprinidae (29% of species and subspecies), Gobiidae (21%), Salmonidae (10%), and Cobitidae (8%). Those species particularly well utilized in recreational

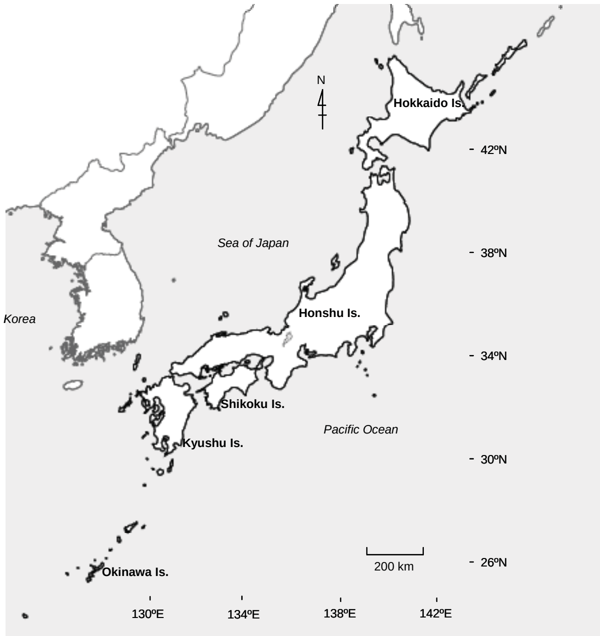

Figure 1. A map showing Japanese archipelago.

fishing in streams are the ayu *Plecoglossus altivelis* and stream-resident salmonids. The stream-resident salmonids fished for include masu salmon *Oncorhynchus masou masou* and its subspecies, red-spotted masu salmon *O. masou rhodurus*, white-spotted charr *Salvelinus leucomaenis*, Dolly Varden *S. malma*, as well as exotic species including salmonids such as rainbow trout *O. mykiss* and brown trout *Salmo trutta*. Because many salmonid species migrate between fresh and marine waters, artificial instream structures being hazardous to their movement have caused severe problems in maintaining their life cycle.

Shiretoko Peninsula is one of a few regions that remain to be relatively well preserved and a part of the peninsula was registered as World Natural Heritage site in 2005 (Figure 2). However, even in this area, stream environments have been degraded severely and resident salmonid fishes have been adversely affected (Komiyama and Takahashi 1988, Shimoda et al. 1993, Taniguchi et al. 2000). In the Shiretoko streams, many studies focused on the dominant fish, Dolly Varden charr, have been conducted (Komiyama 1981, 1982, Komiyama and Takahashi 1988, Kitano and Nakano 1991), but these studies were mostly descriptive and none of them quantified the population density by electrofishing, except for the research by Shimoda et al. (1993).

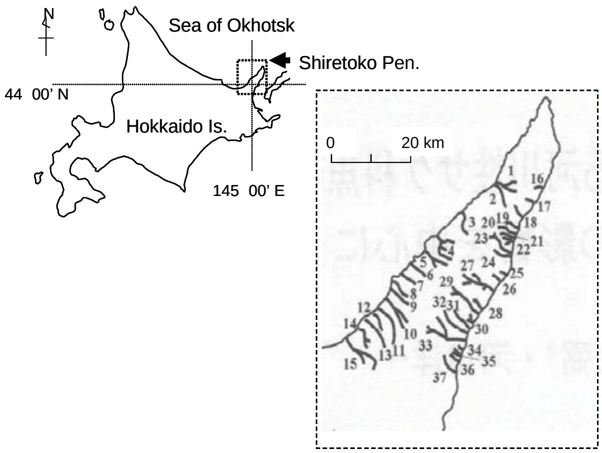

Figure 2. Maps showing 37 study streams on the west and east coasts of Shiretoko Peninsula, Hokkaido.

Habitats of Dolly Varden in Shiretoko have been altered due to the channelization and construction of erosion- and flood-control dams, which also appear to have degraded the thermal habitat (Taniguchi et al. 2000, Kishi et al. 2004). Kishi et al. (2004) examined the riparian deforestation impacts associated with roads and dam construction on thermal habitat of Dolly Varden and showed that fish population density was inversely related to the warmed stream temperatures. Similar anthropogenic impacts have been reported to influence stream fish in Honshu and other regions (Ezaki and Tanaka 1998, Mori 1999), but few studies have investigated the effects by quantifying resident fish population densities in relatively large scale, e.g., the whole peninsula, in Japan. In the present study, we investigated the present condition of population characteristics of Dolly Varden as well as their physical habitat characteristics to propose the future conservation measures.

Methods

Studies were conducted in 37 streams mainly in August through October in 1999, 2000, 2001 for a total of 43 d (Figure 2). In each stream, a 25- to 50-m study section was established so as to have a 100-m^2 reach area and population estimates either by three-pass (DeLury 1951) or one-pass electrofishing were conducted using a backpack electrofishing unit (Model 12, Smith-Root Inc.). Captured fish were recorded for the number of individuals and fork lengths (FL) and released immediately after the measurements. Capture Program (White et al. 1982) was used to estimate the population abundance, but young-of-the-year (YOY) Dolly Varden (<60 mm FL; Ishigaki 1984) were eliminated from the calculation. Physical habitat characteristics measured were water temperature, stream width, depth, and discharge (U.S.G.S. Mid Section Method; Orth 1983).

For the continuous temperature measurements, TidbiT loggers (Onset Inc.) were installed in 12 west coast streams and temperatures were monitored throughout the summer in 2000 when the thermal stress, if there was any, should become most evident. We also estimated the number and locations of erosion- and sediment dams based on 1/25000 topographical maps, forest management maps (Forestry Agency of Japan), and dam management maps (Hokkaido Prefectural Government). Furthermore, those recently built dams that did not appear on the maps were confirmed by interviews with local authorities (Shari and Rausu townships). Dam densities were calculated by dividing the number of the dams by the total stream length (km) including all of the tributaries.

Results and Discussion

Population characteristics in the west coast rivers of the peninsula. --- During the survey (1999-2001), Dolly Varden and masu salmon were captured, but the latter were primarily stocked by the local fish hatchery and we omit presenting those data. The highest fish density was recorded in Rusha River (33/100 m^2) and all other streams had more than 20/100 m^2 except for Iwaobetsu River (Table 1). These population densities did not differ considerably from those reported previously by Shimoda et al. (1993). Shimoda et al. (1993) documented that the Dolly Varden 4-28 cm FL were composed by six age classes from Rusha and Teppanbetsu rivers in 1991, and the condition of these fish populations have not been greatly changed during this 10-year period. This perhaps reflects the fact that no fishing was allowed in both rivers and few artificial instream structures were present. Also, most populations in other rivers showed more than two to three age-classes; for example, YOYs 4-8 cm FL as well as those over 24 cm were captured in Horobetsu River. In contrast, in Iwaobetsu and Nukamappu rivers, Dolly Varden 20 cm FL or greater were not captured. In addition, in both Opekepu and Kanayama rivers, fewer age-classes were found compared to other rivers. These may be attributed to the fact that the relatively high and second highest dam densities were observed in these rivers (>0.5 / km) and that resulted in the habitat degradation such as logging road construction, riparian deforestation, and shallower stream depths associated with the dam construction.

Table 1. Estimated population densities for Dolly Varden.

Rivers	Months and years	Number / 100 m^2
West coast		
Chrassenai	Aug. 1999	39.2
Funbe	Aug. 1999	19.4
Horobetsu	Aug. 1999	33.8
Idashubetsu	Aug. 1999	42.6
Iwaobetsu	Oct. 2000	24.7
Kanayama	Aug. 1999	2.8
Nukamappu	Aug. 1999	47.8
Ochikabake	Aug. 1999	< 1.0
Rusha	Jul. 2000	30.9
Onnebetsu	Aug. 1999	5.5
Orainekotan	Oct. 2001	28.6
Oshopaomabu	Aug. 1999	Not present
Oshokomanai	Aug. 1999	21.8
Teppanbetsu	Aug. 1999	19.6
East coast		
Aidomari	Oct. 2001	4.3
Chashikotsu	Oct. 2001	10.8
Chienbetsu	Aug. 2001	34.2
Chinishibetsu	Aug. 2001	1.8
Chitorai	Oct. 2001	18.2
Hashikoi	Oct. 2001	31.7
Horomoi	Oct. 2001	6.5
Horomoikosawa	Oct. 2001	10.9
Kennebetsu	Aug. 2001	5.2
Kikiribetsu	Aug. 2001	55.2
Matsunori	Oct. 2001	14.1
Mosekarubetsu	Aug. 2001	30.4
Okkabake	Aug. 2001	17.7
Oshorokotsu	Oct. 2001	19.6
Ponrikushibetsu	Oct. 2001	5.4
Ponshunkarikotan	Oct. 2001	15.6
Rausu	Aug. 2001	17.4
Rusa	Oct. 2001	0.8
Shoji	Aug. 2001	35.8
Shojin	Aug. 2001	3.8
Shunkarikotan	Oct. 2001	37.3
Tachikariusu	Oct. 2001	34.6

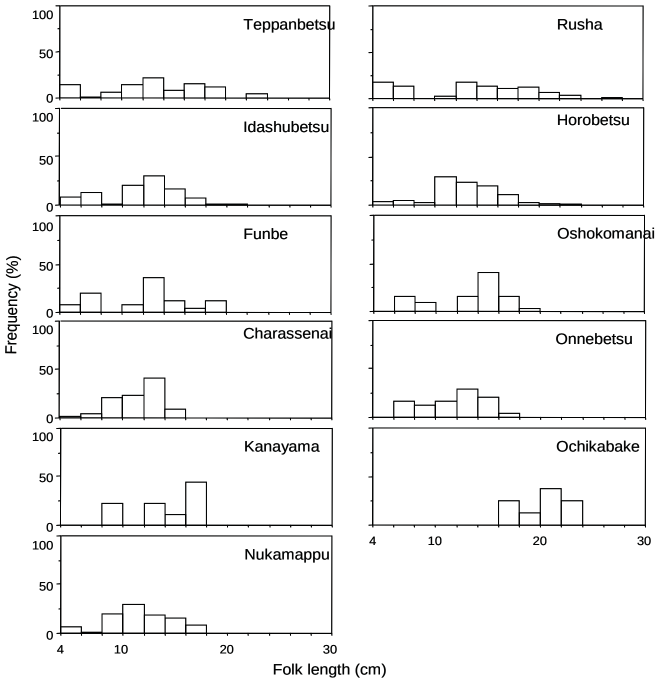

Figure 3. Length-frequency histograms for Dolly Varden in the west coast rivers in August 1999.

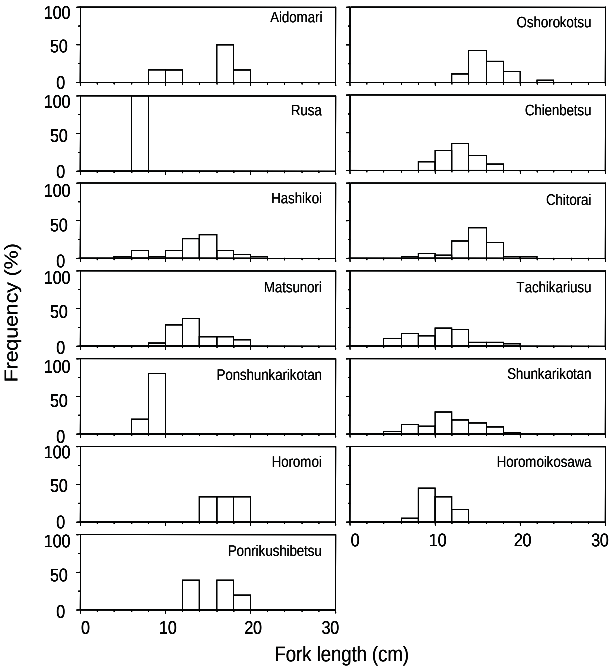

Figure 4. Length-frequency histograms for Dolly Varden in the east coast rivers in Oct. 2001.

Population characteristics in the east coast streams of the peninsula. --- Dolly Varden were found in all of the 22 rivers, and 7 rivers had > 30/100 m^2 population densities (Table 1). The highest density was recorded in Kikiribetsu River (55/100 m^2) followed by the Shunkarikotan River (37/100 m^2). On the other hand, there were 7 rivers where population density of < 10/100 m^2 was recorded and, particularly, in Rusa and Chinishibetsu rivers the density was 2/100 m^2 in which only one age-class was observed. Shimoda et al. (1993) reported the density of 10-30/100 m^2 in the Chinishibetsu River when surveyed in 1991. Several erosion-control dams have been recently built near the study site and the dominant substrates were silt that may have accounted for the low density of Dolly Varden. On the other hand, Siberian stone loach *Noemacheilus barbqatulus* that prefers such bottoms inhabited the study site at much higher density (8/100 m^2) than the Dolly Varden (Kishi et al. 2002), which had never been reported before from the Chinishibetsu River

Water temperatures. --- Foraging activity of Dolly Varden declines below 16˚C and the survival rate declines above 22˚C (Takami et al. 1997). Therefore, the summer maximum water temperatures that do not exceed these temperatures can be considered as an index for their suitable thermal habitat characteristics (Nakano et al. 1996). Of the stream temperature data collected in 2000, all of the streams on the west coast except for Rusha, Teppanbetsu, Idashubetsu, Horobetsu, and Charassenai rivers recorded water temperatures of over 16˚C. In particular, in Ochikabake R. there were 7 d when the water temperatures >20˚C were recorded. In fact, no fish were collected except for the upper reaches where riparian forests were dense in this river. In contrast, in Charassenai River temperature fluctuation was much smaller and the temperature rarely exceeded 10˚C in summer. However, such low water temperature condition may have hampered the fish growth.

Dam density and Dolly Varden population density. --- In those 37 rivers surveyed during 1999-2001, a total of 192 erosion- and sediment dams were present. The Kanayama River had 28 dams, which was the most amongst all rivers and was followed by the Rausu River with26 dams. The highest dam density was found in Opekepu River (4.6 / km), followed by Shojin River (2.6 / km). Dolly Varden

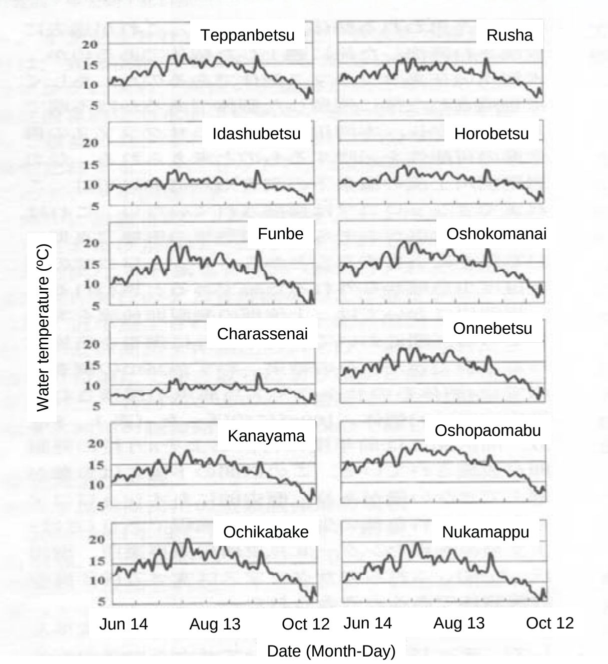

Figure 5. Water temperature fluctuation during June – October, 2000 in 12 west coast rivers.

population density in these rivers with high dam density was very low with only 0.1-0.2 individuals / 100 m^2. When the rivers were grouped into low (< 0.5 / km) and high (> 0.5 / km) dam densities, the mean Dolly Varden population density in the former (n=20) was 26/100 m^2 but that in the latter group (n=17) was 10/100 m^{2,} and a statistically significant difference was found between the groups (*t*=4.59, *P*<0.001; Figure 6).

Most study sections in rivers, except for Rusha and Teppanbetsu rivers that were located within the National Park's preserved area, where we conducted the research in the present study were relatively closely located to the roads that allowed recreational fishing. Also, some stream reaches where no Dolly Varden historically inhabited, such as upper sections of Iwaobetsu River, were eliminated from the analysis. Therefore, either the presence of the dams or potential effects of the dam constructions were considered as underlying causes for the habitat degradation and resulted in the population decline in Dolly Varden. Streams that flow through forests receive significant negative impacts from the riparian deforestation and, in addition, erosion- and sediment dams are known to directly and indirectly negatively

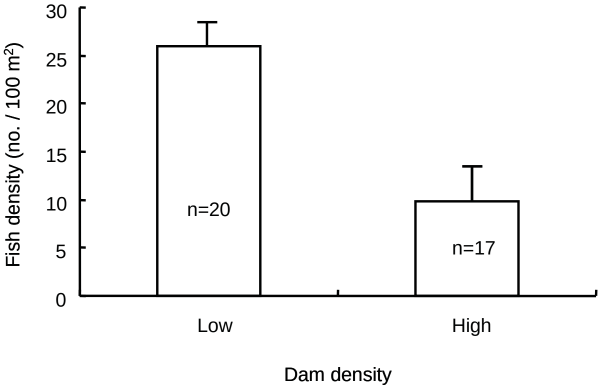

Figure 6. Different effects of low (<0.5 dams / km) and high (> 0.5 / km) dam densities on Dolly Varden population density.

influence stream resident salmonids (Fausch and Northcote 1992). Such impacts have been reported in many Hokkaido streams (Shimoda et al. 1993, Toyoshima et al. 1996Yamamoto et al. 1996,). For example, Nakano et al. (1995) conducted a fish fauna survey covering 64 study sites in Teshio River in northern Hokkaido and reported that the dams negatively impacted masu salmon and Japanese dace populations and that the fish species diversity was low in the rivers with dams. However, the study was conducted in a total of 19 tributaries of the same watershed, and therefore, the samples were not considered statistically independent from each other. The present study quantified a greater number of independent stream systems that allowed us to more accurately evaluate their habitat-population relationships.

Although not reported in the present study, anadromous masu salmon may be more adversely affected by the damming structures. Komiyama and Takahashi (1988) pointed out the dams that lack fishways are the major causes of the species' local extinction in 1980s. Since Shiretoko region was registered as the World Natural Heritage site in 2005, several dams in streams where masu salmon reproduce have been proposed to be either removed or modified so as to make the habitats barrier-free for their migration. The habitat restoration project also aims at rehabilitating endangered the piscivorous Blakiston's fish owl *Bubo blakistoni*. Because Dolly Varden is more readily available compared to masu salmon juveniles throughout the year as a food resource for the owl, restoration of habitats for Dolly Varden should be more effective in terms of the Shiretoko's ecosystem maintenance and future conservation.

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The Geography of Freshwater Habitat Conservation: Roadless Areas and Critical Watersheds for Native Trout.

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Abstract

Inventoried roadless areas on National Forest and Bureau of Land Management (BLM) lands have been the subject of sustained controversy and legal and policy machinations. The importance of presently unprotected roadless areas for conservation has received mention, but little formal analysis. Research from the northern Rocky Mountain Region of the U.S. helps put roadless lands in conservation perspective. We examine how roadless lands spatially integrate with watersheds of known high conservation value for freshwater species and habitats. Roadless areas can be small and fragmented, but can accrue to a large fraction of critical landscape. In the Upper Missouri Basin in Montana, within the 37% of the landscape with watersheds classified as highest value for freshwater conservation, almost one-half occurs within unprotected federal roadless areas; just 7% is inside wilderness and parks. In western Montana, bull trout *Salvelinus confluentus* abundance increases with watershed roadless proportion. Roadless lands tend to occupy middle to lower elevations compared to protected Wilderness, where they more directly interface with high-value fish habitat; a Montana statewide "fine-filter" assessment revealed remarkably high occurrence of native trout populations associated with roadless areas, even within watersheds that are otherwise compromised. Most roadless areas contain steep lands with expanses of erosion-prone soils. We conclude that the value of roadless areas for native trout and biodiversity conservation continues to receive insufficient evaluation and disclosure in roadless policy debates and decisions.

Introduction

Inventoried roadless areas on National Forest and Bureau of Land Management (BLM) lands, officially recognized in the RARE I and RARE II planning processes of past decades (USDA Forest Service 1972, 1979), continue to be the subject of sustained controversy and extraordinary machinations of policy and law. Scientists and fish and wildlife managers across the West recognize that native fish and high-quality waters are often positively associated with watersheds having low overall road density and large proportions of roadless area (Quigley and Arbelbide 1997; Trombulak and Frissell 2000; WNTC 2001). In public debate, however, the conservation value of roadless areas for native fish and water, while occasionally mentioned, has seldom been the focus of rigorous analysis or thorough consideration and public disclosure when decisions about roadless area or national forest management are made.

The Forest Service commonly prefers to consider roadless area decisions primarily in the context of how roads affect offsetting "motorized versus nonmotorized" recreational values—not their ecological and biological conservation values that are an intrinsic function of the lack of roads and many associated forms of human disturbance of land and water (Forman and Alexander 1998; Jones and Swanson 2000; Trombulak and Frissell 2000). The Clinton Roadless Rule (USDA Forest Service 2000) was the first forum where the environmental values of Forest Service roadless lands were more broadly accounted for (see also Gucinski et al. 2001 on National Forest roads), and in so doing, it was explicitly in accord with numerous federal court rulings about roadless area significance. However, as a national rule this analysis did not document the case-by-case natural resource values sustained by roadless areas, and more recent agency efforts press for devolution of roadless area decisions to state and local authorities. Hence, it is increasingly important that a full local accounting of the natural resource conservation value of roadless lands be made.

In this paper we examine scientific evidence at three regional scales to illustrate how National Forest roadless lands in their current state contribute to the conservation of freshwater species and habitats, including native trout, in the state of Montana.

Roadless Areas and Freshwater Values: Statewide Analysis

We used USDA Forest Service digital mapping of roadless areas as the basis for our analysis. These data were "cleaned up" via adjustment for some errors, detached polygons, and redundant entries. We found the Forest Service inventory rosters 223 uniquely named roadless areas, encompassing a total of 26,359 km^2 in Montana. These areas are mapped statewide in Figure 1.

Native Fishes

By spatially intersecting Forest Service roadless area maps with stream and fish species data obtained from Montana Fish, Wildlife and Parks (Frissell et al. In Preparation; statewide fish distribution data with genetics for some species, Natural Resource Information System, Montana State Library, Helena, MT; note these data were adjusted by eliminating occurrences outside the native range of each species) with ArcInfo software, we identified a total of 1,282 occurrences of fish populations from the seven target taxa within inventoried roadless areas (IRAs) statewide. Native westslope cutthroat trout *Oncorhynchus clarkii lewisi*, Montana's official state gamefish, occurred in 1,220 records, occupying 138, or 62% of the total list of IRAs. Known genetically

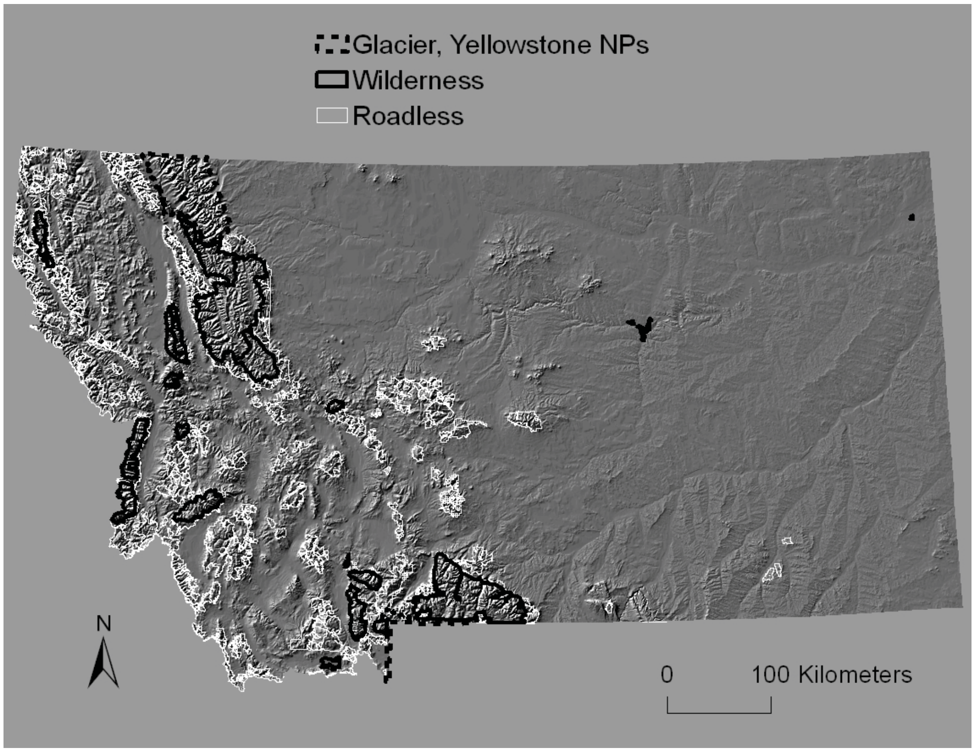

Figure 1. Distribution and relative topographic relationship of inventoried roadless areas (white outlines) on National Forest lands in Montana, USA. Black outlines delimit existing protected lands in congressionally designated Wilderness and National Parks

pure populations (free of hybrid contamination from introduced rainbow trout *Oncorhynchus mykiss* or other trout) occurred in 92 IRAs. In other words, 41% of roadless areas support known pure populations of westslope cutthroat trout—an extraordinary figure because pure populations are thought to occupy far less than 10% of the present range of this subspecies (Allendorf et al. 2004). Bull trout *Salvelinus confluentus* occurred in 286 locations occupying 80, or 36% of IRAs statewide, with known genetically pure populations in 19 of these IRAs (many populations have not been tested). Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri* were found in 54 occurrences within 26 IRAs statewide, and eight of these areas support populations known to be free of hybridization. Columbia River redband trout *Oncorhynchus mykiss gairdneri* occurred in 20 places within 15 roadless areas, with two IRAs supporting known genetically pure populations. Arctic grayling *Thymallus arcticus* had 28 occurrences in 16 IRAs, and native lake trout *Salvelinus namaycush* occupied two IRAs in the Upper Missouri River basin.

Although the spatial extent of the native range of these species within Montana varies, within their ranges all species appear to show a substantial affinity for watersheds with a high proportion of roadless area. Native trout populations within roadless areas tend to be more frequently free of hybrization influence and demographically robust enough to be considered "strong" in population status (e.g., Quigley and Arbelbide 2000). Comparatively many streams in designated Wilderness and National Parks drain headwater lake basins that were historically targeted for introduction of nonnative trout; hence, native trout in some Wilderness and National Parks are more extensively hybridized or displaced by nonnative species (Hitt and Frissell 1999; Adams et al. 2001) than are those in many National Forest roadless areas.

Elevation and Slope Hazards in Roadless Areas

To examine how roadless areas relate to the remainder of the landscape with regard to general geomorphic features and landscape setting, we sought a range of data sets concerning soils and slope stability. Ultimately, within the time available and with a need for statewide coverage, the primary source we found to be useful was a digital elevation model (DEM), which we used to characterize the elevation and slope of roadless areas relative to other parts of the landscape. Our source of DEM data for this analysis was the USDA Forest Service Region 1's 200-m grid Digital Elevation Model (http://www.fs.fed.us/r1/gis/thematic_data/dem_region1_200m.zip). Digital elevation model data were processed and related to roadless areas and other land categories using ArcEditor mapping and GIS software. Slopes were derived from the DEM using ArcGIS's Slope tool, then classified with the desired class breaks using the Reclassify tool. Inventoried roadless areas were downloaded from http://roadless.fs.fed.us/documents/feis/data/gis/coverages/, as were Forest Service lands boundary data (nfsland_us_dd.zip). Then IRAs and FS lands within Montana were extracted using a state boundary polygon dataset. We used Montana designated Wilderness areas mapped by the Montana Natural Heritage Program (http://nris.mt.gov/nsdi/nris/shape/wild.zip), masked with the Forest Service lands layer to extract only Forest Service Wilderness areas for these slope and elevation comparison analyses.

Figure 2 compares the elevation distributions of inventoried roadless areas, roaded portions of the National Forests, and National Forest lands protected as Wilderness. The graph clearly shows that the previously managed, roaded portions of the National Forests are concentrated at lower elevations. This is important because soils, climate, growing seasons, and other elevation-related factors often confer resilience to disturbance that is lacking in higher-elevation ecosystems. Roadless areas comprise a large proportion of high-elevation lands, as do existing Wilderness areas, but also clear in Figure 2 is that roadless areas contain a higher-than average concentration of land within the middle elevation range from 2000 to 6000 m. Land in this elevation range receives relatively high snowpack, but tends to have shorter growing seasons and less resilient soils than lower-elevation terrain. A geographer might characterize lands in this elevation range as the hydrologic “bread and butter” of watersheds across the region.

Steep hillslopes are prone to mass failure, channelized debris flows, increased vulnerability to surface erosion and gully incision, and longer transport distances of detached sediments, yielding a greatly increased probability of delivery of sediments to streams compared to gentler slopes. All of these erosion types are significantly aggravated and sometimes initiated by disturbance of vegetation and soil surfaces through logging, grazing, mining, fire suppression activities, and other management practices that are supported by roads, as well as by construction, maintenance, drainage alteration by, and use of the roads themselves. We could not find direct and integrated metrics of soil surface erosion and landslide hazard, but the comparison of land categories by slope steepness distribution is revealing (Figure 3).

First, note that the roaded landscape of the national forests in Montana—sometimes referred to as “the working landscape” is dominated by gently sloping terrain. Using an arbitrary slope threshold

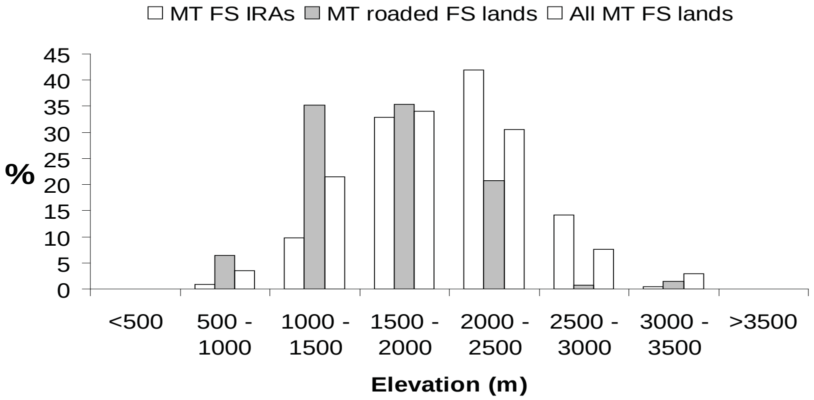

Figure 2. Elevation distribution of aggregated inventoried national forest roadless areas statewide (crosshatched bars, left), roaded national forest lands (gray shaded, middle bars), and all national forest lands in Montana (wilderness, roadless, and roaded, open bars).

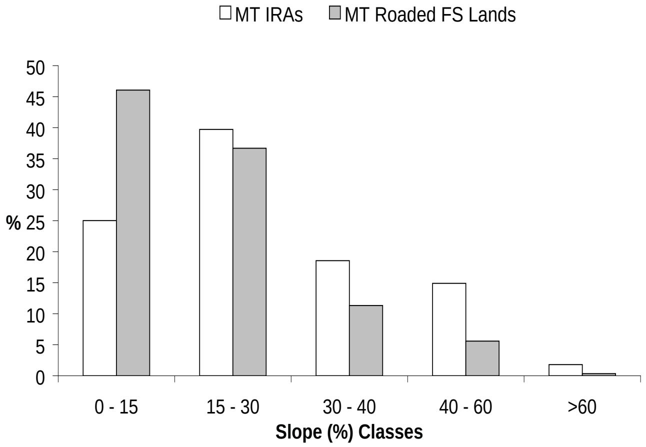

Figure 3. Distribution of slope steepness in Montana inventoried national forest roadless areas in aggregate (crosshatched) and roaded national forest land (shaded).

of 40% for comparison, just under 6% of the managed, roaded landscape exceeds 40% slope angle; 94% is comparatively gentle or moderate in slope. By contrast, almost 17% of the area of inventoried roadless lands exceeds 40% in slope. Keep in mind, slope classifications based on DEMS of this resolution are biased downward for steep slopes, and the bias increases with average landscape slope. Hence, the difference is likely greater than depicted in these data. In simple terms, hazardous conditions are at least three times more prevalent in remaining roadless areas than they are on the already-roaded portion of the national forests. This is but one piece of evidence that risk of incremental harm to watersheds and fish habitat caused by management disturbance is severely elevated compared to that in the portion of the landscape where Forest Service managers have previous experience. In fact, the history of nearly every national forest and ranger district in Montana is fraught with one or more incursions of roads and logging projects into steeper portions of the landscape that led to immediate, disastrous consequences, followed by formal or informal decision to halt further development on those lands. This history is precisely the origin of the majority of inventoried roadless areas today.

Roadless Areas at the Basin Scale: the Upper Missouri

In 2002 a consortium of nongovernmental organizations sponsored a region-wide assessment of watersheds in the Upper Missouri drainage of Montana, spanning most of the Rocky Mountain Front and the headwaters of the Big Hole, Beaverhead, Jefferson, Madison, and Gallatin rivers (Oechsli and Frissell 2002). In the assessment process, we compiled comprehensive spatial data on native fish species distribution and status, nonnative species introduction and fish stocking, Montana Natural Heritage Program occurrences of aquatic-, riparian-, and wetland-dependent plant and animal species, and road networks as an indicator of landscape and habitat disturbance. All sub-watersheds were scored and ranked across these factors using different models, with the final result based on behavior across multiple models. The result is a map of this large region of central and southwest Montana showing variation in the relative ecological integrity of its streams, rivers, and watersheds (http://www.y2y.net/science/aia/AIA_UMfinal.pdf).

For this analysis, using data from Oechsli and Frissell (2002) we selected the highest-ranked 37% of the landscape where watersheds were classified as highest value for freshwater conservation and evaluated its land management status relative to national forest roadless areas. We found that just under one-half of this high-value acreage occurs within unprotected federal roadless areas. By contrast just 7% of this highest-priority area lies inside designated Wilderness and National Parks that can be considered to afford comprehensive watershed protection (Oechsli and Frissell 2002). This case analysis shows the extreme importance of roadless areas in maintaining the integrity of watersheds that support high conservation value. These are the watersheds needed to serve as the cornerstones of effective regional species recovery and aquatic restoration programs (Moyle and Sato 1991; Frissell and Bayles 1996; Frissell 2000).

Roadlesss Areas and Fish Abundance within Basins: Rock Creek

Bull trout are less likely to use highly roaded basins for spawning and rearing, and if present, were likely to be at lower population levels (Quigley and Arbelbide 1997, USFWS 1999). Baxter et al. (1999) reported an inverse correlation of bull trout abundance and roads in the Swan River Basin that strongly implicated the importance of protecting remaining roadless areas. Similarly, extensive habitat and population surveys on the Clearwater National Forest, Idaho, found that with few exceptions, native salmonid abundance was higher and nonnative brook trout *Salvelinus fontinalis* were scarce or absent in streams draining largely un-roaded compared to road-impacted landscapes (Huntington 1995). Baxter et al. (1999) found that bull trout population trend over time was strongly negatively associated with road density.

In Rock Creek, tributary to the Clark Fork River in western Montana, we first indexed bull trout spawner abundance from redd survey counts made in 19 tributary sub-basins within the Rock Creek drainage (Frissell and Carnefix 2002). We compared response metrics of spawner abundance against a large suite of environmental variables, including measures of geomorphology, summer stream temperature, and land management.

We used pairwise correlation of environmental variables with redd density to select 44 candidate predictor (independent) variables across 11 major categories such as geology, basin relief, channel slope, climate, size, and land use/management disturbance, for entry into stepwise and backward model selection routines.

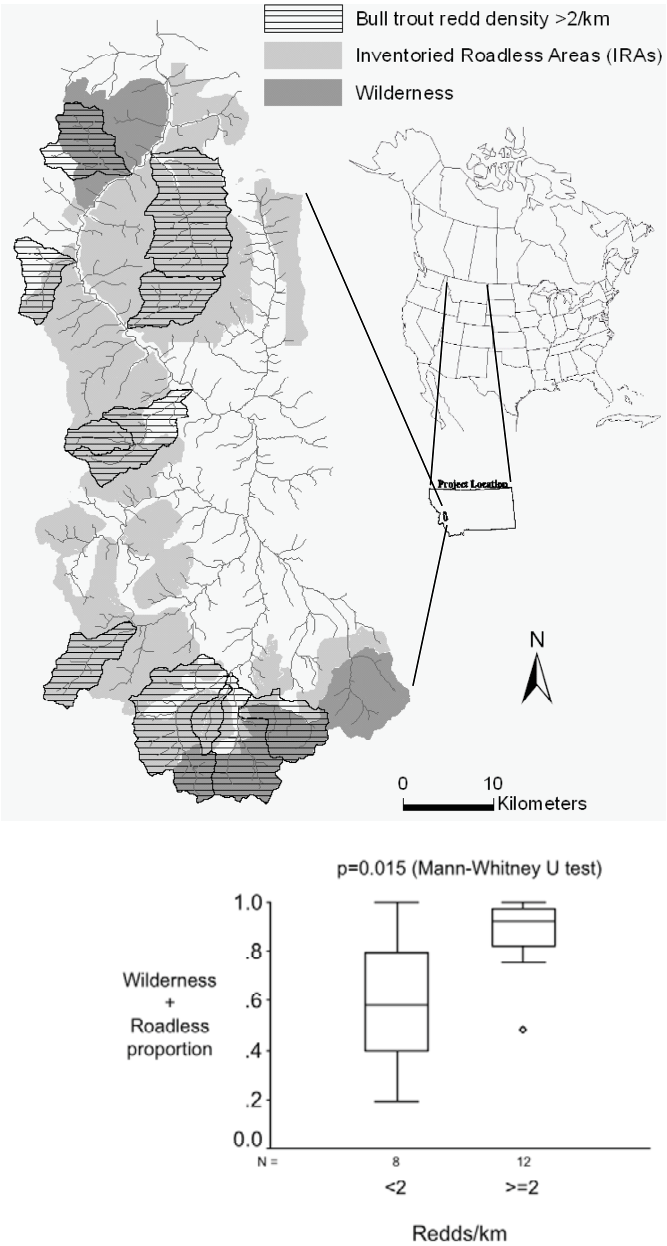

Figure 4. Top: Map of Rock Creek, Clark Fork Basin, Montana, showing the association between national forest Inventoried Roadless Areas (gray shading), designated Wilderness (black shading), and subwatersheds with high bull trout spawner density (crosshatched). Unshaded (white) portions of the basin are roaded areas and a small area of non-Forest Service land. Bottom: Box plot of proportion of un-roaded land area (Wilderness plus roadless) within basins of low (left) and high (right) bull trout spawning density.

We iterated multivariate analyses to compare effects of alternate aggregation and stratification methods for both response and environmental variables. Across iterations, significance tests revealed several robust results: spawner abundance increased with channel or sub-basin slope and extent of bounded alluvial valley geomorphology, and declined with maximum stream temperature. Abundance increased with increasing proportion of sub-basin comprised by wilderness and roadless areas, and the roadless variable was not significantly correlated with the other environmental correlates. Surprisingly, catchment road density did not correlate with bull trout spawning, but the range of road density among Rock Creek sites was far lower than regional average and one order of magnitude lower than in a previously published analysis for Swan River tributaries (Baxter et al. 1999).

Based on the Rock Creek results, we hypothesize that proportional roadless area, a variable that reflects the dispersion of road disturbance within a catchment, is an important measure of human disturbance at lower road density, but at moderate and higher road densities prevailing across the bull trout's range, total road density tends to saturate or override the effect of spatial distribution of roads within the catchment. These results are highly consistent with contention that undeveloped roadless areas are of special importance for sustaining, among other regional biological values, bull trout populations of relatively high abundance. In other words, even in landscapes marked by relatively limited road development, roadless areas appear to provide a critical and prominent function as refugia to sustain robust local populations of native fish. Protecting roadless areas will be a key element determining the success of any recovery or restoration plan.

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Management Strategies for Cutthroat Trout in the Prince William Sound Area of South-central Alaska

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Abstract

Prince William Sound and the Copper River Delta in south-central Alaska are at the far northern limit of the range of cutthroat trout *Oncorhynchus clarkii*. These waters are managed collectively for sport fisheries as the Prince William Sound Management Area (PWSMA). The coastal cutthroat trout *O. clarkii clarkii* is the only subspecies of cutthroat trout found in PWSMA waters. Management strategies for cutthroat trout in Alaska are delineated in regulation within the State of Alaska Wild Trout Management Policy. Regulations within the entire PWSMA have changed several times, including area-wide size limits, lowered bag limits, and no retention regulations in certain drainages. Regulations have been different between areas of the PWSMA as a whole. Data trends in catch and harvest of cutthroat trout in the area show differences after implementation of, and most likely resulting from, new regulations. Datasets for catches show cycles in catch, or in some cases increases on the Copper River Delta. Datasets for harvests in streams of both the Copper River Delta and Prince William Sound show decreases after regulations mandating release of large fish were implemented. Research programs are directed at management questions attempting to gather data to implement the trout policy in this complex multi-fishery area.

Introduction

Cutthroat trout (*Oncorhynchus clarkii)* management in the Prince William Sound Management Area (PWSMA) is directed by the State of Alaska Wild Trout Management Policy. The policy recognizes the value of wild trout as a sport fish and recognizes that in many cases the lack of stock-specific data necessitates conservative management guidelines. This policy created statewide management guidelines that are used to guide local management decisions. The policy guidelines direct the department to manage trout fisheries for sustainability, protection of trout habitats, and to maintain current size at age attributes in trout populations when practical. The trout policy sets standard daily limit guidelines for angling regulation, but these guidelines can be relaxed or restricted with special management plans if specific goals are desired in a trout fishery, such as high catch rates in high-use areas, or trophy-trout fisheries with no retention.

Regulations for trout management have gone through recent changes in PWSMA waters allowing analysis of the effects on catch and harvest of trout in the area. The current regulations for all trout in the area, also the statewide standard guidelines, are 2 trout per day, 2 in possession, only one per day may be 20 in or greater, and only 2 per year may be 20 in or greater. Within a special trout management area of the PWSMA waters, no trout may be kept and only single hooks lures are allowed. Additionally, all waters are closed to trout fishing from April 15 to June 15, to protect spawners.

Restrictive regulatory changes for cutthroat trout started in 1983 in the PWSMA. Bag limits were subsequently lowered several times for portions of the area but remained higher in some other areas. A spawning time angling closure for all waters was also implemented in 1994. A Special Trout Management Area was created in 1999 in one section of the area, where no trout can be kept. In 2005, the trout angling regulations in the remainder of the PWSMA waters were lowered to conform to the conservative statewide standard. Regulatory changes generally have moved to the more restricted harvest opportunities since 1991, and since 1999 research projects have begun to create a knowledge base to preserve habitats and cutthroat trout fisheries. Catch and harvest data are gathered for the PWSMA for all sport fisheries including trout, and are available dating back to 1983 (Miller and Stratton 2001, Marston 2005).

Methods

The PWSMA is in South-central Alaska surrounding the town of Cordova, and includes all waters between Cape Suckling and Point Puget including the lower Copper River below Haley Creek (Figure 1). The area contains freshwater fisheries for all eastern pacific salmon species *Oncorhynchus spp*., rainbow trout *O. mykiss*, cutthroat trout, Dolly Varden char *Salvelinus malma*, and lake trout *Salvelinus namaycush*, as well as numerous other species in saltwater fisheries.

Catch and harvest data for all recreational fisheries in Alaska are gathered with a Statewide Harvest Survey (Jennings et al. *in press).* Data are consistent and available for analysis in the PWSMA for year 1996 to present. I compiled data from this source for this report of catch and harvest of cutthroat trout in the PWSMA. To observe the effects of regulation changes, I used two area groupings, one for the Copper River Delta (CRD) drainages east of Cordova, and one for Prince William Sound (PWS) drainages west of Cordova (Figure 1). I chose these two groupings for comparative purposes, because regulations have been different between those areas, habitats are different, and to a certain degree, cutthroat trout populations and fisheries differ (Currens 2002, Marston 2005). I compared catch and harvest trends between these to areas graphically with standard regression trend lines, and report the regulation history of those areas.

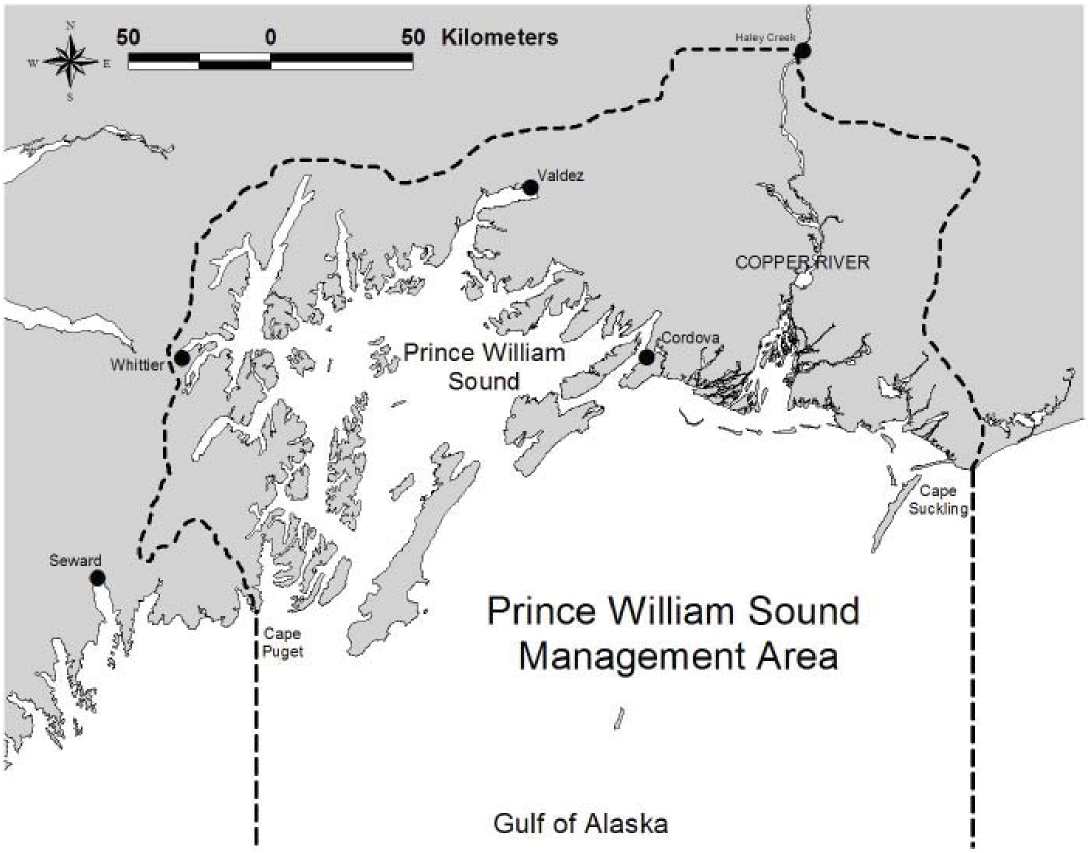

Figure 1. Cordova (center dot) and the Prince William Sound Management Area in South-central Alaska (within dashed lines). Copper River Delta Drainages (CRD) are east of Cordova and Prince William Sound Drainages (PWS) are to the west.

Results

In general, regulatory rule changes for cutthroat trout have become stricter since 1983 in all areas, but the CRD drainages have had higher daily limit regulations in comparison to PWS drainages from 1991 until 2005. (Table 1).

The fishery trend lines from the CRD drainages show a slight increase in catch but a decrease in harvest since 1996 (Figure 2, a-b) . The fishery trends for catch and harvest in the PWS drainages are both decreasing (Figure 2 c-d). The Eyak River, an individual stream representing the largest trout fishery in the areas, also shows similar trends (Figure 2 e-f). Most recently, in 1999 after a change in regulation on some CRD drainages that created a Special Management Area where trout cannot be kept, catch increased but not harvest, and this trend was similar in other streams not included in the Special Management Area (Figure 2 a-b and e-f).

Discussion

Recent regulation changes for cutthroat trout appear to be effective at lowering harvest of cutthroat trout in the PWSMA. Earlier and more stringent regulation changes in the PWS drainages appear to have limited catch and harvest prior to the CRD drainages where strict regulations went into effect later. Catch in the CRD drainages remained more stable or increased in the last decade, but harvest did decrease (Figure 2 a-b). Size limits in the CRD drainages that allowed only one fish over 10 in most likely caused lowered harvest of the larger fish but still allowed high harvest of smaller fish. Allowing higher harvest in that popular roaded area was the intent of that regulation in 1991. Increased catches in recent years on the CRD drainages may also have occurred because anglers chose to fish there over PWS drainages since regulations were more lax. The lower daily limit in PWS drainages but higher minimum size may have actually allowed more harvest of large fish than CRD drainages, but

Table 1. Cutthroat Trout Regulation history in the PWSMA

Year of change	Regulations
1957-1983	Part of an aggregate freshwater limit of trout, grayling, and lake trout (later “char”) of 15/day, 30 in possession with a limit of only 3 over 20 inches. No saltwater limits.
1983	Limits for each species were established. The limit for “trout” was set at 3 per day 6 in possession over 20 inches and 15 per day, 30 in possession under 20 inches.
1985	Trout limits were set at 5/day, 10 in possession with only 1 over 20 inches.
1991	Bag limits separated from rainbow trout and were set 2 per day and in possession (PWS) except along the Cordova road system (CRD) where it is 5 per day and in possession, with only 1 per day and in possession over 10 inches.
1994	A spawning season closure from April 15 through June 14 was put in place.
1999	Established the *Copper River Delta Special Management Area for Trout*: (CRD) Only unbaited, single-hook, artificial lures are allowed year-round in all fresh waters south of Miles Lake Glacier and east of the Copper River (excluding the Clear Creek drainage), and all waters draining into the Gulf of Alaska west of Cape Suckling. In addition no retention of rainbow/steelhead trout or cutthroat trout is allowed year-round.
2002	Established new limits that combined rainbow and cutthroat trout as a single bag and possession limit for all trout. For Cordova road system streams (CRD), 5 trout per day and in possession, with only 1 per day and in possession over 10 inches. All other waters bag and possession is 2 fish with only 1 over 20 inches.
2005	Lowered daily limit to 2 per day 1 over 20, 2 over 20 inches per year on Copper River Delta (CRD) to conform to statewide standards.

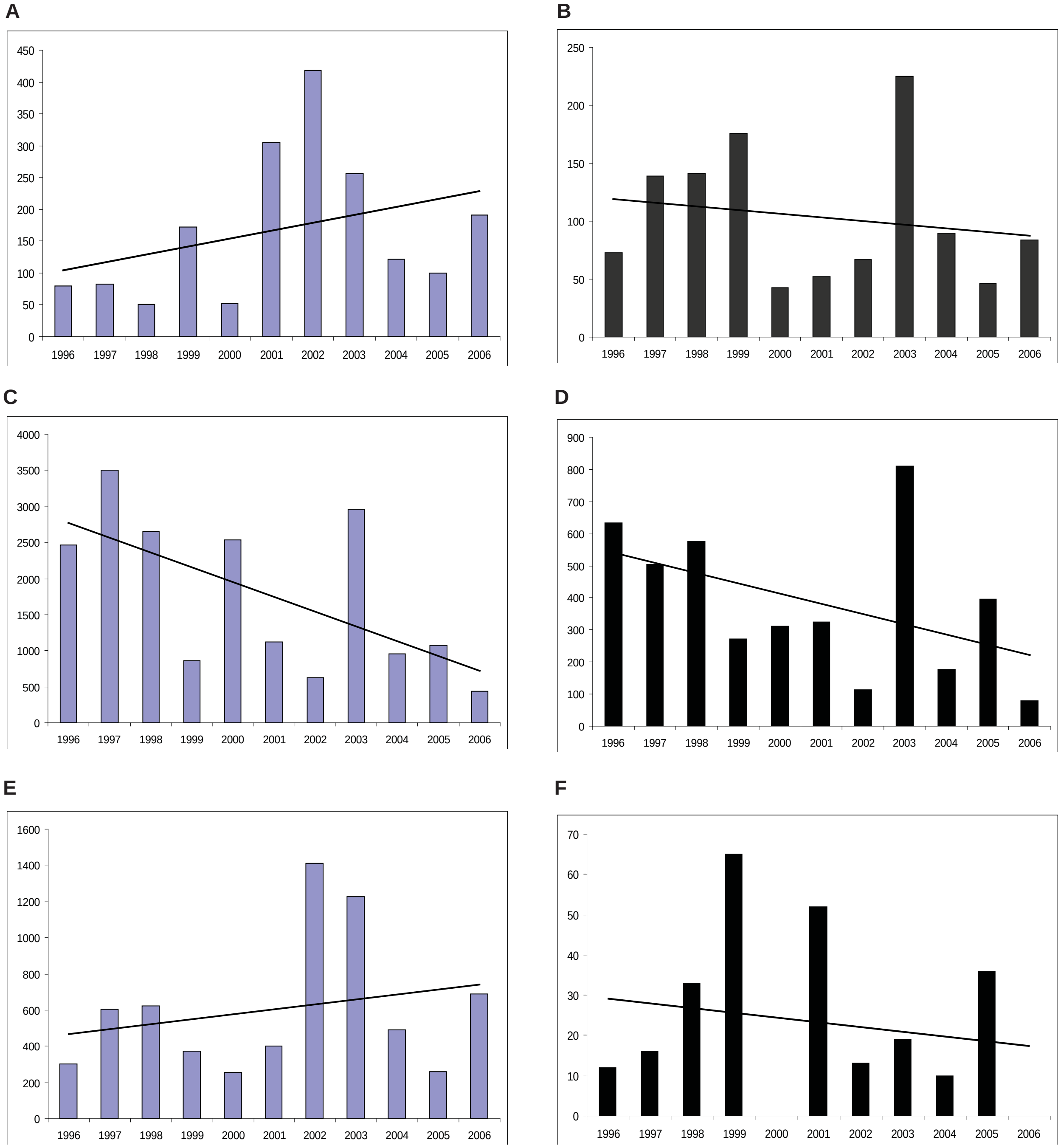

Figure 2. Catch (left) and harvest (right) trends for Cutthroat trout in CRD drainages (a-b), PWS drainages (c-d), and Eyak River (e-f) of the Prince William Sound Management area for 1996 - 2006.

overall fishery trends decreased sooner because of earlier restrictive changes. Lastly, higher catches in the last 8 years for the CRD drainages do not seem to be from the Special Trout Management Area where release is mandated, as the catch increases also occurred on Eyak River a stream not in that Special Trout Management Area but in the CRD (Figure 2 e-f). However, increasing awareness of the trout fishery as a whole brought on by the creation of the Special Management Area may have caused anglers to target trout in other CRD streams and increased catch.

Many aspects of the fisheries may affect success other than regulation. The effect of regulation changes on the fishery success in the PWSMA should be viewed in light of the reality of other fisheries in the area that result in incidental capture of cutthroat trout. Large coho salmon *Oncorhynchus kisutch* or sockeye salmon *Oncorhynchus nerka* fisheries also exist in these streams (Marston 2005), and most likely result in untargeted capture of cutthroat trout. Catch of cutthroat trout remained high in areas of the CRD where these salmon fisheries are largest, possibly due to incidental capture, so that regulation changes for cutthroat trout may have less direct effect on catch than harvest. Another confounding effect could be that trout populations are declining and masking any effects of regulation changes, but the increased catches in CRD drainages do not support that possibility. The CRD drainages have the largest trout fishery in the area as a whole. Fishing effort has increased throughout the PWSMA since 1996 (Marston 2005); hence, decreasing fishery statistics are not likely caused by lower effort.

Management of cutthroat trout in the PWSMA as a whole revolves currently around low harvest regulations and research projects to identify critical biological characteristics of trout populations. Recent research (Miller 2002, Marston et al 2005, Marston et al. in press) projects have begun to identify spawning habitats and size-at-age characters of trout in one area of the PWSMA that has had proposed mineral developments. In the PWSMA, these projects are directed to create preemptive management data that are used to protect fisheries and fish populations when changes to fish habitats are planned in the future.

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Large Scale Assessments: Lessons Learned for Native Trout Management

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Abstract

Large-scale assessments are useful tools for identifying population status of trout and other species throughout their ranges. We reviewed published and unpublished assessments for 15 native inland trout species in the United States to (1) evaluate common elements; (2) estimate lost habitat for native trout; and (3) identify effective approaches or actions taken after completion of assessments to sustain native trout. Land use changes, loss of riparian vegetation, fragmentation of landscapes, poor land management practices, and presence of nonnative fishes were the most common perturbations associated with the loss of native trout. We conservatively estimate that over one-half of the streams in the United States that historically supported native trout no longer do so. Many extirpated habitats may be hard to restore because of the difficulty of reversing land use changes or removing nonnative fishes. Many extirpations occurred in the first 150 years after pioneer settlement, but additional losses continue today. While many assessments have been effective at educating environmental professionals, most have had little influence in changing land use or realigning budgets for preservation or restoration. As human population growth and demands for natural resources increase, threats to native trout will likely increase, thereby resulting in further declines and extirpations. .

Introduction

Large-scale assessments have become useful tools for identifying spatial configurations and population status of North American trout species throughout their ranges (Nature Serve Explorer 2007). These assessments often are used to compare the current distribution with historic distribution so that changes through time can be assessed. Because assessments are conducted at large scales, they often have sufficient analysis for making determinations whether or not a species should be listed under the Endangered Species Act (ESA) (Nelson et al. 1991). Additionally, decision makers, managers and the public use large scale assessments as common starting points for setting priorities for watershed-level conservation, restoration, and monitoring programs as well as a justification for funding to protect or expand the range of important species (Williams et al. 1993; Davis and Simon 1995; Frissell and Bayles 1996; Warren et al. 1997; Master et al. 1998).

The economic, social, and ecological importance of native trout in North America has provided the impetus for nearly 50 assessments over the last century (Table 1). These assessments have concluded that the physical, chemical and biological characteristics of habitats for native trout have been dramatically altered over the last 250 years with the result that many native trout populations have been locally or regionally extirpated (MacCrimmon and Campbell 1969; Gresswell 1988; Meehan 1991; Marschall and Crowder 1996; Hall et al. 1997; Yarnell 1998; Hudy et al. 2005). Specific reasons for these habitat alterations include historic and current land use practices (King 1937; King 1939; Lennon

1967; Kelly et al. 1980; Nislow and Lowe 2003), declining water quality and quantity (Meisner 1990; Fiss and Carline 1993; Gagen et al. 1993; Keleher and Rahel 1996; Clayton et al. 1998; Hudy et al. 2000; Driscoll et al. 2001), competition and hybridization with nonnative fishes (Li and Moyle 1981; Moore et al. 1983; Larson and Moore 1985; Moore and Ridley 1986; Krueger and May 1991; Dowling and Childs 1992; Hayes et al. 1996; Strange and Habera 1998; Galbreath et al. 2001, Allendorf et al. 2001), catastrophic fire (Brown et al. 2001), fragmentation of habitats by dams and roads (Belford and Gould 1989; U. S. Army Corps of Engineers 1998; Gibson et al. 2005), grazing (Belsky et al. 1999), stream channelization, sediment (Curry and MacNeil 2004), and natural stochastic events (Roghair et al. 2002).

More recent assessments have collected data that allow estimation of current and historically occupied habitat at the stream reach, lake, or watershed scale (Rieman et al. 1997; Thurow et al. 1997; May et al. 2003; Shepard et al. 2003; Hudy et al. 2005). Use of these newer assessments has allowed decision makers to establish priorities for conservation (Williams et al. 1993; Warren et al. 1997) as well as to better understand the likelihood of long-term species persistence. The objective of this paper is to (1) evaluate elements common to most assessments; (2) estimate the number of stream miles of habitat lost for trout native to the United States; and (3) identify effective approaches and actions taken post assessment to sustain native trout.

Methods

Assessments Reviewed

We reviewed published and unpublished assessments, conservation strategies, recovery plans, status reports, petitions for listing and other documents for the following 15 native inland (and primarily non-anadromous) trout and char species in the United States: Apache trout *Oncorhynchus gilae apache* (USFWS 1983; Behnke 1992; Behnke 2002); brook trout *Salvelinus fontinalis* (King 1937; MacCrimmon and Campbell 1969; Kelly et al. 1980; Hudy et al. 2005; EBTJV 2006)*;* Bonneville cutthroat trout *Oncorhynchus clarkii utah* (Behnke 1992; Kershner 1995; Hepworth et al. 1997; USFWS 2001); bull trout *Salvelinus confluentus* (Behnke 1992;Thurow et al. 1997; Rieman et al. 1997; USFWS 1999a; USFWS 2005; Budy et al. 2007); California golden trout *Oncorhynchus mykiss aguabonita* (Behnke 1992; Behnke 2002; Stephens et al. 2004); Colorado River cutthroat trout *Oncorhynchus clarkii pleuriticus* (Behnke 1992; Young et al. 1996; Kershner et al. 1997; Behnke 2002; Hirsch et al. 2006); coastal cutthroat trout *Oncorhynchus clarkii clarkii* (Nehlsen et al. 1991; Behnke 1992; Hall et al. 1997; Johnson et al. 1999; Behnke 2002; Johnson et al. (in press); Gila trout *Oncorhynchus gilae gilae* (Behnke 1992; Behnke 2002; USFWS 2003); greenback cutthroat trout *Oncorhynchus clarkii stomias* (Behnke 1992; USFWS 1998; Behnke 2002); Lahontan cutthroat trout *Oncorhynchus clarkii henshawi* (Behnke 1992; USFWS 1994; Behnke 2002); Paiute cutthroat trout *Oncorhynchus clarkii seleniris* (Behnke 1992; Thurow et al. 1997; Behnke 2002; USFWS 2004); redband trout *Oncorhynchus mykiss gairdneri* (Behnke 1992; Thurow et al. 1997; Behnke 2002); Rio Grande cutthroat trout *Oncorhynchus clarkii virginalis* (Behnke 1992; Behnke 2002; Japhet 2007); westslope cutthroat trout *Oncorhynchus clarkii lewisi* (Behnke 1992; Shepard et al. 1997; Thurow et al. 1997; USFWS 1999b; Shepard et al. 2003); and Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri* (Jordan 1891; Hanzel 1959; Behnke 1992; Thurow et al. 1997; Kruse et al. 2000; May et al. 2003).

Based on these assessments and literature cited within these documents we summarized (1) the legal history of each species under the 1974 Endangered Species Act (ESA); (2) differences in the common elements of scale, historic reference points, genetics, handling of unknown data, population status determinations and perturbations; and (3) an estimation of the percentage of historic habitat no longer supporting reproducing populations. Finally, we used these trends to discuss the future of native trout within the United States.

Results and Discussion

Common Themes Among Assessments

These assessments had a myriad of objectives, methods, completeness, quality, and resolution. Many assessments were triggered by actions taken under the Endangered Species Act, but others were intended to better understand the threats to these species. Despite many differences there also were common themes in how these assessments addressed scale, historic reference, genetics, unknown data, and the characterization of populations.

All assessments addressed how to determine the correct scale based on the objectives of the assessment (Table 1). The finest scale used was 1:24,000. The big advantage of this scale is the ability to use 1:100,000 cartographic feature files and hierarchically evaluate distributions within watersheds of various sizes (typically 4th – 6th hydrologic unit (HU) codes; EPA 2002), or within meaningful polygons such as eco-regions, evolutionary significant units (ESU's), geographic management units (GMU's), and political boundaries.

Assessments often summarized the distribution of native trout species at the watershed scale instead of stream segments, because data were often difficult to obtain for all stream segments. This increases consistency but can reduce the resolution of the analysis and impair the ability to determine why a species may or may not be present in a specific location (Thurow et al 1997; Rieman et al. 1997; Hudy et al. 2005; Table 1). Because many earlier assessments tended to not be repeatable, more recent assessments have employed rule sets for compatibility with future assessments (May et al. 2003; Hudy et al. 2005). Even with consistent rule sets, the stream mileage estimates (Table 1) may be biased because of bias in the underlying GIS datasets and the different assumptions used by the different practitioners.

Generally, the reference point for assessment is the time of European settlement. European settlement varied from the 1700s within the range of the brook trout (Hudy et al 2005) to the 1800s for many of the western native trout species (May et al. 2003). In addition, many assessments also described events within a geologic time frame to provide an evolutionary context for populations (Smith et al. 1968; Behnke 1992; Behnke 2002). Exactly how the historical range is determined can have a large effect on estimates of the decline of a species. For example, the Eastern Brook Trout Joint Venture (EBTJV 2006) eliminated several thousand subwatersheds (6th HU) within the potential historic range of brook trout (MacCrimmon and Campbell 1969) because of the lack of historic habitat to support self-sustaining brook trout populations. Similar concerns were addressed within many of the recent assessments conducted for cutthroat trout subspecies (May et al. 2003; Shepard et al. 2003; Hirsch et al. 2006). If habitat that was historically uninhabited is included within the historic range of a species, the result will be an overestimate of the decline.

Nearly all assessments after 2000 give consideration to genetic issues such as hybridization, genetic introgression, and unique life histories (fluvial, adfluvial, resident, anadromous). When genetic data exist for the majority of populations (i.e., Gila trout; Apache trout) or a large subsample of existing populations (Yellowstone cutthroat trout; westslope cutthroat trout; May et al. 2003) it is often necessary to have an operational definition of a genetically "pure" population. The reduced cost involved in processing genetic material as well as the increasing number of unique markers for a population will enable the detection of introgression at lower and lower thresholds in the future, thereby making specific conservation guidelines difficult to determine (Allendorf et al. 2001). The increasing numbers of genetic markers for subspecies (for example see Pritchard et al. 2007) could also cause changes in the current distribution of some of the cutthroat subspecies (Kevin Rodgers, Colorado Division of Wildlife, personal communication). The brook trout assessment was the only assessment where genetic information was not collected (Hudy et al. 2005), because data were not available for over 90% of the sample units.

All assessments included streams or lakes with no or insufficient data. The methods for assigning status in those areas included qualitative assessments based on expert opinions, assessments that combined expert opinions and sample data, and predictions based on modeling techniques (Riemen et al. 1997; Thurow et al. 1997; Hudy et al. 2005; Thieling 2006).

Introduced and naturalized trout outside of their known historic ranges generally were not considered in the assessments. If locations where fish introductions were included for species such as brook trout, then the North American range would have greatly increased while the health of the species declined in its native range.

Populations were characterized as present /absent (occupied/not occupied) or various levels of quantitative abundance, or qualitative classifications (i.e. strong, depressed). Assessments at the sub-watershed scale usually classified native trout status on the percentage of habitat in each sub-watershed still maintaining self-sustaining populations of native trout (Rieman et al. 1997; Thurow et al. 1997; Hudy et al. 2005). Areas above natural barriers that were historically fishless were noted in many assessments (May et al. 2003), but total areas within a watershed that were inhabited may be overestimated because of difficulties associated with identification of barriers to movement in streams.

There were common perturbations identified for the loss, in both abundance and spatial distribution, of native trout. Land use changes such as conversion from forest to agriculture, loss of riparian vegetation, and landscape fragmentation were usually cited as primary reasons for decline. Along with landscape conversions, poor land management practices (i.e. logging practices, road construction, absence of best management practices) were negatively associated with trout abundance and distribution. Biological stresses such as the introduction of nonnative fishes (legal and illegal introductions) and the loss of genetic integrity through hybridization also were associated with low abundances and limited distributions. Many extirpations and reductions of native trout numbers and distributions occurred in the first 150 years after pioneer settlement because of dramatic land use changes and the stocking of nonnative fishes that quickly followed human settlement. For example, local extirpations of brook trout in New Hampshire lakes and ponds were caused by the introduction of chain pickerel *Esox niger,* which were introduced in the 1800s (Noon 2003). Although many historic threats have not been entirely eliminated, the devastating disregard for land and wildlife no longer occurs to the extent that it did between 1750 and 1950. However, the historic changes in land cover have resulted in most of the healthy native trout populations now being located on public lands managed by the U.S. Forest Service, National Park Service, and Bureau of Land Management. While being located on public land can be a benefit, local extirpations still occur on public lands. Local extirpations are not limited to historical activities and continue today. For example, the top ranking land use perturbations affecting the 539 conservation populations of westslope cutthroat trout were grazing (23.7%), roads (25.8), and timber harvest (17.8%)(Shepard et al. 2003). In contrast, declines of brook trout, a species where less public land is available, were associated with agriculture (36%), increased water temperature (35%), roads and associated sedimentation (27%), and presence of exotic fish species (26%)(Hudy et al. 2005).

Occupied Habitat

We conservatively estimate that over one-half of native trout habitats in the United States have been lost. Over 58 % of stream miles (66,385 stream miles out of 114,155), which historically had native trout, are currently not occupied by at least one native species. Where stream mile estimates were not possible, greater than 39 % of sub-watersheds **(**5,908 sub-watersheds extirpated out of 14,901 for the aggregate of brook trout, bull trout, redband trout) were no longer occupied (Table 1). No stream mileage or watershed estimate was available for coastal cutthroat trout. When we added together very conservative estimates of the stream miles no longer inhabited by brook trout, bull trout, and

Table 1. Summary of assessment data for 15 inland trout species (status under the Endangered Species Act (Federal endangered = FE; Federal threatened = FT; Species of concern = SOC; Estimated extirpated/historic; % of historic habitat extirpated; references).

Species	Federal Status: historic, current, or pending	Recovery Plan	Estimated: extirpated/ historic (units)	% of historic habitat extirpated	Primary References
Apache trout *Oncorhynchus gilae apache*	FE 1967 FT 1975	1979 1983	570/600 stream miles (1:24000)	> 90 %	USFWS 1983; Behnke 1992; Behnke 2002
Brook Trout *Salvelinus fontinalis*	None		1,451/5,001[1] subwatershed (6th HU)	28 %	MacCrimmon and Campbell 1969; Behnke 2002; Hudy et al. 2005
Bonneville cutthroat trout *Oncorhynchus clarkii utah*	None; Petitioned 1998; Finding:Not warranted 2001		4,378/6,758 stream miles (1:24000)	65 %	Behnke 1992; Kershner 1995; USFWS 2001
Bull trout *Salvelinus confluentus*	FT 1999	Various 2002-2004	2,484/4,462[2] subwatershed (6th HU)	56 %	Rieman et al. 1997; Thurow et al. 1997; USFWS 1999a; USFWS 2005
California Golden trout *Oncorhynchus mykiss aguabonita*	Candidate 1991 SOC 1996, Petitioned 2000		92/100 stream miles (1:24000)	> 90 %	Behnke 1992; Behnke 2002; Stephens et al. 2004
Colorado cutthroat trout *Oncorhynchus clarkii pleuriticus*	None; Petitioned 1999; Finding: No action at this time		18,364/21,386 stream miles (1:24000)	87 %	Behnke 1992; Young 1995; Young et al. 1996; Hirsch et al. 2006
Coastal cutthroat trout *Oncorhynchus clarkii clarkii*	None; Umpqua Sea-Run FE 1996; Delisted 2000; Petitioned 1997; Finding: Not warranted 2002.		Could not be determined	Could not be determined	Nehlsen et al. 1991; Behnke 1992; Hall et al. 1997; Johnson et al. 1999; Johnson et al. (in press)
Gila trout *Oncorhynchus gilae gilae*	FE 1967 FT 2005	1979; 1984; 1993; 2003	121/144 stream miles (1:24000)	>82 %	USFWS 2003
Greenback cutthroat trout *Oncorhynchus clarkii stomias*	FE 1967 FT 1978	1978; 1983; 1998	900/1,000 stream miles (1:24000)	>90 %	USFWS 1998; Behnke 1992; Behnke 2002
Lahontan cutthroat trout *Oncorhynchus clarkii henshawi*	FE 1970 FT 1975	1995	3,240/3,600 stream miles (1:24000)	96.6 % lake 80.3 % stream	USFWS 1994
Paiute cutthroat trout *Oncorhynchus clarkii seleniris*	FE 1967 FT 1973	1985 2004	0/10 stream miles (1:24000)	0	Behnke 1992; Thurow et al. 1997; Behnke 2002; USFWS 2004
Redband trout *Oncorhynchus mykiss gairdneri*	None; Petitioned 1997; Finding: Not warranted		1,854/5,438[3] subwatershed (6th HU)	>34 %	Behnke 1992; Lee et al. 1997; Thurow et al. 1997; Behnke 2002
Rio Grande cutthroat trout *Oncorhynchus clarkii virginalis*	None; Petitioned 1998; Finding:Under candidate status review		5,850/6,660 stream miles (1:24000)	88%	Behnke 1992; Behnke 2002; Japhet 2007
Westslope cutthroat trout *Oncorhynchus clarkii lewisi*	None; Petitioned 1997: Finding:Not warranted 2000		23,001/56,5001 stream miles (1:24000)	41 %	Behnke 1992;USFWS 1999b; Shepard et al. 1997; Shepard et al. 2003
Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri*	None; Petitioned 1998; Finding :Not warranted 2001		9,869/17,397 stream miles (1:100000)	57 %	Jordan 1891; Hanzel 1959; Behnke 1992; May et al. 2003

[1] Does not include the native range of brook trout in the states of MI, WI, MN

[2] Only includes bull trout range within the Interior Columbia River Basin and portions of the Klamath and Great Basins

[3] Only includes redband trout range within the Interior Columbia River Basin and portions of the Klamath and Great Basins.

red band trout, approximately one-half (280,445 out of 561,185 miles) of the streams are no longer inhabited by native trout. This conservative estimate does not include any uninhabited stream miles in sub-watersheds where brook trout, bull trout, or redband trout are still present and has no uninhabited stream miles for any coastal cutthroat trout. An unknown percentage of the uninhabited habitat for the western species involves possible double counting because of sympatry with other native trout. Individual native trout species range from having the entire historic habitat occupied to a > 90 % loss of historic habitat (Table 1). Many of the "extirpated" sub-watersheds, streams, and lakes have lost native trout but still maintain naturalized nonnative trout or stocked trout populations. Because many native trout populations are restricted to small headwater streams, and the status reports and figures are based on stream length, the true spatial reduction in distribution may be more significant (Behnke 1992). We could not determine a similar figure for lake habitats but believe the losses are > 90%. Most of the data provided by state and federal agencies used for the estimates of stream mileage had neither been published nor subject to peer review and despite criteria provided for the data, there remains some element of subjectivity. It was impossible to generate a comprehensive review without such data (Rieman et al. 1997). However, we believe our estimate of an approximate loss of 50 % of native trout habitat is reasonable and with our stated caveats, conservative.

Differences Among Assessments

Assessments for the same species often yielded different results. For example, delineation of historical habitats of Yellowstone cutthroat trout by May et al. (2003) differed from previous assessments (Hanzel 1959; Behnke 1979; Varley and Gresswell 1988; Behnke 1992; Gresswell 1995) for a number of reasons including improved mapping techniques (Firman and Jacobs 2002), additional inventory and monitoring, and differences in the reference period and methods for estimating historical occupancy. Differences in the reporting scale also can influence results; in the brook trout assessment, 88% of 4th level HU watersheds but only 72% of 5th level HU's and 72% of 6th level HU's were occupied by brook trout. It is estimated by the authors that only 46% of historic stream miles are occupied by brook trout (Hudy et al. 2005). The scale at which the results are reported can bias impressions of the true status. In general the smaller the scale the smaller the bias, but fine-scale assessments require large amounts of fine scale data that rarely are available for large extents of species distributions.

Several assessments found that many native trout populations consist of independent non-networked units (e.g., a single stream or stream segment) disjunct from adjacent populations (May et al. 2003; Shepard et al. 2003; Hudy et al. 2005). Isolated populations tend to be vulnerable to local extirpation due to stochastic events. If effective population size for native trout consists of 500 reproducing adults based on the 50/500 "rule" (Franklin 1980; Soulé 1980), many biologists have found that most small isolated populations of native trout are at an extremely high risk of extinction (Hilderbrand and Kershner 2000; Kruse et al. 2001). Hilderbrand and Kershner (2000) estimated that to maintain and effective population of 500, cutthroat trout need at least 5.7 mi (9.3 km) of habitat. Harig and Fausch (2002) determined that cutthroat trout translocations were most successful when the drainage area was at least 5.6 mi^2 (usually inhabited stream lengths of at least 2 to 3 mi). In contrast, Rieman and Dunham (2000) provided data that indicated small, isolated populations of cutthroat trout might not be as prone to extinction as other vertebrates, and even other salmonids, based on their evaluation of the persistence of isolated headwater populations of westslope cutthroat trout in the Coeur d'Alene basin of Idaho. Even with no further decline in habitat or the additional spread of exotic fishes, a number of these isolated populations may become locally extirpated because of their isolation and vulnerability to stochastic events such as wild fire (Propst et al. 1992).

There appears to be an inverse relationship between connectivity and genetic integrity. Many isolated populations show no evidence of genetic introgression. The majority of conservation populations (native trout populations with the primary purpose to sustain the existence of the species or subspecies) of Yellowstone cutthroat trout (73 %) and westslope cutthroat trout (81 %) were considered isolated with no evidence of introgression (May et al. 2003; Shepard et al. 2003). For many native trout populations, genetic introgression and nonnative competition probably are currently a greater threat than stochastic events. However, these isolated populations, particularly in the west are vulnerable to wildfires. Isolation of some remaining non-introgressed populations may be a prudent, short-term conservation strategy (Shepard et al. 2003).

Restoration

Most assessments addressed restoration of native trout habitats. Restoration and priority setting need to be viewed in the context of restorability, because many of the over 280,000 mi of extirpated habitat may be lost forever owing to the complexity of removing nonnative fishes or reversing land use conversions (i.e. forest to agriculture to urbanization). For example, over 6,200 mi of Yellowstone cutthroat trout habitat (47% of potentially restorable streams) may be difficult to restore because of the need to remove nonnative fishes (May et al. 2003). Many miles of potentially restorable brook trout waters are occupied by rainbow trout *Oncorhynchus mykiss*, brown trout *Salmo trutta*, or both, and are un-restorable given current technology and the socio-political climate. Similarly, land that has progressed from forest to agriculture to urbanization or subdivisions is unlikely to be restored as native trout habitat. In the native range of brook trout, human land uses now average 30 % at the sub-watershed scale (USGS 2004). Less than 6 % of intact brook trout sub-watersheds had less than 68% forest in the sub-watershed while 71 % of extirpated watersheds had less than 68 % forest in the sub-watershed (Hudy et al. 2005). As noted for brook trout, wilderness and roadless areas provide important strongholds for many native western salmonids (Lee et al. 1997). Wilderness and roadless areas are not always a panacea for all native trout populations, as shown by the extirpation of brook trout in roadless, wilderness areas because of acid rain. Similarly, climate change impacts may dramatically change the distribution of some native salmonids where current temperature regimes are marginally suitable for some species. Strategic decisions and funding are needed to determine restoration priorities whether the model is to protect the “best of the best” or to restore “the worst first” (Frissell 1993).

Future Changes and Effective Actions

We believe future changes in native trout distribution and status will be driven primarily by changes in land cover, land use practices, and habitat fragmentation (Rieman et al. 1997; Hudy et al. 2005). There is a strong negative relationship between human population centers and strong trout populations (Thieling 2006). While metropolitan population growth may be slowing, population growth rates in rural areas are likely to increase (Johnson and Beale 2003), thereby increasing the likelihood of conflict between human and native trout populations. Hence, while some native trout species are not currently at risk, their futures are not that bright.

Many future landscape changes will result not only from human activities but also from indirect human activity that results in global climate change (Flebbe 1997; Rieman et al. 1997). Given the increased certainty of global warming (Intergovernmental Panel on Climate Change 2007), the risk of losing native trout species or subspecies will continue to increase, even if our direct impacts are minimized and it is unlikely that the future direct effects will be minimal.

Certainly, an important component of any plan protecting native trout populations is to maintain current strongholds, which are often centered on public lands (Lee et al. 1997). These lands typically are least impacted by humans and are in areas that foster production of cold-water habitats. But while protection of the remaining native trout necessarily will be focused on public lands, if restoration efforts are to be successful, it will be necessary to involve private lands where county and other authorities may be unaware or indifferent about native trout populations. Non-experts often view the outcomes in a pass/fail context as it relates to listing under the Endangered Species Act. In general, education of the non-angling or non-environmental publics has been absent or ineffective (Angermeier 2005) and without broad-based support, native trout protection and restoration will at best achieve rearguard status.

Many native fishes have detailed recovery plans and strategies that have never been funded or funded only as brief initiatives, even though restoration may take decades. It has been said that conservation without funding is just conversation. There have been lots of conversations about native trout but little long-term funding and commitment similar to the North American Waterfowl Plan now in its third decade. Without such long-term commitment, native trout conservation will be a series of brief, ineffective initiatives rolled out every 5 to 10 years. The recent National Fish Habitat Initiative and the various joint ventures under its umbrella have the potential to improve native trout, if they can become long-term commitments.

Improved inventory and monitoring is critical to tracking successes and failures of conservation and restoration efforts for native trout. Through monitoring it will be possible to better assess the reasons different restoration efforts have succeeded or failed. Increased sampling also will be needed to evaluate and monitor impacts of land use changes, both on private and public lands, as well as to track the spread of exotic species and hybridization rates. Increased monitoring of the status of native trout should be a priority for long-term conservation efforts, and the additional data will help increase the accuracy with which large-scale assessments can be conducted.

This assessment review paints a clear picture that native trout across the United States face similar threats, and it is likely that these threats will increase in the future, putting most native trout at risk of further extirpations. The only way to maintain these species is to develop and implement well funded, clearly articulated, coordinated restoration plans among all the different management agencies and interest groups. Focusing restoration efforts in areas that benefit the species, rather than by political boundaries, will increase the likelihood that native trout will persist..

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Climate Change and Western Trout: Strategies for Restoring Resistance and Resilience in Native Populations

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Abstract

Global warming and associated climate change will cause unprecedented environmental challenges for cold-water dependent fishes. We model three future conditions expected to impact western trout populations most severely – warmer summer temperatures, increased winter flooding, and increased wildfires – to identify those sub-watersheds and river basins where three cutthroat trout *Oncorhynchus clarkii* subspecies are likely to be at greatest risk. Many isolated and smaller Bonneville cutthroat *Oncorhynchus clarkii utah* populations, particularly those at lower elevations, will face increased risk from higher stream temperature and winter flooding. Lowest risk areas for this subspecies occur in the Bear River basin. Colorado River cutthroat *Oncorhynchus clarkii pleuriticus* populations will be at low risk in the Upper Green River; however, all other basins include sub-watersheds at moderate to high risk. Current westslope cutthroat *Oncorhynchus clarkii lewisi* populations are in relatively better condition, but approximately one-third face high risk from increased winter flooding. We argue that management agencies should meet these threats with accelerated and strategically located actions that restore resistance and resilience to climate change in native trout populations and their habitats by protecting best remaining populations, increasing population size and habitat in isolated populations, reducing outside habitat stressors, reconnecting habitats, and restoring migratory life histories. Control of nonnative salmonids should accompany these efforts. Given future uncertainty of climate change impacts and nonnative species expansion, more consistent monitoring and dedication to adaptive management principles are critical.

Introduction

Rapid global warming and associated climate change are likely to have significant negative impacts on most native trout populations. As ectotherms, trout physiology is directly regulated by temperature, and their life history stage-specific habitat requirements make them vulnerable to the many changes predicted to occur in aquatic habitats because of climate change (Rahel et al. 1996; Poff et al. 2002; Ficke et al. 2005). Native trout species are already struggling in the face of wide-scale habitat degradation, fragmentation, and the introduction of nonnative species (Dunham et al. 2002; Lee et al. 1997). Many of these existing threats are likely to be compounded by the effects of climate change.

Perhaps the most pervasive change associated with climate change is a warming of the Earth's surface. During the late 20th century, the Earth's average surface air temperature rose 0.6°C, a rate unprecedented in the past 1,000 years (Mote et al. 2005). Warming air temperatures will cause numerous fundamental environmental changes, including increased stream and lake temperatures and increased evaporation rates. This will reduce annual snowpack and reduce water storage in mid to lower elevation watersheds (Barnett et al. 2004). Precipitation changes are also predicted to result in peak flows occurring earlier in the year and longer, lower base flows (Barnett et al. 2004; Ficke et al. 2005). In general, disturbance events such as floods, drought, and wildfire will increase as climate change progresses (Poff 2002; McKenzie et al. 2004).

Although the general trends are clear, physical characteristics of the catchment, such as topography, vegetation, and orientation, will influence impacts to local watersheds and populations. Also important in determining local impacts will be existing stressors, such as road densities and livestock grazing. The presence of nonnative fishes will add still more complexity and uncertainty. Nonetheless, the effects of a rapidly changing climate are already beginning to manifest themselves. Harper and Peckarsky (2006), for instance, report earlier mayfly and other aquatic insect emergences in Rocky Mountain streams because of reduced snowpack and earlier peak runoff during the past decade.

In this paper, we present our analysis of climate change impacts – increased summer temperature, increased flood risk, and increased wildfire risk – on three subspecies of native trout in the western U.S., and suggest management strategies that will help restore resistance and resilience within populations to climate change. Despite the likely negative implications of climate change to western trout, we remain hopeful. Our hope rests on our ability to implement ecologically based restoration strategies that have proven effective for trout populations and their watersheds. We argue that strategic implementation of such strategies will increase the likelihood that native trout populations will persist in the future, even if this future is characterized by rapid environmental change. Salmonids evolved in highly dynamic environments and have substantial dispersal abilities that will aid in their survival if provided reasonable assistance.

Methods

Our analysis models three elements of environmental change that are widely predicted to result from global warming and are likely to affect cold-water fish adversely:

1. Increased summer water temperature resulting from an increase in air temperature,

2. Larger and more frequent winter flood events resulting from an increase in rain on snow as warm midwinter air masses become more common, and

3. More frequent wildfires where longer, hotter, and drier summers aggravate a situation that is already volatile due to past management practices.

The analyses were conducted at the sub-watershed scale in a GIS environment. For each factor, each sub-watershed was scored as low, moderate, or high risk for adverse environmental affects on cold-water fish populations. A composite map of the three elements was projected across the current distribution of Bonneville cutthroat trout *Oncorhynchus clarkii utah*, Colorado River cutthroat trout *Oncorhynchus clarkii pleuriticus*, and westslope cutthroat trout *Oncorhynchus clarkii lewisi* to identify populations that are the most vulnerable to global warming induced environmental change.

Summer Temperature

The strong correlation between air temperature and water temperature and the lack of regional temperature data for streams and lakes makes air temperature a practical indicator for modeling environmental change across large geographic areas (Rahel 2002). We apply the methods of Rahel et al. (1996) who used changes in mean July air temperature to model habitat loss due to global warming for a cold-water guild of brown trout *Salmo trutta*, rainbow trout *Oncorhynchus mykiss*, brook trout *Salvelinus fontinalis*, and cutthroat trout *Oncorhynchus clarkii* in the Rocky Mountains. Analyzing average daily

July temperature seems appropriate, because this is typically the hottest month in the Rocky Mountains.

The PRISM Group in the Oregon Climate Service at Oregon State University (PRISM 2007) recently published a series of national data sets of average monthly minimum and maximum temperatures from 1970 to 2000 at a resolution of 800 m. We averaged the minimum and maximum July temperatures for this 30-year period to establish a baseline from which to model change.

Before modeling the effects of increasing temperature, it was first necessary to determine the thermal limits for each of the three species evaluated that incorporate species-specific adaptations to local environmental conditions. This was accomplished through a comparison of the historic distribution (in kilometers of habitat) for each species and mean July temperature (Figure 1).

Less than 1% of the total distribution for westslope cutthroat trout and Colorado River cutthroat trout was found in streams with an average July air temperature greater than 22°C. In contrast, nearly 20% (1,400 km) of the historic distribution of Bonneville cutthroat trout was associated with a mean July air temperature greater than 22°C. The thermal distribution of Bonneville cutthroat trout was bimodal, as opposed to the bell curve exhibited by the other two species' distributions. The warmer second peak may be associated with an extensive network of lower elevation valley bottoms that historically contained Bonneville cutthroat trout populations.

Based on this analysis, an upper thermal limit of 22°C was applied to westslope cutthroat trout and Colorado River cutthroat trout, while 24° C was used for Bonneville cutthroat trout. We also identified a 'marginal' temperature range for each species that was within thermal limits but

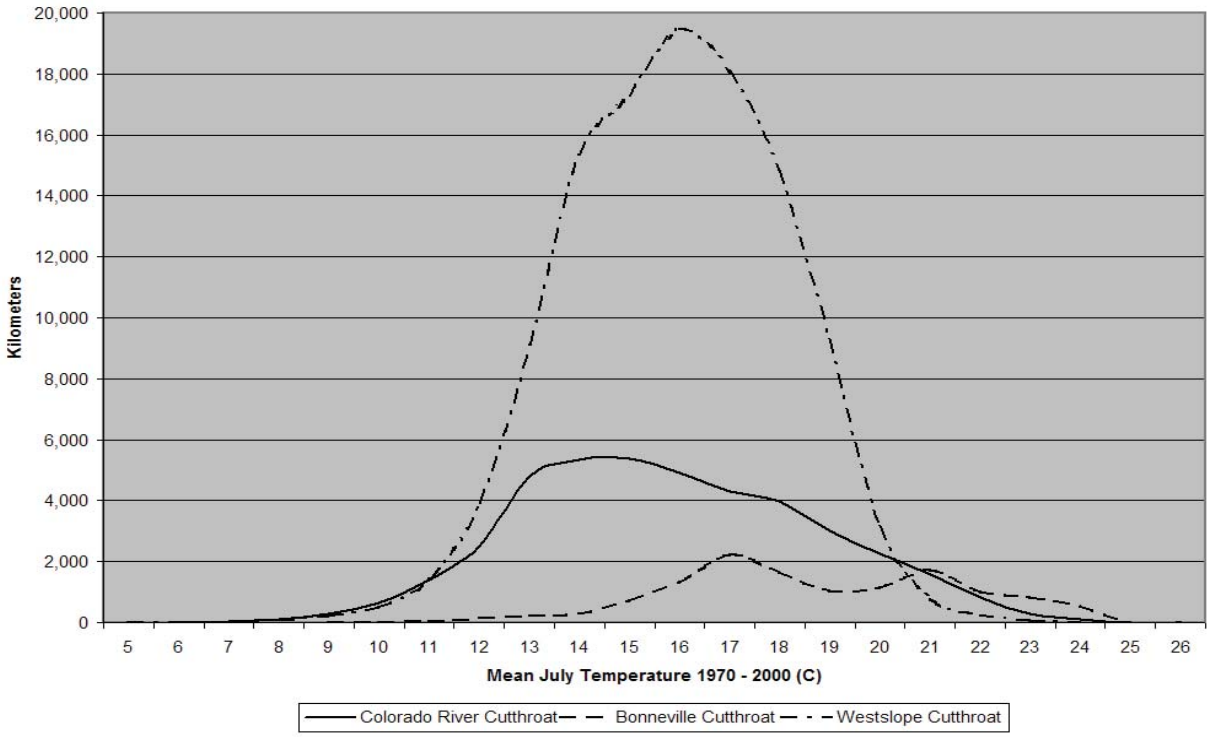

Figure 1. Historic distribution of Colorado River, Bonneville, and westslope cutthroat trout as measured in kilometers of stream habitat relative to July air temperature.

was on the upper end of the respective habitat curve. This marginal habitat range for westslope cutthroat trout and Colorado River cutthroat trout was defined as 20° C - 22° C and for Bonneville cutthroat trout as 22° C - 24° C. Any temperatures less than the lower end of these ranges were considered thermally suitable.

Our analysis of global warming impacts on thermal suitability applied a 3°-C temperature increase to the 1970-2000 mean July air temperatures. This increase has been projected as the most likely scenario for the American West within this century (Climate Impacts Group 2004). An area-weighted average temperature under the global warming scenario was calculated for each sub-watershed within the species' ranges. Using the species-specific 'suitable', 'marginal' and 'unsuitable' temperature break points previously defined, each sub-watershed was then scored for the level of risk to local populations from increased summer air temperatures: 1 (suitable, low risk), 2 (marginal, moderate risk), or 3 (unsuitable, high risk).

Increased Flood Risk

Hamlet and Lettenmaier (in review) modeled uncharacteristic winter flood events for basins of the Pacific Northwest as a result of global warming. Their analysis recognized three types of winter precipitation regimes for basins in the Pacific Northwest: rain dominant, snow dominant, and transient. Winter flooding in rain-dominant basins is a function of the individual storm event and the size and runoff characteristics of the catchment. Snow-dominant basins do not typically flood in mid-winter but rather flooding occurs later as spring run-off. Transient basins, where both rain and snowstorms occur, are the primary location of significant mid-winter flooding events. The magnitude of the flood event is dependent on the intensity and duration of the rainstorm and the antecedent snow pack.

Given the uncertainty of climate models with regard to future precipitation patterns, it is not possible currently to model increased flood risk as a function of changes in precipitation amounts. However, warmer winter temperatures will likely result in increased winter flooding due to increases in rain on snow events as snow-dominant watersheds shift to transient precipitation regimes.

Our analysis of uncharacteristic winter flooding due to global warming assumed the same 3°-C temperature increase used in our model of thermal impacts. For winter flooding we used mid-winter temperatures (January – March) as our baseline. We again relied on the PRISM average monthly minimum and maximum temperatures for 1970 – 2000. These data sets were processed to establish a mid-winter average temperature across the ranges of our three species of interest.

In addition to temperature data, we also acquired average annual and monthly precipitation data for the same time period. For each sub-watershed, the area weighted mean of three variables was calculated: annual precipitation, winter precipitation, and winter temperature. Sub-watersheds where the three months of winter precipitation comprised less than 25% of the annual precipitation were classified as having a non-winter-dominant precipitation regime and therefore were at low risk for uncharacteristic winter flooding.

Once the sub-watersheds dominated by winter precipitation were identified, we classified them by type - rain, snow, or transient - using the data on mean winter air temperature. We assumed that sub-watersheds with a mean winter temperature less than -1° C were snow dominant while those with a mean winter temperature greater than +1° C were rain dominant. The remainder of the sub-watersheds was classified as transient.

A 3°-C temperature increase was added to the current winter mean temperature and the sub-watersheds were reclassified. The change in basin type between current temperatures and the global warming scenario served as the basis for scoring the risk of uncharacteristic winter flooding. The highest score was assigned to sub-watersheds that change from snow dominant to transient or rain dominant. Sub-watersheds that change from transient to rain were assigned a moderate risk score because they would be likely to experience more flood events (and currently are) in the near term as they continue to receive some snow along with an increasing frequency of warm mid-winter storm events until they ultimately become rain dominant. Once this occurs, the winter flood risk may actually decline since there will no longer be an antecedent snow pack to contribute to high run-off. Sub-watersheds that remain as either snow or rain dominant, or are non-winter precipitation dominant, received the lowest risk score.

Increased Wildfire Risk

Recognizing that fire is a part of the western landscape and fire risk will continue to increase as predicted under a warming climate, the increased wildfire risk analysis sought to identify areas at greatest risk for uncharacteristic wildfire. Several factors contribute to increased risk for uncharacteristic wildfire, including changes in fuel loads, and vegetation type, composition, and structure. Past land management practices have resulted in the removal of large, fire-resistant native conifers and the spread of invasive, and highly flammable, species such as cheatgrass, resulting in an increase in the frequency, duration, and intensity of western wildfires (DellaSala et al. 2004).

To identify those areas that have been the most altered and are therefore at greatest risk for uncharacteristic fires, we used the Fire Regime Condition Class Departure Index developed by the Forest Service LANDFIRE program. The Index uses a scale of 0 – 100% to depict departure from the presumed historical vegetation reference conditions incorporating plant composition, structure, and disturbance regimes (Hann et al. 2004). Area weighted means of the departure index were calculated for each sub-watershed and grouped into three classes of risk: low is less than 50% departure, moderate is 51 – 75% departure, and high risk is greater than 75% departure.

Composite Climate Risk

The sub-watershed risks for each of the three elements (increased summer temperature, increased flood risk, and increased wildfire risk) were combined to generate a composite score for risk of habitat loss due to environmental change from global warming. Each sub-watershed was scored as low, moderate, or high risk based on the highest score from each of the three elements modeled and then evaluated against the current distribution of each subspecies. This allowed us to quantify potential habitat loss due to global warming and identify populations at greatest risk.

Results

Bonneville Cutthroat Trout

For a 3^{o}-C increase in temperatures predicted with climate change, 77% of sub-watersheds with existing populations were modeled to be at moderate or high composite risk for Bonneville cutthroat trout (Table 1). A disproportionately large share of remaining habitat was projected to face thermal challenges in the West Desert and Southern Bonneville basins, where many remaining populations already are fragmented and occupy small stream segments. Stream habitats in the Bear River and Northern Bonneville basins were mostly at lower risk for thermal problems, except along the lower-elevation western flanks of those basins.

Table 1. Percent of currently occupied sub-watersheds in low, moderate, and high risk category for each of the climate change factors.

	Increased Summer Temperature			Increased Flooding			Increased Wildfire			Composite Risk		
Cutthroat trout subspecies	High	Mod	Low	High	Mod	Low	High	Mod	Low	High	Mod	Low
Bonneville	8	16	76	48	7	45	13	37	50	57	20	23
Colorado River	5	23	72	12	0	88	1	20	79	14	27	59
Westslope	3	35	62	31	7	62	3	42	55	36	31	33

Areas of moderate to high risk for winter flooding were modeled to occur primarily in the Southern Bonneville and Northern Bonneville basins. Much of the West Desert will be in moderate risk while much of the Bear River and eastern portions of the Northern Bonneville basins are likely to remain as snow-form precipitation and therefore at low risk of increased winter flooding. Wildfire models suggest that highest risk areas are found in the lower elevations of the Bear River and Southern Bonneville basins. In general, the composite risk analysis showed that most of the West Desert, Southern Bonneville, and Northern Bonneville basins were in the moderate to high-risk range. Only populations in the extreme eastern portion of the Northern Bonneville basin, and most of the Bear River basin were modeled to be at low risk (Figure 2).

Colorado River Cutthroat Trout

Colorado River cutthroat trout are more isolated in headwater tributaries that are less susceptible to thermal changes. Historically, 89% of stream habitat occupied by Colorado River cutthroat trout was less than or equal to 19^{o} C, and this percentage decreases only to 72% with the 3^{o}-C increase projected from climate change. Twenty-eight percent of currently occupied sub-watersheds were likely to be at thermal risk with the 3^{o}-C increase

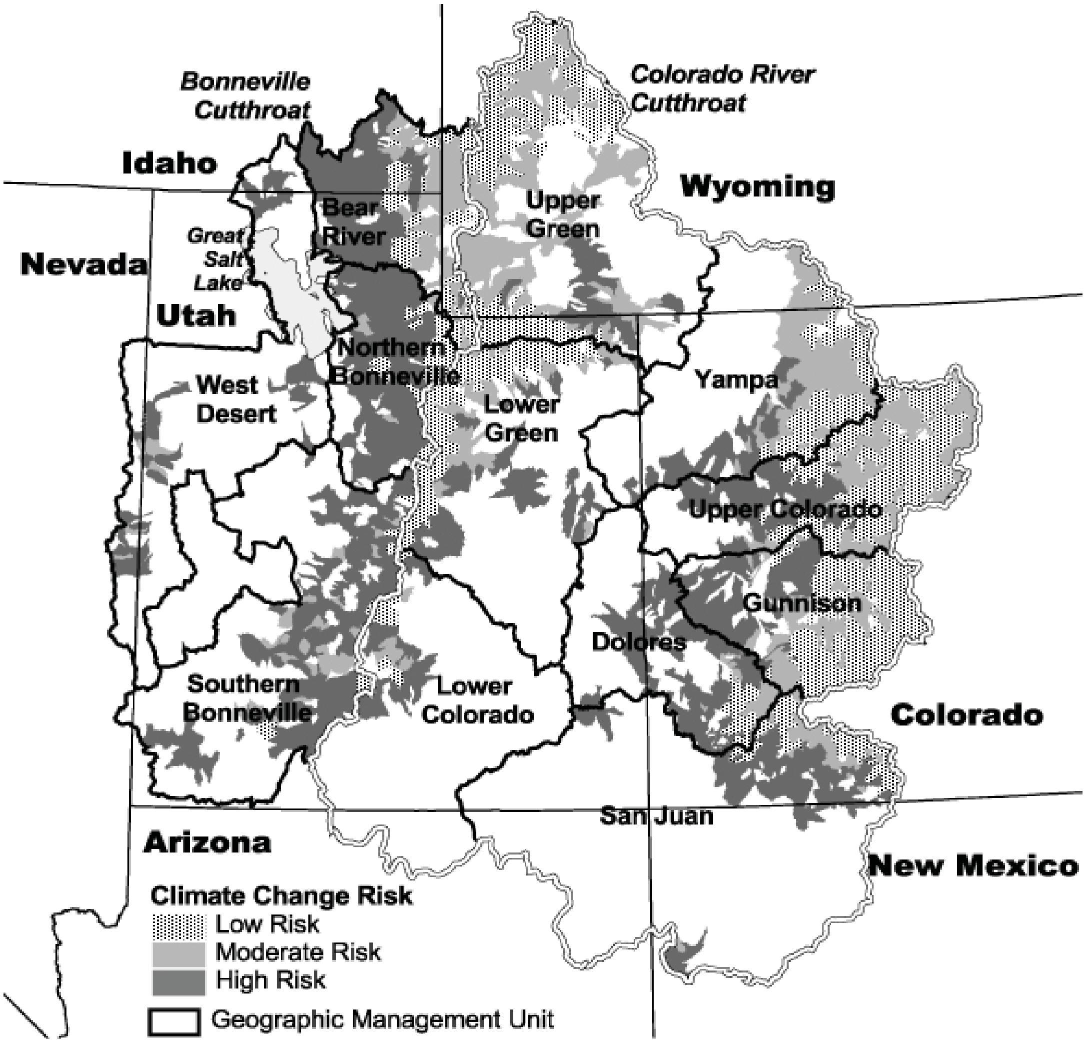

Figure 2. Composite climate change risks for Bonneville cutthroat and Colorado River cutthroat trout. Sub-watersheds within historic and current range were scored as low, moderate, or high risk. The range for the Colorado River cutthroat trout is outlined by double line; the range of the Bonneville cutthroat trout is shown to the left.

(23% of sub-watersheds occur in 19-22° C range, and 5% in greater than 22° C). All basins will be affected by increased temperature but a greater relative impact is likely in the Upper Colorado, Gunnison, Yampa, and Dolores river basins.

Increased risk for winter flooding was identified in habitats at lower elevations within the Lower Green, Yampa, Upper Colorado, Gunnison, Dolores, Lower Colorado, and San Juan river basins. All of the Upper Green and higher elevation habitats all other basins were modeled at low risk for increased flooding. Increased wildfire risk was generally lower and more scattered within the range of Colorado River cutthroat trout, but those basins in the eastern portion of the range had a higher percentage of sub-watersheds in the moderate and high risk categories. In general, the composite risk analysis showed mostly low risk in the Upper Green basin. Higher elevation zones of other basins were mostly in low risk categories despite increased risk for wildfire in scattered sub-watersheds (Figure 2).

Westslope Cutthroat Trout

When the 3°-C temperature increase was applied to the 1970-2000 mean July temperatures, results for westslope cutthroat trout show 3% of sub-watersheds within the current range at high risk from increased temperatures and 35% at moderate risk (Table 1). Current westslope cutthroat trout populations are less fragmented and occupy many lower elevation streams that are moderately vulnerable to temperature increases over the next century. Most thermal risks occur in the Upper Missouri, Clearwater, and Coeur d'Alene river basins, as well as the Oregon portions of the range. Most existing habitat in the Salmon and much of the Clark Fork Basin was modeled at low risk from summer temperature increase.

High risk from winter flooding was identified in 31% of the current range, especially within the Clearwater, Coeur d'Alene, Clark Fork, Kootenai river basins, as well as those portions of the range in Washington and Oregon. Remaining basins were primarily at low risk from flooding. Increased risk from wildfire was more variable, but at high risk levels in much of the Marias, Upper Missouri, and Middle Missouri river basins. In the composite risk analysis, the Salmon and Madison river basins were at the lowest composite risk to climate change impacts. Highest risk areas were predicted in the Marias, northeastern portions of the Upper Missouri, northern portions of the Middle Missouri, and much of the range in Washington. The Clearwater, Coeur d'Alene, Kootenai, western portions of the Clark Fork, and the range in Oregon were mostly in the moderate or high composite risk categories (Figure 3).

For all subspecies, local stream-specific impacts were unpredictable in our analysis because of the scale of the data and the categorization by sub-watershed. Nonetheless, many sub-watersheds and larger river basins were identified at high risk of significant impacts to stream populations from climate change events. This does not mean that restoration efforts should be abandoned from these regions. Much to the contrary, our analysis illuminates those regions that should receive immediate actions to expand habitats and populations – that is, restore resistance and resilience to climate change – so that the genetic, life history, and population diversity within these subspecies can be maintained in the face of a rapidly changing climate.

Strategies to Restore Resistance and Resilience

While we may not be able to stop a rapidly changing climate, we can implement measures designed to increase the likelihood of native trout persistence. We describe six strategies that draw on existing and proven methodologies and will increase the ability of habitat and populations to withstand rapid environmental change (**resistance**), and improve the ability of habitats and populations to rebound after disturbance (**resilience**). These strategies generally fit within what can be described as a "protect-reconnect-restore" model of fisheries sustainability, where emphasis is to **protect** the best remaining habitats and populations, **reconnect** fragmented habitats by removing in-stream barriers and reestablishing in-stream flows, and **restore** vital mainstem

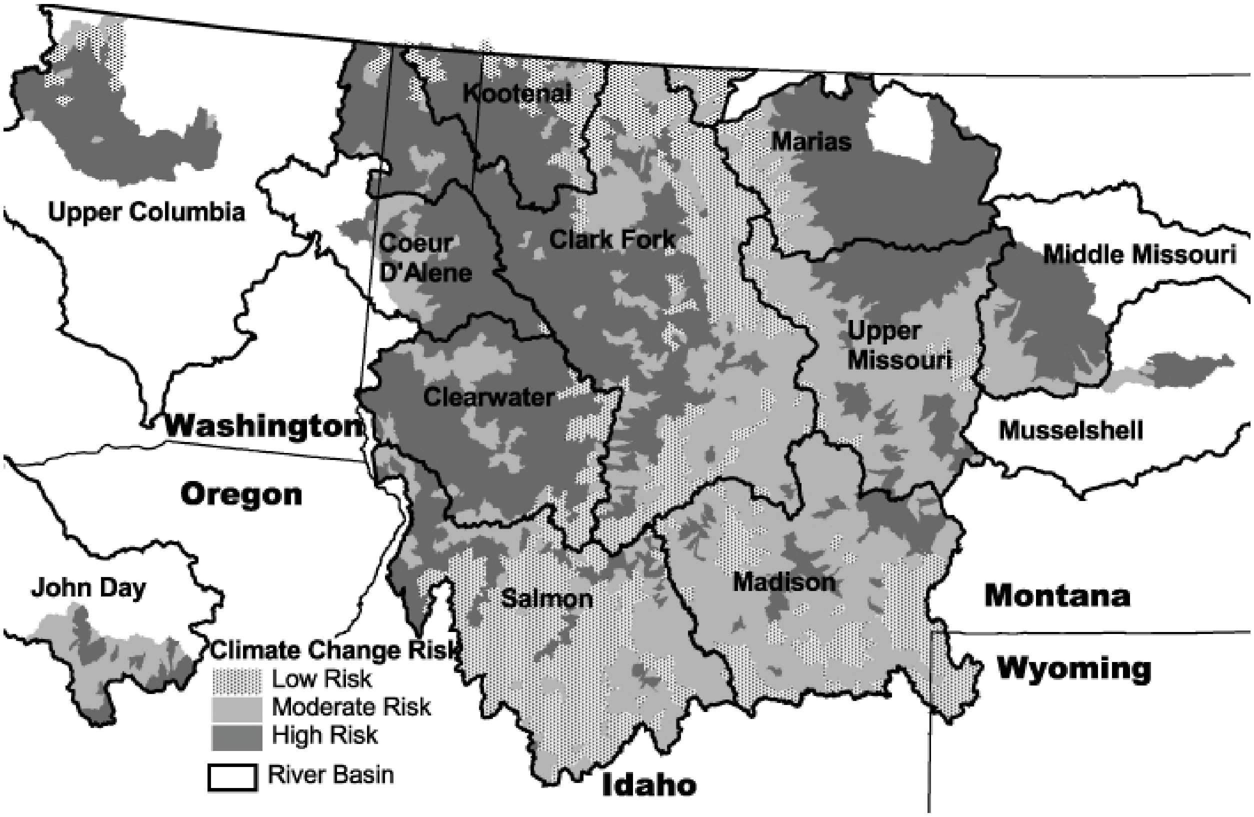

Figure 3. Composite climate risk map historic and current range for westslope cutthroat trout that combines risk of increased summer temperature, winter flooding, and wildfire.

river and riparian habitats. Trout Unlimited has encouraged implementation of these strategies as a contingency plan to prepare for future climate change impacts.

Strategy 1: Protect remaining population and habitat strongholds

The first rule of strategic restoration is to protect remaining core strongholds (Frissell 1997; Williams et al. 1997). Existing trout strongholds should be maintained in high quality condition because these areas will have the greatest likelihood of resisting climate change and will be key to future population expansions. Similarly, watersheds that produce reliable supplies of cold water should be protected, because these areas will be key to maintenance of suitable downstream conditions.

Strategy 2: Maintain genetic and life history diversity

Genetic and life history diversity help buffer populations against environmental changes by allowing populations to maintain broad suites of behavioral characteristics, increasing the likelihood that some individuals will be better adapted to novel conditions (Schlosser and Angermeier 1995). Restoring life history diversity, especially migratory forms, serves the dual purpose of maintaining genetic diversity and increasing the ability of a population to explore and colonize habitats that had recovered from earlier disturbance (Dunham et al. 2003; Colyer et al. 2005; Neville et al. 2006). Larger, migratory individuals also have higher fecundities and therefore are better able to resist outside stressors such as nonnative species.

Strategy 3: Increase size and extent of existing populations

Small, fragmented populations are at greater risk of extinction because of habitat limitations as well as demographic and environmental variability (Hilderbrand and Kershner 2000; Rieman and Allendorf 2001). Many populations of native trout have been relegated to smaller, upper elevation streams by degraded downstream habitat and advances from nonnative salmonids. Climate change is likely to exacerbate these threats by increasing environmental variability and reducing suitable water quality and quantity (Poff 2002; Poff et al. 2002). Populations occurring over larger geographic areas, or greater stream lengths, will be more stable and more resistant to local extinction.

Strategy 4: Minimize outside stressors

For many watersheds, climate change will add stress to drainages that are already impacted by a multitude of anthropogenic disturbances such as roads, overgrazing by livestock, poor timber harvest practices, off-road vehicle use, mining, pollution, and agriculture. The cumulative effect of climate change impacts may deteriorate some watersheds to the point that they will not be able to rebound following disturbance events, or may move watershed conditions to new and reduced-integrity thresholds following floods, drought, wildfire, or other major changes. Restoration of natural conditions and ecological processes will improve the ability of populations to rebound after catastrophic events, including increased floods, particularly when focused on restoring riparian habitats, floodplains, and reconnecting streams to larger river systems (Williams and Williams 2004).

Strategy 5: Manage at watershed scales to reconnect stream systems

Restoring connectivity within and among watersheds by removing barriers to dispersal or by restoring in-stream flows will facilitate the recovery of migratory life histories, and increase the likelihood of fish finding suitable habitat conditions. Restoring connectivity in watersheds helps to reverse the habitat fragmentation and isolation of small populations, often cited as principal causes of population loss among cold-water fishes (Dunham et al. 1997; Hilderbrand and Kershner 2000). As waters warm in response to climate change, increasing access to suitable habitat conditions will become critical to survival for many populations. However, because nonnative species can expand as connectivity increases, site-specific decisions will have to be made that weigh this factor among potential gains (Fausch et al. 2006).

Strategy 6: Increase monitoring and improve adaptive management

Langston (1995) appropriately characterized successful adaptive management as "listening to the land," with managers being responsive to monitoring results and acting on new knowledge by modifying management programs appropriately. Climate change will add variability to natural systems that are already exceedingly complex and subject to synergistic effects of human actions that further confound management. Nonnative species and pathogens are present in many watersheds harboring native trout and the response of these animals to climate change may be particularly hard to predict. If carefully designed, monitoring programs should be valuable in unraveling the complexities that climate change will add to natural systems (Kershner 1997).

Conclusion

The impacts of climate change on western trout populations and particularly native trout will be significant. Many of the current ranges of these fishes already have been greatly reduced from historic conditions. For example, based on sub-watersheds, Colorado River cutthroat trout occupy 18% of their historic range, Bonneville cutthroat trout 37% and westslope cutthroat trout 56%. Yet our modeling shows significant portions of this remaining range at high risk from climate change (57% of Bonneville cutthroat trout range is at high climate change risk, 14% of Colorado River cutthroat trout, 36% westslope cutthroat trout). Modeling increased risk factors can help identify those areas where existing populations are at greatest risk and where restoration and reintroduction efforts should be expanded. These models can be useful in determining how climate change may compound current stresses, and in developing strategies to protect, reconnect and restore populations of Bonneville cutthroat trout, westslope cutthroat trout and Colorado River cutthroat trout. Monitoring will be critical in understanding local stream impacts and appropriately placing streams within broader basin-wide strategies.

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Conservation and Restoration of Native Trout in the Face of Climate Change, Invasive Species, and Development

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Extended Abstract

Individual populations of trout have evolved distinct life-history characteristics in response to the diverse environments in which they have evolved; however, anthropogenic activities have resulted in a substantial reduction in the historical distribution of numerous taxa. In fact, many unique local populations in the western USA have been extirpated. Of 14 subspecies recognized by Behnke (1992), one (yellowfin cutthroat trout *Oncorhynchus clarkii macdonaldi*) is extinct. Four cutthroat trout subspecies have not been officially described, but all of the nine recognized subspecies have been designated as a “species of special concern” or a “sensitive species” by the respective management agencies. These subspecies have also been petitioned for listing under the Endangered Species Act, and the greenback cutthroat trout *Oncorhynchus clarkii stomias*, Paiute cutthroat trout *Oncorhynchus clarkii seleniris*, and Lahontan cutthroat trout *Oncorhynchus clarkii henshawi* are listed as “threatened.” Other western trout including the Gila trout *Oncorhynchus gilae*, Apache trout *Oncorhynchus gilae apache*, California golden trout *Oncorhynchus mykiss aguabonita,* and bull char *Salvelinus confluentus* have also been listed as “threatened.” For most of the remaining taxa, the presence of numerous populations, primarily in headwater streams, has precluded listing under the ESA despite acknowledged declines in the distribution and abundance (Table 1). Management actions initiated in the past several decades appeared to stabilize, and in some cases improve, the probability of persistence of some trouts; however, the introduction and spread of invasive fishes and fish pathogens, and years of drought in the Intermountain West suggest that these trends may be ephemeral.

Primary threats to native trout include (1) invasive species, (2) habitat degradation (e.g., surface water diversions, grazing, mineral extraction, timber harvest, and associate road building), and (3) climate change. All of these threats are geographically ubiquitous, and perhaps insidious, because when systems have been exposed to these threats, it is often impossible to restore altered environments to previous conditions. Furthermore, in many cases, management has often focused on a single “limiting” factor rather than using a systems approach that integrates threats and solutions. Although each threat may be significant in isolation, the synergistic effects of these factors can lead to rapid extirpation. Furthermore, the historic decline and disappearance of individual populations or assemblages have led to increasing isolation and fragmentation of remaining assemblages, a fact that increases susceptibility to the demographic influences of disturbance (both human and stochastic) and genetic factors.

Climate change may ultimately be the greatest threat to the persistence of native western trout, because it will exacerbate current negative effects of invasive aquatic species and habitat degradation. Air temperature is expected to continue warming globally from 1.4 to 5.8°C during the 21st century (IPCC 2001). Stream temperature will be affected most by changes in maximum summer temperatures and minimum winter temperatures (Keleher and Rahel 1996). With warming temperatures, the current ranges of cold-water species are expected to shift north and up in elevation. Using upper temperature threshold of 22°C as a constraining variable, Keleher and Rahel (1996) predicted that with increases in temperature from 1 to 5°C, the length of stream occupied by a guild of cold-water fish (brook trout *Salvelinus fontinalis*, cutthroat trout *Oncorhynchus clarkii*, and brown trout *Salmo trutta*) would decrease 7.5-43.3% in Wyoming. These estimates include minor increases in suitable habitat at high elevations as temperatures increase. Fish inhabiting lakes will also be affected. Shallow lakes may desiccate completely as temperatures increase, and water depth of deeper lakes will probably decrease. It appears that lake habitats for cold-water fish may decline up to 45%, and the largest negative impacts will be in lakes of moderate depth (≤13 m maximum depth; Stefan et al. 2001).

Most of the future climate predictions to date have been based on simple, single-variable models focused on temperature at the global scale, and models do not account for the interaction of physical variables that will be affected by climate change. For example, Jager et al. (1999) demonstrated that hydrology is another important variable to consider with effects of climate change on trout. Changing the juxtaposition of the fish incubation period with flow-related disturbances in models revealed nonadditive interactions between hydrologic and temperature effects (Jager et al. 1999).

Table 1. Extant recognized taxa of native trout of the western USA, conservation status (P[1] = Petitioned under the Endangered Species Act and T = Listed as threatened under the Endangered Species Act), and historic distribution by state. Scientific and common names reflect current designation (Nelson et al. 2004)

Taxa	Status	Locations
Cutthroat trout		
Bonneville cutthroat trout (*Oncorhynchus clarkii utah)*	P	ID, NV, UT, WY
Coastal cutthroat trout (*Oncorhynchus clarkii clarkii)*	P	AK, CA,OR, WA,
Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*)	P	CO, UT, WY,
Greenback cutthroat trout (*Oncorhynchus clarkii stomias)*	T	CO
Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi)*	T	CA, OR, NV
Paiute cutthroat trout (*Oncorhynchus clarkii seleniris)*	T	CA
Rio Grande cutthroat trout (*Oncorhynchus clarkii virginalis)*	P	CO, NM
Westslope cutthroat trout (*Oncorhynchus clarkii lewisi)*	P	ID, MT
Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*)	P	ID, MT, NV, UT, WY
Redband trout		
California golden trout (Oncorhynchus mykiss aguabonita)	T	CA
Little Kern golden trout (*Oncorhynchus mykiss whitei)*	P	CA
Redband trout subspecies (*Oncorhynchus mykiss* ssp.*)*	P	CA, WA, ID, MT, NV, OR
Gila Trout		
Apache trout *(Oncorhynchus gilae apache)*	T	AZ
Gila trout (*Oncorhynchus gilae)*	T	AZ, NM
Char		
Bull char *(Salvelinus confluentus)*	T	MT, NV, OR, WA

[1] *All petitions for listing under the Endangered Species Act have been found unwarranted by the U.S. Fish and Wildlife Service except for the California golden trout and the Colorado River cutthroat trout; petitions for the latter fishes are pending.*

Over 100 million acres have been burned by wildfire in the West during the last 20 years, and evidence suggests that climate change will continue to increase the probability of large stand-replacing fires. Currently, however, it appears that even in the case of extensive, high-severity fires, local extirpation of fishes is patchy, and recolonization is often rapid. Lasting detrimental effects on fish populations are most often associated with areas where native populations have declined and become increasingly isolated because of anthropogenic activities. Unfortunately, this situation is exacerbated by decreasing water availability at a time when demand is increasing. Furthermore, the potential of invasive species to expand under these altered habitat conditions is poorly understood.

Of course, solutions to these problems are not simple, but it is important to recognize that the status of native trout, no matter how optimistic, is not static, especially in the face of changing climate, invasive species, and a legacy of destructive land use. Despite incomplete knowledge of the negative consequences current and future perturbations to the persistence of native trout, it is apparent that managers must begin to develop broad-based management strategies that focus on protecting remaining native fish populations and associated habitat from further anthropogenic degradation and restoring degraded habitat and connectivity. Strategies for individual taxa will require a range-wide approach than integrates conservation and restoration activities within and among stream networks.

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WILD TROUT
SYMPOSIUM

The Role of Environmental Factors in Determining the Spawning Density and Distribution of Brown Trout Along an Elevational Gradient

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Abstract

We used redd counts, habitat data, and adult population estimates to investigate the role of factors such as habitat availability and adult fish density in determining the spatial distribution of brown trout *Salmo trutta* spawning activity in the Logan River, Utah. Brown trout in our study stream spawned considerably later than other North American brown trout populations documented in the available literature. We observed a strong relationship between reach-specific brown trout population abundance and redd counts, highlighting the potential of using redd counts as an index of adult brown trout population abundanceWhile we did not observe significant study-wide (± 50 km scale) effects of available habitat on brown trout spawning activity, habitat availability appears to be a limiting factor at smaller scales (e.g. at the reach level). Our results suggest that survival at a different life stage (i.e. not spawning success) may be limiting the abundance and distribution of brown trout.

Introduction

Following widespread anthropogenic impacts on riverine ecosystems (Malmqvist and Rundle 2002; Rahel 2002), many streams across the Intermountain West demonstrate a fish distribution pattern whereby lower elevation areas are dominated by introduced fishes, and native trout populations are relegated to headwater reaches (Behnke 1992; Peterson and Fausch 2004; Rieman et al. 2006). This species distribution structure appears to be largely a result of the competitive and/or predatory effects of introduced trout (Courtenay and Stauffer 1984; Ross 1991); however, specific factors limiting the upstream invasion of nonnative fishes, and consequently, allowing for the persistence of native fish populations in higher elevations, are poorly defined. Thus for exotic trout in these longitudinally-arranged systems, it is critical to (1) identify the limiting life stage, and (2) understand the mechanism, or mechanisms, within that life stage that prevents their further expansion.

Understanding the importance of environmental factors and how they affect the distribution of brown trout *Salmo trutta* is paramount, because the species is widely distributed outside of its native range, yet often exhibits an apparent upper limit of distribution in streams (Vincent and Miller 1969; Gard and Flittner 1974; Weigel and Sorensen 2001). Brown trout are native to Europe and have been extensively introduced throughout the United States (MacCrimmon and Marshall 1968; Lever 1996). Exotic brown trout are known to outcompete native fish (Wang and White 1994; McHugh and Budy 2006; Shemai et al. 2007), and their presence has been attributed to the decline of a number of native cutthroat trout *Oncorhynchus clarkii* populations in the Intermountain West (Behnke 1992). Recent research has described population distribution, growth, and survival of brown trout in native Bonneville cutthroat trout *Oncorhynchus clarkii utah* streams (de la Hoz Franco and Budy 2005; McHugh and Budy 2005); however, our understanding of brown trout spawning ecology and early life history, and the factors that limit these life stages remains limited.

As part of a broader effort to provide a scientific template to guide conservation and management of an important population of endemic Bonneville cutthroat trout, we have been studying trout population dynamics, species interactions, and disease in the Logan River since 2001 (Budy et al. 2007a). From this research, we demonstrated that adult brown trout have the ability to successfully outcompete cutthroat trout during the summer months, even at stream elevations where they have not currently established viable populations. In addition, when reared experimentally at high elevations in the Logan River, above their apparent sub-adult and adult distribution, brown trout survived and demonstrated high growth rates, indicating they were not limited by abiotic or biotic factors at these sites, during these life stages (McHugh and Budy 2005). Based on these observations, factors affecting the spawning success or survival of early life stages are likely limiting brown trout in the upper elevations of the Logan River. Thus, the overall goal of this study was to provide a better understanding of brown trout spawning ecology and factors limiting brown trout at this life-history stage in the Logan River, UtahWe conducted a census of spawning activity via weekly redd counts, and used this information, along with habitat and population data, to achieve three main objectives: (1) document the timing and extent of brown trout spawning, (2) identify the effects of limiting factors such as available spawning substrate on redd densities, and (3) evaluate the relationship between adult brown trout population abundance and redd density.

Methods

Study Area

The Logan River originates in the Bear River Mountains in southeastern Idaho and flows about 64 km southwest from the Idaho border through Logan Canyon until it joins the Bear River in Cache Valley, Utah (Figure 1). Entering Utah at an elevation of 2,590 m, the river drops to an elevation of about 1,370 m as it flows into Cache Valley and the city of Logan. Primary tributaries to the Logan River include Temple Fork (river km 22.5, 1,745 m elevation), Right Hand Fork (river km 36, 1,590 m elevation), and Spawn Creek (1,800 m elevation at mouth), a tributary of Temple Fork. Strong seasonal variation is evident in the hydrograph, with fluctuations in discharge ($< 3\ m^3 \cdot s^{-1}$ to $> 30\ m^3 \cdot s^{-1}$) caused by spring snowmelt and dry summers. Like most mountain streams, key environmental attributes change notably along the elevation gradient in the Logan River. More detailed information describing physical habitat characteristics in the Logan River can be found in de la Hoz Franco and Budy (2005)

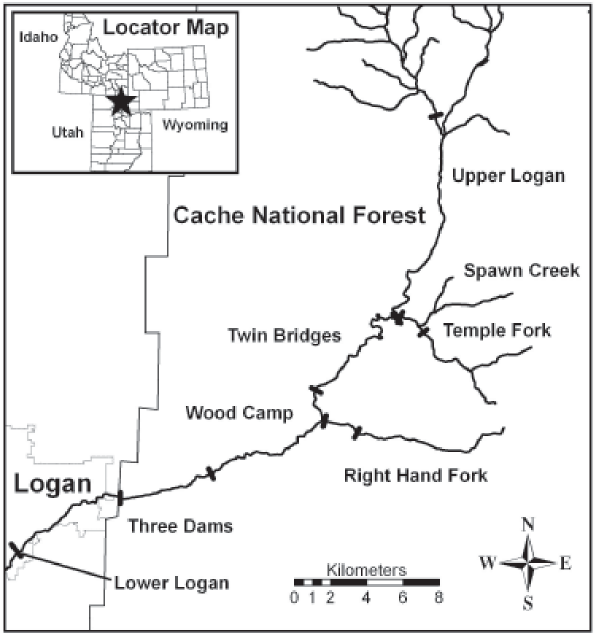

Figure 1. Map of the Logan River drainage in northern Utah, where brown trout spawning surveys took place. Reach names are labeled and their boundaries are marked with dashes.

The Logan River contains one of the highest remaining densities of native Bonneville cutthroat trout on record (Budy et al. 2007a), and as such, this population is considered important in maintaining the long-term viability of this subspecies. Introduced species include brown trout, which are dominant and occur in high densities in lower reaches of the river. Bonneville cutthroat trout and brown trout exhibit an allopatric distribution in the river, with lower elevation areas dominated by brown trout, upper elevation areas dominated by cutthroat trout, and a transition zone where both species exist in sympatry, but in lower overall density (de la Hoz Franco and Budy 2005; McHugh and Budy 2005).

Habitat Surveys

Prior to the brown trout spawning season in autumn of 2006, we conducted visual habitat surveys to identify potential brown trout spawning areas. We surveyed approximately 50 km of the Logan River and visually identified potential patches of spawning gravel. Potential habitat was identified using specific literature derived values (Raleigh et al. 1986) describing substrate size (0.3-10 cm diameter), water depth (over 6.4 cm), and water velocity (15-90 $m \cdot s^{-1}$). After determining that an area likely contained suitable spawning habitat, we estimated the average length and width of each habitat patch, and marked their locations using GPS coordinates.

Timing and Extent of Spawning

Redd Counts - During the autumn months (September and October), we investigated various potential spawning locations throughout the Logan River at a minimum of every two to three days to look for spawning activity. Upon the first sign of spawning activity in the river, we began conducting weekly redd counts in the main stem of the Logan River and the tributaries (Right Hand Fork, Temple Fork, and Spawn Creek), and continued surveys until spawning activity diminished. Based on previous research on fish distribution and abundance, abiotic factors, and natural breaks in topography and geomorphology, we divided the main stem into five adjacent reaches, within which each previously identified spawning habitat location was revisited weekly and examined for the presence of redds. The main stem reaches were referred to as follows: *Lower Logan* (elevation 1,363-1,368 m), *Three Dams* (1,425-1,530 m), *Wood Camp* (1,530-1,621 m), *Twin Bridges* (1,621-1,761 m), and *Upper Logan* (1,761-2,032 m) (Figure 1).

Upon surveying each area during our redd counts, we carefully examined the river for spawning activity. A redd was defined as an area containing clean substrate in relation to surrounding conditions, and characteristic structure containing a pit and tailspill (Ottoway et al. 1981; Witzel and MacCrimmon 1983). We marked each individual redd with flagging tape and recorded its location using GPS coordinates.

Data Analysis

Population density – To evaluate the relationship between number of adult brown trout and number of redds counted by site, we used 2006 population estimate data from a long-term index site sampled within each reach via electrofishing during low flows (Budy et. al 2007a; 2007b). We used available population estimates from each site (fish ≥ 100 mm total length and ≥ age-3) as an index of the entire reach sampled for redds. We used estimates for fish (≥ 100 mm), because this is the smallest size at which we can obtain accurate population estimates (Budy et al. 2007b), and used estimates for fish (≥ age-3) (based on our scale aging data) because most female brown trout seem to mature at age-3 (Elliot 1994; Alp et al. 2003). We tested the relationship between the number of brown trout per kilometer (≥ 100 mm and ≥ age-3) and the number of redds per kilometer by site using regression analyses (SAS Institute 2005; a priori α-level of 0.10).

Spawning Habitat - We assessed the relationship between available spawning habitat and the number of redds within each site based on linear regression of the number of redds (dependent variable) versus the total area of available spawning substrate (independent variable) recorded during our visual habitat surveys (SAS Institute 2005; a priori α-level of 0.10). We then calculated the ratio of area covered by redds (unpublished data) to area of available spawning habitat for each site, to determine what proportion of the spawning habitat appeared to be used

Results

Habitat Surveys

Based on our visual habitat surveys, we identified an estimated 16,213 m^2 of gravel suitable for spawning. Estimates of suitable habitat varied greatly in magnitude across sites and ranged from 53 m^2 (*Twin Bridges*) to 8,244 m^2 (*Three Dams*)

Timing and Extent of Spawning

Literature Review – Of the four other studies describing resident, stream brown trout spawning populations, all described spawning periods that occurred at least partially during the months of October and November (Table 1). Only one other study described a spawning period occurring during the month of December, and none described brown trout spawning as late as that identified in our study. Although variable across sites, the brown trout spawning period in the Logan River occurred primarily over the months of November and December

Redd Counts – The onset of brown trout spawning coincided with low flow and decreasing water temperature, fluctuating around an apparent threshold of 5°C (Figure 2). We observed the first sign of brown trout spawning activity on 3 November 2006, on the main stem of the Logan River near the mouth of Temple Fork. The last redds constructed may have been completed as early as late December, but were not identified until early January due to sampling intervals. In most areas censused, we observed a typical bell-shaped pattern of spawning activity over time, which peaked in late November, with some interruptions likely due to changes in weather. Overall, we counted a total of 1,775 redds, 1,506 (84.8%) of which we observed on the main stem of the Logan River during our weekly counts. The remaining 269 redds (15.2%) were observed in the tributaries.

Population Density - We observed a wide variation in redd density across sites in the Logan River (4-122 redds/km), with redd density generally decreasing as elevation increased. The highest elevation at which we observed redds was 1,983 m. This pattern in redd density tightly paralleled the pattern in adult brown trout density observed during our summer electrofishing surveys. The number of redds per kilometer increased positively with the number of brown trout (≥ 100 mm) per kilometer (r^2=0.79; P=0.008; Figure 3), as well as number of age-3 and older brown trout per kilometer (r^2=0.95; P=0.02; Figure 3).

Table 1. Timing of the brown trout spawnin gperiod in this study compared to other stream resident brown trout in North America

Area	Spawning Period			References
	Oct	Nov	Dec	
northern Utah		▬	▬	this paper
Pennsylvania		▬	▬	Beard and Carline 1991
Arkansas	▬	▬		Pender and Kwak 2002
southern Ontario	▬	▬		Zimmer and Power 2006
southwest Ontario	▬	▬		Witzel and MacCrimmon 1983

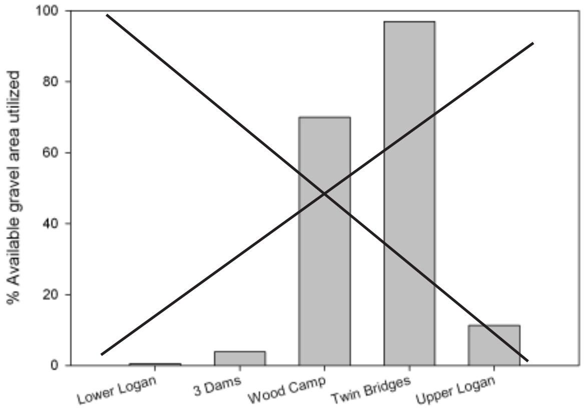

Figure 2. The brown trout spawning period (shaded area) plotted as a function of daily water temperature and discharge in the Logan River, 2006.

Spawning Habitat - Similar to the pattern observed with temperature, we failed to identify a significant relationship between the number of redds counted and available spawning gravel measured by site in the Logan River (r^2=0.25; P=0.39; Figure 4). While the three upper elevation sites contained relatively similar amounts of available gravel (53-227 m^2), they differed considerably in number of redds (48-408). Similarly, the two lower elevation sites contained relatively equal amounts of spawning gravel (7,524-8,244 m^2); however, the *Three Dams* reach contained over eight times the number of redds as compared to the *Lower Logan* reach. Brown trout used the highest percentage of available spawning gravel area in the *Wood Camp* (70%) and *Twin Bridges* (97%) reaches (Figure 5), and used relatively low percentages of available gravel in the other three reaches (1-11%).

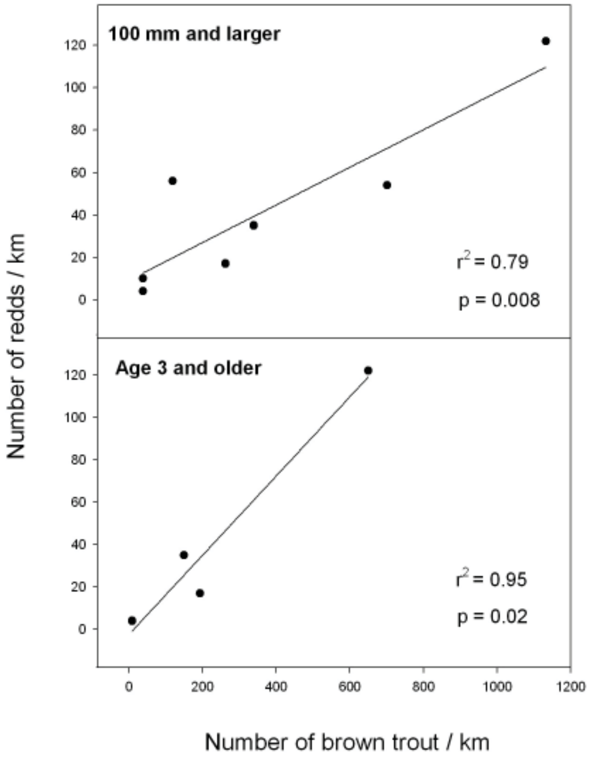

Figure 3. Relationship between the number of brown trout per kilometer, as estimated by electrofishing depletion surveys, as a function of the number of redds counted per kilometer in four main stem reaches and three tributary reaches in the Logan River, 2006. While the upper plot contains estimates of fish ≥ 100mm at all sites, the lower plot contains estimates of fish ≥ age 3 in the four main stem reaches.

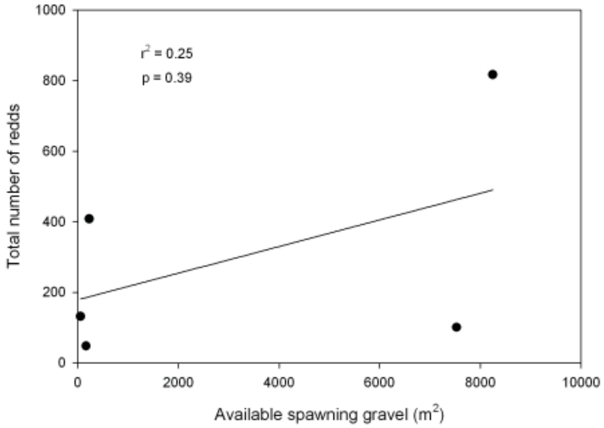

Figure 4. Relationship between available spawning gravel and total number of redds counted in the five main stem reaches of the Logan River, 2006.

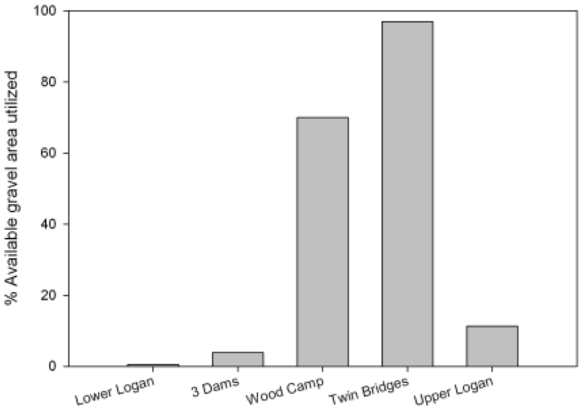

Figure 5. Percentage of available spawning gravel covered by redds in the five main stem sites in the Logan River, 2006.

Discussion

The onset of brown trout spawning was concurrent with decreasing day length, low flow, and average daily water temperature below 5°C. While the influence of day length is consistent with spawning timing elsewhere (Crisp 2000), the differences in spawning times of brown trout populations throughout North America do not appear to be consistently explained by differences in latitude, which then determines day length. Raleigh (1986) reports that the timing of brown trout spawning appears to be influenced by decreasing day length, increasing flow, or a drop in water temperature, all of which are usually concurrent. Our data suggest that the onset of brown trout spawning in the Logan River may be triggered by a combination of decreasing day length and decreasing water temperature, which occur during stable base-flow conditions in most years, but we do not have a good explanation of why spawning occurred later here than other North American brown trout populations in the literature.

Due to their potential to negatively affect native cutthroat trout populations, it is critical to better understand factors that limit the expansion of the brown trout population in the Logan River and elsewhere. Beard and Carline (1991) highlight the importance of available spawning habitat in determining the spatial distribution of brown trout populations. While we observed a strong correlation between number of adult brown trout and number of redds counted in the Logan River, we did not observe a significant relationship between amount of available spawning gravel and number of redds counted, suggesting that spawning gravel does not limit the brown trout population in the Logan River as a whole. However, we did document that areas with similar amounts of spawning habitat were used at very different intensities. In the *Wood Camp* and *Twin Bridges* reaches, brown trout used over 70% of the area of suitable spawning gravel we identified; the majority of the spawning habitat available in these reaches consisted of slow-water areas behind structures near the stream banks, which had trapped small patches of gravel during spring runoff. The extremely high percentage of spawning habitat used (up to 97%), suggests that available spawning habitat could be limiting the brown trout population in these reaches. In the other three reaches, spawning habitat use is much lower (1-11%), and the brown trout population is probably limited by other factors.

To our knowledge, this is one of only a few studies to date that used a complete census of spawning activity to examine factors limiting brown trout population distribution and abundance across a large and heterogeneous stream system (Beard and Carline 1991). Based on our observations, there is a need for further research into other factors that influence brown trout spawning, as well as factors that affect brown trout abundance at other life stages (e.g. egg-to-fry). Our results highlight the potential for using redd counts to monitor brown trout populations, as a potentially cost-effective and non-invasive alternative to other methods. Identifying differences in reproductive success among areas within a heterogeneous stream system furthers our understanding of factors limiting brown trout from expanding their distribution. Because competitive and predatory brown trout occupy much of the historic habitat of cutthroat trout, factors limiting brown trout have the potential to allow cutthroat trout populations to persist within this important meta-population in the Logan River, as well as elsewhere within their native range

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Wild Trout and Angler Expectations on the Henry's Fork

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Abstract

The Harriman State Park section of the Henry's Fork ("the Ranch") is legendary worldwide among anglers, few of whom understand that the legend was created in part by stocking. When catch rates recently declined, many of the river's devotees called for "enhancing" the wild trout fishery with stocked fish. The Ranch's management history is complex, from its origins as a native Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri* fishery through an era of heavy stocking to today's wild trout river, with water management playing a crucial role in the health of the fishery. Indeed, it was only in the last few years that the Ranch became a true wild trout fishery. The West's ongoing drought severely reduced the fishery, but now, even as the calls for stocking continue, enlightened water management has dramatically improved the wild trout population. The story of the Henry's Fork is an object lesson for wild trout advocates everywhere: a potentially prolific fishery limited not by its ability to produce trout, but by the management of its trout habitat, and the expectations of the angling public versus the reality of the ebb and flow of a wild trout population. If we cannot adhere to wild trout management on an iconic stream like the Henry's Fork, where can we?

The Henry's Fork of the Snake River in eastern Idaho is arguably the most famous trout stream in the world. At the heart of the Henry's Fork's fame is the 15-mi stretch of river from Island Park Dam downstream into the Box Canyon and thence through Harriman State Park, the legendary "Railroad Ranch" or (to its die-hard aficionados) simply "The Ranch." The river rose to international angling prominence in the 1970s on the strength of the smooth, broad, spring-creek waters of the Ranch and the extraordinary abundance of large, surface-feeding rainbow trout *Oncorhynchus mykiss* that they supported. In the early 21st century, however, the quality of the angling on the Ranch declined dramatically. Angler expectations had formed and solidified over 30 years, and many Ranch devotees – including erstwhile wild trout advocates – began to question openly the Idaho Department of Fish and Game's (IDFG) wild trout management policy, and to advocate stocking to "enhance" the fishery. To assess that idea, we must first examine the histories of both water and fishery management on the Ranch, and in that context address the question of whether or not stocking would, in fact, improve the fishery – or the fishing. Ultimately, though, the question that must be answered is informed by science and by history but transcends both: Is stocking the Ranch the right thing to do?

The Island Park Dam and reservoir complex were completed in 1939, creating a major irrigation storage facility and giving water managers the ability to control the timing and volume of flows into the Box Canyon and the Ranch below. For more than three decades a typical water management scenario was to close the dam gates in the autumn at the end of the irrigation season, storing virtually all inflow until the reservoir was full or nearly full before opening the gates to allow water to pass into the river belowThus, in 76% of the non-irrigation seasons (defined by the period November 1 through March 31) in the years between 1939 and 1972, flows below the dam were completely shut off for at least 30 d, and in 12% of those years this situation persisted for at least 90 d. Although the storage season was lengthened in 1972, this practice persisted intermittently into the early 1990s, and as recently as 2002 winter flows below the dam were often a mere 80-100 cfs for the duration of the storage season – approximately 25% of typical winter inflow to the reservoir.

These conditions make the maintenance of a wild trout fishery difficult, particularly given the fact that winter survival of juveniles is the critical limiting factor for the Henry's Fork's wild trout fishery. The 25-mi section of river flowing from Island Park Dam through Harriman State Park to Upper Mesa Falls was stocked regularly and heavily from the late 1950s until 1978, the year that the IDFG discontinued stocking and began to manage the river as a wild trout fishery. By that time, the Henry's Fork's only native trout, the Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri*, had been largely relegated to the fringes of the watershed, and rainbow trout had become the dominant species on the Ranch. The wild trout policy did not mean that this section of the river became a wild trout fishery overnight, however; a succession of reservoir drawdowns over the years flushed large numbers of stocked Island Park Reservoir rainbow trout into the river below the dam. It was not until 1994, when Island Park Dam was retrofitted for hydropower generation and the hydro facility's screened intake became the dam's primary outlet system, that the Ranch became a wild trout fishery in the full sense of the term.

In the late 1990s, drought conditions settled over eastern Idaho and much of the mountain West, and water managers responded by reducing winter flows to around 80 cfs below Island Park Dam – the minimum flow possible without shutting the gates completely – for several successive winters. By 2003 trout numbers in the Ranch had, according to anglers, declined to a point at which the quality of the recreational angling experience had become virtually unrecognizable when compared to its status only a few years earlier. The wide, relatively shallow and featureless character of the Ranch water makes accurate population sampling virtually impossible, but angler reports continued to be dire through the 2004 and 2005 seasons, while support for stocking grew.

Ironically, at this apparent nadir of the Ranch's fortunes, the seeds of the fishery's recovery had already been sown. In September, 2003, the Fremont-Madison Conveyance Act was passed by Congress, transferring certain Henry's Fork irrigation facilities from federal to local hands. A single line item, buried in the text of the legislation but the product of months of negotiations by the Henry's Fork Foundation and Trout Unlimited, ordered local stakeholders to initiate "a drought management planning process to address all water uses, including irrigation and the wild trout fishery." Not coincidentally, that winter flows below Island Park Dam from late December through the onset of the irrigation season in the spring hovered around 200 cfs, more than double the 80 cfs flows of previous drought winters. Flows of at least 180 cfs have been the norm for three subsequent winters, despite the fact that all but one of those winters were in years of below average precipitation.

The wild trout fishery below Island Park Dam has responded magnificently to the improved winter flows. In the spring of 2006, the IDFG conducted its annual population survey in the Box Canyon, immediately upstream of the Ranch. Their final estimate was 2,636 trout/mi – a 30% increase over the 2005 survey result and a 60% increase over 2003. In 2007, the Box Canyon estimate was greater than 3,700 trout/mi – more than double the 2003 estimate. The Box Canyon is generally assumed to drive fish numbers in the Ranch, and angler reports of fishing on the Ranch have been increasingly positive over the course of the summers of 2006 and 2007. The Ranch appears to be on the mend. Managing fishery habitat – in this case water – has been the key to improving the recreational fishery.

And yet, amid all of the positive signs, the stocking question persists. The fishing on the Ranch is still, by most accounts, a far cry from what it was in the 1970s and 1980s. Two unanswered, and for the moment unanswerable, questions remain about the fishery. First, the section of the Henry's Fork below Island Park Dam has only been managed as a true wild trout fishery, in conjunction with favorable habitat conditions, for a few years, raising the question of just how productive the river can or will prove to be when measured in trout-per-mile termsSecond, can the river, given the constraints placed upon it by irrigation-centered water management, ever reproduce the numbers of big trout that made the Ranch an angling household name 30 years ago?

There are a number of strong practical arguments against stocking the Ranch. For one thing, wild rainbow trout spawn with great success in the Box Canyon and, to a lesser extent, in the Ranch itself; there is no shortage of juvenile trout. If juvenile wild trout cannot survive low water conditions in the winter, there is no reason to suppose that stocked "put and grow" trout would fare any better. The alternative stocking strategy would be to plant large numbers of "catchable" adult trout into the Box Canyon and below, assuming that eventually sufficient numbers of these fish would hold over and grow to make an appreciable improvement to the quality of the recreational fishery on the Ranch. Given the poor long-term survival prospects of the average stocked rainbow trout, this process would almost certainly take many years to bear any fruit, and there is no reason to suppose that allowing the wild trout fishery to continue to expand (assuming favorable winter flows) will not achieve the same result in the same or less time. Stocking would have social ramifications as well; today's wild and strictly-regulated fishery would be tomorrow's hatchery-supported and, inevitably, harvest-oriented fishery.

Ultimately, however, the most important question is this: Should the focus of fisheries management on the Ranch be wildness or numbers? The core concept of wild trout management – that a trout population in a healthy stream should be able to sustain itself – is simple, readily and widely understood in the circles from which most Henry's Fork anglers are drawn, and beautifully illustrated by the last 4 years of water and fishery management below Island Park Dam. But an unspoken reality of that concept, that wild trout fisheries will ebb and flow with the changing fortunes of the larger natural systems of which they are a part, has thus far proven to be unpalatable to some elements of the Henry's Fork's angling public (although the Henry's Fork below Island Park Dam is clearly heavily influenced by human manipulation of flows, recent water management – as described above – has approximated natural flow regimes to a far greater extent than ever before in the post-dam construction era).

There are no ready solutions to this impasse, least of all stocking the Ranch and, in the words of one fisheries biologist, "turning the Ph.D of trout fisheries into the GED." That course of action would render nearly 25 years of conservation work by the Henry's Fork Foundation and other organizations and resource management agencies obsolete, for what reason is there to advocate and fight for enlightened water management and overall watershed health when the focus of so much of that work, the trout fishery, can be supplied artificially? The stocking "solution" embraces the notion that impacts can be mitigated, turning the focus of conservation away from core resource problems and challenges. This is a dangerous precedent, readily applied across the whole spectrum of watershed conservation, from planning and zoning to water quality to agriculture. At the moment, the health of the Henry's Fork's wild trout fishery is one of the most tangible natural assets that the watershed as a whole can boast, and the need to preserve that healthy fishery plays an extraordinarily important role in a broad and varied range of resource management decision-making.

It may be that the role of angling as a conduit to conservation is on the wane. If fishing's deep historical roots and its traditional emphasis on such notions as contemplation and patience are being replaced by latter day obsessions with speed and numbers, then fishing's path into the future will increasingly diverge from that of conservation. If that happens, wild trout, with the exception of a few isolated and legally-driven native trout cases, will cease to be relevant not only to angling, but also to the larger business of protecting and preserving the natural landscape. If we cannot make wild trout work on an iconic river like the Henry's Fork, where can we?

Acknowledgements

This is not a research paper, but the basic history and science of the Henry's Fork has been discovered and refined through years of endeavor by many researchers. I am grateful to each of them, and in particular to Dr. Rob Van Kirk of Idaho State University, who first brought many of these facts to light.

Comparative Effects of Rotenone and Antimycin on Macroinvertebrate Richness

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Abstract

As part of a Bonneville cutthroat trout *Oncorhynchus clarkii utah* reintroduction plan, Great Basin National Park used piscicides to eradicate nonnative trout from two streams prior to the reintroduction of native cutthroat trout. Rotenone was used to treat Strawberry Creek in 2000 and antimycin to treat Snake Creek in 2002. We sampled aquatic macroinvertebrate communities in each stream before and after treatments to document the effect of these piscicides on nontarget aquatic macroinvertebrate community richness and to determine when richness recovered to pretreatment levels. Rotenone devastated taxonomic richness in the short term, and it required 3 to 5 years for richness to recover to pretreatment levels. Antimycin had no effect on taxonomic richness and consequently, required no recovery time. Our data suggest that antimycin is superior to rotenone in maintenance of aquatic macroinvertebrate diversity during fish removal projects.

Introduction

As human populations grow and biodiversity declines, the maintenance and restoration of native biodiversity is increasingly important for land management agencies (Brown, 1995; Gehrt, 1996; Czech, 2000). The National Park Service (NPS) is unique among agencies in that the Organic Act of 1916 mandates that NPS units protect and preserve their resources “unimpaired for both present and future generations.” This is a difficult task due to the negative impacts of historical management actions on aquatic biodiversity. During the founding years of the NPS, there was little knowledge of ecological principles or ecosystem function, and managers manipulated fish populations for recreational angling. By 1935, the introduction of nonnative sport fish for recreational angling was a common practice in most national parksThis practice continued until 1968 when the NPS officially adopted a policy that eliminated stocking in NPS units By this time, nonnative fish species had already replaced many native species through competition and hybridization. In an effort to reverse these impacts, many parks implemented native fish restoration programs to remove nonnative fishes. National Parks are mandated to protect and preserve natural resources unimpaired; thus, a native fish restoration project cannot alter the structure of other components of the aquatic community. National Park Service managers wishing to restore native species must determine which technique will result in minimal impacts to nontarget organisms and preserve natural ecological processes.

Historically, fisheries managers have used the piscicides rotenone and antimycin (McClay, 2000; Finlayson et al., 2002) to eradicate nonnative fish. Both piscicides are effective, but may have undesirable impacts on aquatic macroinvertebrates, which are critical components of aquatic ecosystem functioning (Meyer et al., 1988; Barbour et al., 1999; Allan, 2007).

As part of the range-wide conservation plan for native Bonneville cutthroat trout *Oncorhynchus clarkii utah* and Great Basin National Park's Bonneville cutthroat trout (BCT) restoration plan, piscicides were used to eradicate nonnative trout from two park streams prior to reintroduction of BCT. Rotenone was used to treat Strawberry Creek and antimycin to treat Snake Creek. This resulted in an opportunity to compare the effects of the two piscicides on macroinvertebrate diversity within the same park.

In general, native fisheries restoration projects should prefer a piscicide, which eradicates nonnative fish and minimizes impacts to aquatic biodiversity. Currently this information is lacking. While the effects of rotenone and antimycin on macroinvertebrate diversity have been studied individually (Engstrom-Heg et al. 1978; Minckley and Mihalick 1981; Mangum and Madrigal 1999), a comparative analysis of the two piscicides within a statistical framework, using both treated and untreated sites, has not been completed, to our knowledge. To meet NPS policy and provide science-based information to the fisheries community, we examined the impacts of rotenone and antimycin on macroinvertebrate taxonomic richness and composition.

We address two questions:

1. How do rotenone and antimycin affect macroinvertebrate taxonomic richness?
2. When does taxonomic richness recover following rotenone and antimycin application?

Methods

Study Area

Great Basin National Park (GRBA) is located in eastern Nevada (Figure 1) in the Central Basin and Range ecoregion (Omernik, 1987). Elevations range from 1,585 m in Snake Valley to 3,982 m at the summit of Wheeler Peak. Most precipitation falls as snow with stream flows primarily resulting from snowmelt.

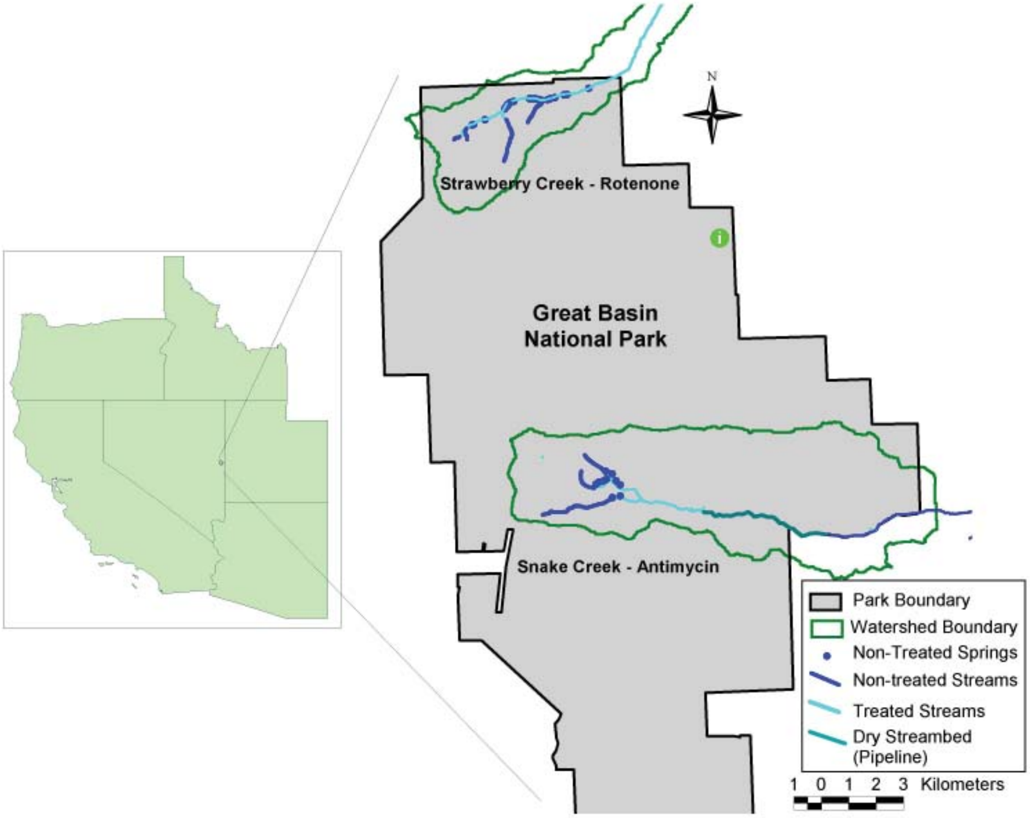

Figure 1. Great Basin National Park rotenone and antimycin treatment sites.

Piscicide Treatments

Rotenone – We treated 11.9 km of Strawberry Creek with rotenone (Prentox PrenFish Toxicant) to remove rainbow trout *Oncorhynchus mykiss*, brook trout *Salvelinus fontinalis*, and hybridized BCT. Treatment protocols followed standard Nevada Department of Wildlife operating procedures for rotenone treatments. We dispensed 125 liters (33 gallons) of 5% rotenone and 10.9 kg (24 lbs.) of 8.5% rotenone dry powdered toxicant on September 12 and 13, 2000. In-stream concentration from drip stations over the 2 d treatment was 5 mg/l the first hour and 2 mg/l for 7 h each day. The rotenone dry powder was mixed with sand and gelatin with handfuls deposited in rivulets that fed the main channel from seeps and springs. Larger rivulets, where sand eroded away quickly, were treated with backpack sprayers.

Antimycin – We treated 7.6 km of Snake Creek with antimycin (Fintrol) to remove brook trout. Treatment protocols followed Great Smoky Mountains National Park standard operating procedures for antimycin treatments. Four liters (1.1 gallons) of Fintrol was dispensed into Snake Creek from drip stations on August 5-10, 2002. In-stream concentrations of antimycin averaged 8 µg/l. Back eddies of the stream and adjacent springs and seeps were treated with Fintrol using backpack sprayersAreas sprayed corresponded to the treated reach for that day and the amount of antimycin used for these areas was 10% of the total used for that day.

Fishless headwater portions of streams and adjacent springs were not treated with piscicides. Basic water quality parameters for both streams are presented in Table 1.

Sampling

Macroinvertebrates were sampled pre- and posttreatment using a kicknet following the Environmental Protection Agency Rapid Bioassessment of Creeks and Small Rivers multi-habitat qualitative survey protocols (Barbour *et al.*, 1999). Collections were placed in a pan and all visible specimens were handpicked over a one-person hour time constraint and placed in a 50-ml bottle with 95% ethanol.

The National Aquatic Monitoring Center, Logan, Utah, identified all specimens to a standard taxonomic level. This level varied according to taxonomic group. For example, trichopterans were identified to species while turbellarians were identified to class. A standardized identification level allowed direct comparisons to be made over the course of the project and ensured that differences in diversity were not due to changes in identification level (http://www1.usu.edu/buglab/process/results.htm). All samples and data are archived and available from the National Aquatic Monitoring Center.

Short-term recovery - We compared the short-term effects of rotenone and antimycin (up to 1-year posttreatment) on taxonomic richness using four treated and two untreated sites per piscicide. All sites were sampled approximately at the following intervals relative to piscicide treatment: 1-year pre-, 1-day pre-, 2-week post-, 1-month post-, 9-month post-, and 1-year posttreatment. For analysis, treated and untreated sites were combined by piscicide type for each time interval.

Longer term recovery - Only two treated sites and no untreated sites were available to monitor the

Table 1. Basic water quality parameters for treated streamsAverage June measurements (Great Basin National Park, unpublished data).

	temp (°C)	pH	DO (mg/L)	Specific Conductance (µg/cm)	Flow (m^3/s)	Piscicide
Strawberry Creek	9.4	8.0	8.4	75	0.09	Rotenone
Snake Creek	9.5	8.0	9.5	76	0.44	Antimycin

longer-term recovery of the rotenone treatment (>1-year posttreatment). Samples were collected from treated sites at the following intervals relative to rotenone treatment: 1.2-years pre-, 1-year pre-, 1-day pre-, 1-day post- 2-weeks post-, 1-month post-, 8-months post-, 9-months post-, 10- months post-, 11-months post-, 1-year post-, 3-years post-, and 5-years posttreatment. No samples were collected to monitor the antimycin treatment after 1-year posttreatment. For analysis, treated and untreated sites were combined for each time interval.

Data Analysis

Due to the variable level of taxonomic resolution (i.e. some taxa identified to species while others to family), we used taxonomic rather than species richness as the response variable. Richness generally increases with increasing numbers of individuals collected, presenting a difficulty in directly comparing richness between samples. Rarefaction provides a solution to this problem. Data are re-sampled by a common number of individuals across samples to allow direct comparisons of richness (Gotelli and Entsminger, 2006). Rarefied samples are generated in a probabilistic manner and more abundant taxa are more likely to be re-sampled than less abundant taxa. Probabilistic re-sampling eliminates the need to arbitrarily remove “rare” taxa from datasets and allows the incorporation of all sample information into hypothesis testing.

We used the Species Diversity option in the program EcoSim to re-sample 1,000 times and generated rarefied mean richness and 95% confidence intervals. We report statistically significant differences when 95% confidence intervals do not overlap ($p \leq 0.05$; Keller 2001).

Untreated sites served as reference sites to allow cautious inference of causation of the effects of piscicides. Changes in treated sites without changes in untreated sites suggest piscicide effect. Our study design was unable to compare treated and untreated site richness directly, because of differences in sampling intensity and stream order between sites. Only two untreated sites were sampled per piscicide treatment and these sites were located in 1st order headwater streams. In contrast four treated sites were sampled per treatment and these sites were located in 2nd and 3rd order streams.

Results

Piscicide Treatments

Both piscicide treatments accomplished their primary management objective: eradication of nonnative trout and BCT have been subsequently reintroduced.

Piscicide Effects on Taxonomic Richness

Rotenone Treatment

Taxonomic richness of treated sites was significantly reduced posttreatment and had not recovered to pretreatment levels at 1-year posttreatment. Untreated sites did not differ significantly from pretreatment levels, with the exception that 1-month posttreatment was significantly lower than 1-day pretreatment, by a single taxon (Figure 2).

Antimycin Treatment

Taxonomic richness of treated and untreated sites was not significantly reduced following the antimycin treatment (Figure 3).

Longer Term Recovery of Taxonomic Richness

Rotenone

Following the rotenone treatment at 1-year and 3-years posttreatment, taxonomic richness had not recovered to pretreatment levels. Richness recovered to pretreatment levels between 3 and 5-years posttreatment (Figure 4).

Antimycin

Antimycin had no effect on taxonomic richness (Figure 3) and no recovery period was required.

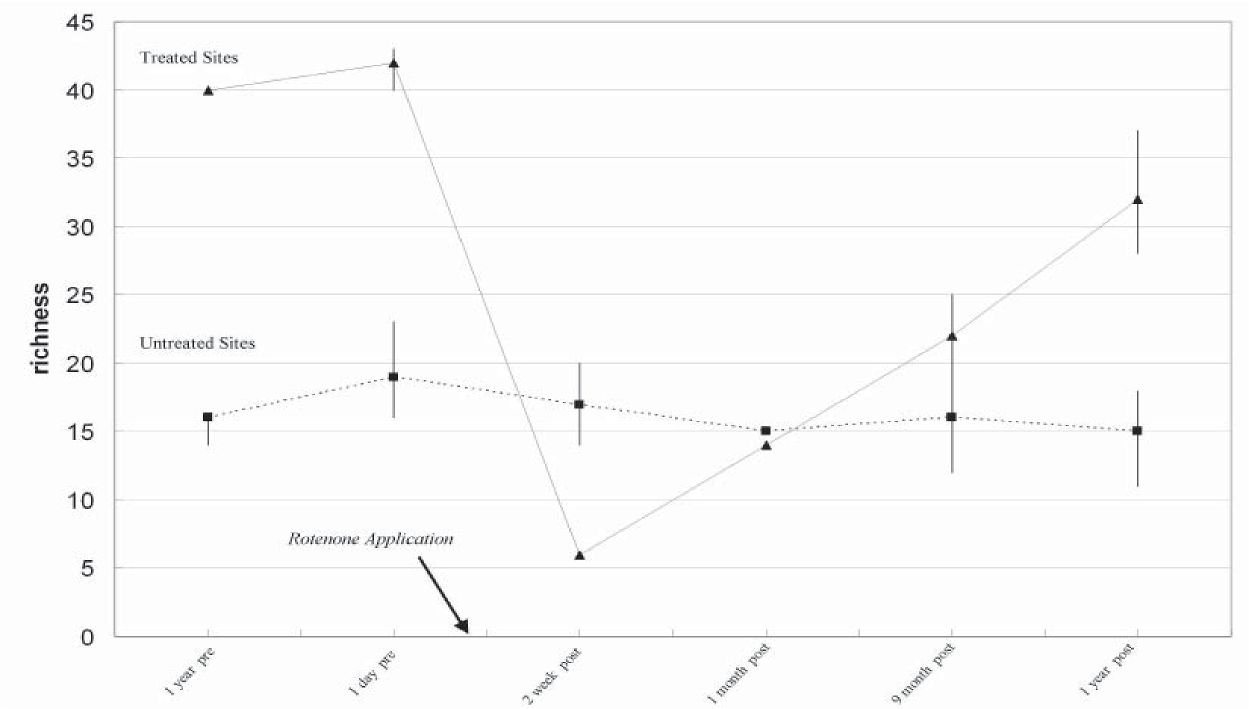

Figure 2. Effects of rotenone on macroinvertebrate richness. Data represent rarefied mean richness and 95% CI. P< 0.05 when CI do not overlap. Treated sites (n=4) were rarified by 236 individuals and untreated sites (n=2) by 50 individuals. Symbols without CI bars were not rarefied because of low numbers of individuals collected.

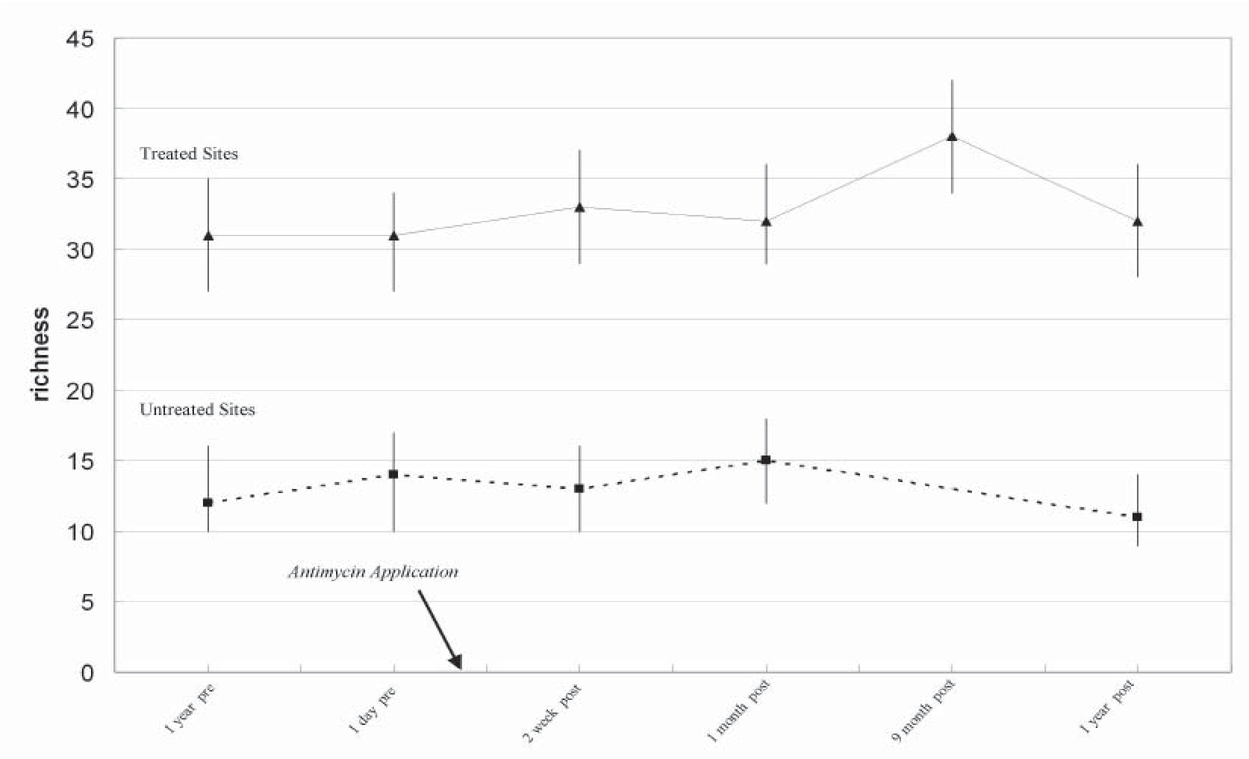

Figure 3. Effects of antimycin on macroinvertebrate richness. Data represent rarefied mean richness and 95% CI. *P*< 0.05 when CI do not overlap. Treated sites (n=4) were rarified by 236 individuals and untreated sites (n=2) by 50 individuals. No samples were collected at 9 month posttreatment for untreated sites.

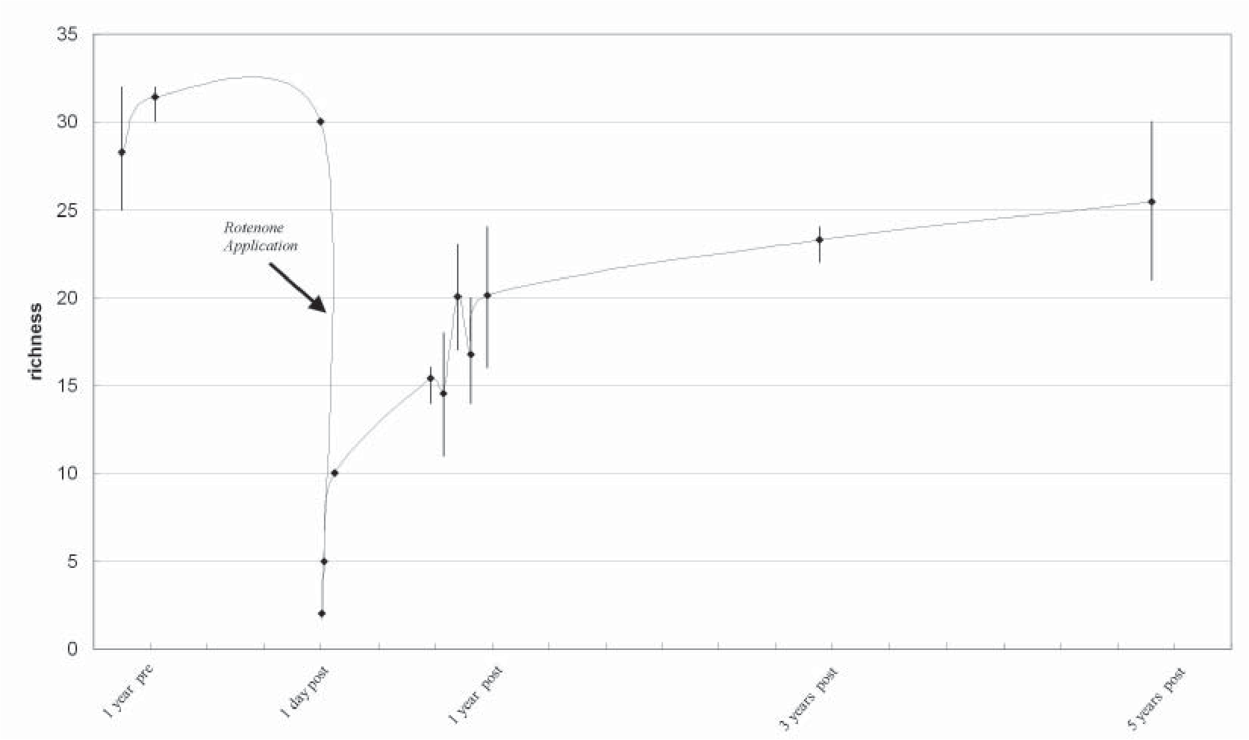

Figure 4. Longer term recovery of richness after rotenone treatment. Data represent rarefied mean richness and 95% CI. P< 0.05 when CI do not overlap. Treated sites (n=2) were rarified by 109 individuals. Symbols without CI bars were not rarefied because of low numbers of individuals collected.

Discussion

Our data provide a statistical comparison of the effects of rotenone and antimycin on macroinvertebrate diversity. Although unreplicated and non-experimental, our use of untreated reference sites upstream from treated sites allows for cautious inference of causation. For the short-term comparison, untreated sites did not differ significantly in taxonomic richness for either piscicide, with the exception of rotenone at 1-day pre- and 1-month posttreatment, which differed by a single taxonomic group. We suggest that a single difference in the untreated sites by one group is not representative of a trend of decreasing richness in the untreated sites and does not weaken the value of the untreated sites as references.

In the short term, rotenone devastated richness, while antimycin had no effect. Because antimycin did not affect posttreatment taxonomic richness, no recovery was required. In contrast, rotenone-treated sites required several years to recover. Although full recovery did not occur until 3 to 5-years posttreatment, the major catastrophic effects on richness occurred immediately following the treatment and recovery initially progressed rapidly, and then leveled off. One and 3-year posttreatment samples differed from pretreatment samples by a single taxonomic group. Although these differences were statistically significant, their biological significance is open to debate.

We urge some caution in the interpretation of longer-term recovery of rotenone because only two treated sites and no untreated sites were included, in contrast with the four treated and two untreated sites in the shorter term comparisons. In spite of this reduced sample size, the longer-term recovery trend approximated the shorter-term trend, which provided further support of the data. Additionally, macroinvertebrate diversity fluctuates over time in response to natural and anthropogenic drivers (Boulton *et al.*, 1992; Closs and Lake, 1994; Hutchens *et al.*, 1998; Fritz *et al.*, 1999; Lake, 2000), indicating that differences in richness may not be exclusively attributable to piscicide treatment. As time from treatment increases, it is increasingly likely that macroinvertebrate community response to treatment effects is confounded by other factors, such as drought or nutrient inputs.

Native fisheries restoration projects by definition value biodiversity. The controversial nature of piscicides and the critical role of macroinvertebrates in aquatic systems dictate careful piscicide choice. Currently the fisheries restoration literature is equivocal regarding the question of which piscicide has the least effect on macroinvertebrate diversity. This study provided a comparative analysis of rotenone and antimycin in a statistical framework using both treated and untreated sites. Our data indicate that the effects of antimycin on macroinvertebrate diversity are minimal relative to rotenone.

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The Impacts of the Nuisance Alga *Didymosphenia geminata* on Trout

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Abstract

The diatom *Didymosphenia geminata* is emerging as an organism with an extraordinary capacity to impact stream ecosystems on a global scale. In recent years, streams in New Zealand, North America, Europe, and Asia have been colonized by masses of *D. geminata*, and its extracellular stalk growth. This freshwater diatom is able to dominate stream surfaces by covering up to 100% substrate with thickness greater than 20 cm, thereby altering physical and biological conditions within streams. This species is expanding its geographic range in North America, and the rates that nuisance blooms are reported by the public and local media are increasing. Ecological impacts to fisheries populations have been suggested through studies on macroinvertebrate drift, shifts in macroinvertebrate communities, and changes in trout age-class structure. While there is no question that this diatom can blanket streambeds and colonize new habitats rapidly, the outcome of these invasions is not well documented or understood. Several studies are underway that examine the impacts of *D. geminata* upon fisheries, macroinvertebrates, and methods to manage the occurrence. Two case studies will examine the history, impact to fisheries, and the management actions taken in response to specific occurrences.

Introduction

The diatom *Didymosphenia geminata* is emerging as an organism with an extraordinary capacity to impact stream ecosystems on a global scale. This freshwater diatom is able to dominate stream surfaces by covering up to 100% of substrate with thicknesses greater than 20 cm, altering physical and biological conditions within streams (Figure 1).

Figure 1. Thick growth *of Didymosphenia geminata* covers a rock. The extracellular stalks secreted by individual diatom cells create the visual matsImage by South Dakota Game, Fish and Parks.

Didymosphenia geminata, often associated with high elevation, nutrient poor waters, was historically rare in algal assemblages. Historical descriptions of physical parameters of *D. geminata* by diatomists include oligotrophic habitats, low water temperature, and broad range of water conductance (Stoddard et al. 2005). Recent expansion of range and distribution has broadened these physical parameters (Table 1). Diatoms are silica-based cells with a raphe that allows for the cells to move along surfaces. At the end of each cell is an apical porefield from which a mucopolysaccaride stalk is secreted. A stalk allows attachment to rocks, plants, or other submerged substrate. Massive amounts of stalks create the

Table 1. Summary of physicochemical parameters of *Didymosphenia geminata* for distribution and growth.

Physical Parameter	Range value	Median Value
Water temperature (°C)	4 - 27	10
pH	At or above 7	7
Conductance (µmho/cm)	0 - 650	40
Phosphorus (µg/l)	0 - 38	>2
Nitrate (mg/l)	0 - 9	>1

visual appearance and negative impacts associated with *D. geminata* blooms. Stalks are resistance to biodegradation by bacteria and fungi.

Over a century ago, early records of *D. geminata* characterized the distribution as common in Scotland, Sweden, Finland, and China and were noted by periodic blooms (Cleve 1894-1896). The earliest records of *D. geminata* in North America are on Vancouver Island, British Columbia (Cleve 1894 -1896). More recently, the distribution and growth habits have expanded. In recent years, streams in New Zealand, North America, Europe, and Asia have been colonized by masses of "didymo" and its extracellular stalk growth. In North America, the distribution of both nuisance and non-nuisance occurrences of *D. geminata* have been widespread and most recently in nutrient-rich habitats (Figure 2). Although *D. geminata* can be found in both flowing water and lakes, nuisance blooms have occurred primarily in rivers and streams.

The large amounts of non-nutritious stalks that characterize blooms attached to stream substrate are predicted to have negative impacts upon fish populations. Thus, fish that use benthic habitats, consume benthic prey, or use substrate for spawning may be most impacted. Benthic macroinvertebrates may also be negatively affected by the thick growth of *D. geminata*. Changes to macroinvertebrate quantities or communities that provide important food sources may impact fish populations.

Several studies are underway to understand the impacts that this species may have upon fisheries, and macroinvertebrates. Two case studies will examine the history, impacts to fisheries and the management actions taken in response to specific occurrences.

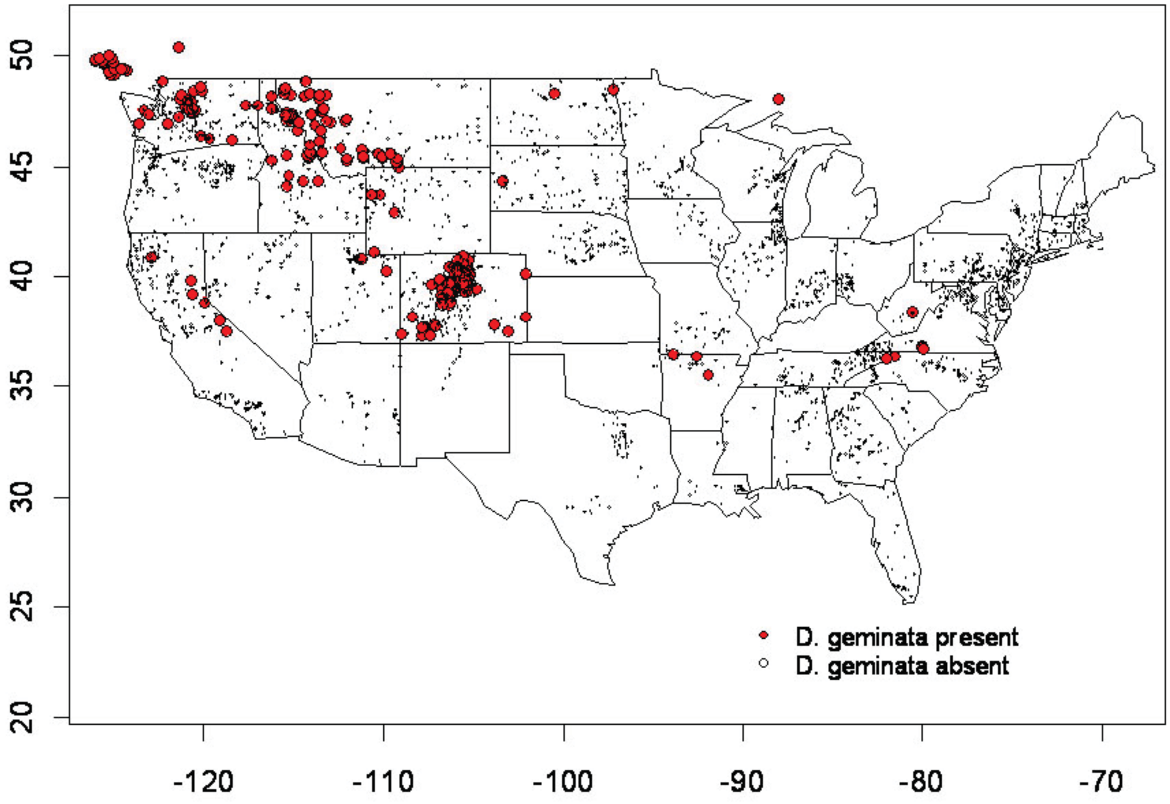

Figure 2. Confirmed presence and absence record of *D. geminata* in the United States as of August 2006A total of 4569 samples were included and *D. geminata* is present in 283 sitesRecords are based on data from USGS National Water Quality Assessment (NAWQA), EPA Environmental Monitoring and Assessment (EMAP), and samples from other studiesMap by Sarah Spaulding, US Geological Survey.

CASE STUDY 1: RAPID CREEK, SOUTH DAKOTA

Rapid Creek is located in the southwest corner of South Dakota, USA, in the Black Hills. The average width of the stream is 6 to 10 m. Pactola Dam controls water flow and creates water storage within Rapid Creek. Pactola Reservoir is oligotrophic, nutrient limited due to an upstream bog, and water is release from the bottom of the reservoir. The tailrace waters below the reservoir are a controlled flow of cold, clean waters with limited nutrients. Rapid Creek has been historically recognized as a highly productive brown trout fishery. Surveys of streams throughout the western U.S. estimated the mean total biomass of salmonids per unit area for wadeable streams. The mean total biomass of salmonids in Rapid Creek was an estimated 25 g·m^{-2} (South Dakota Fish, Game and Parks, unpublished data 1999) compared to the average of 11 other productive western streams of 5.4 g·m^{-2} (Platts et al.1988). South Dakota Fish Game and Parks have been collecting fisheries distribution and productivity data from Rapid Creek for 20 years. In 2002, *D. geminata* was discovered in Rapid Creek for approximately 15 km and beginning below Pactola Dam with patchiness of 20% to 100% coverage of stream substrate (Jeff Shearer, South Dakota Fish, Game and Parks, personal communication).

Impacts to Fisheries

Concurrent with the discovery and growth of *D. geminata* in Rapid Creek was the decline in the brown trout *Salmo trutta* population (Figure 3). A distinct bottleneck in age class was observed with abundant juvenile (young of the year and age-1) fish and very few adult (>200mm long) fish. Additional stress on trout populations may also include an extended drought throughout the western U.S. with lower flows and higher temperatures in streams. Three-pass electrofishing in 100-m sections was used to estimate population size both before and after *D. geminata* was discovered in Rapid Creek. Prior to 2002, the estimated number of adult brown trout (>200 mm) ranged from 50 to 120 fish .100 m^{-1}. From 2002 to 2006, the estimated number of adult brown trout (>200 mm) ranged from 5 to 20 fish .100 m^{-1} (Figure 3).

Management Response

In 2005, South Dakota Fish, Game and Parks began to stock catchable-size rainbow trout *Oncorhynchus mykiss* to provide recreational angling opportunities and mitigate the loss of catchable brown trout. Additionally, two research projects are underway. To mitigate loss of brown trout, a nutrient enrichment experiment by SD Fish Game and Parks and SD Department

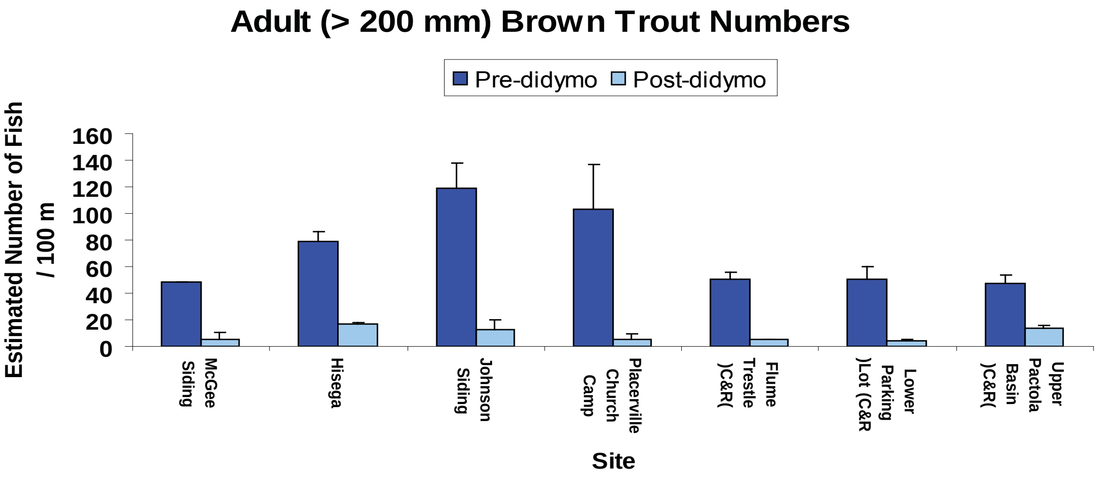

Figure 3. Population depletion estimate of brown trout >200 mm·100 m^{-1} using 3-pass electrofishing in sections of Rapid Creek, South Dakota. Image from South Dakota Fish, Game and Parks

of Environment and Natural Resources in conjunction with South Dakota State University began in 2007. To stimulate primary productivity and potentially increase algal community diversity and increase young-of-the-year survival, nutrients in the form of slow-release fertilizer were added to Rapid Creek in burlap sacks and observation tiles were places on the stream bottom. A potential outcome of the nutrient enrichment may alter *D. geminata* growth with changes in the algae community composition and diversity. Water quality parameters, macroinvertebrate samples, and fish biomass estimates will also be collected throughout the study (John Carreiro SD Fish, Game and Parks, personal communication). A study that examines the potential effects of *D. geminata* blooms on the bioenergetics of brown trout is also underway. Examining trout foraging ecology and modeling bioenergetics of trout in a *D. geminata*-rich area may improve our understanding of interactions among trout, macroinvertebrates, and *D. geminata*.

CASE STUDY 2: SOUTH ISLAND, NEW ZEALAND

The South Island of New Zealand is rural country with few people. Prior to 2004, *D. geminata* had not been documented in New Zealand, or any other location in the Southern Hemisphere. In early October 2004, *D. geminata* was confirmed in the lower Waiau River of the South Island of New Zealand (Kilroy 2004). Within 2 years it was found in more than 15 rivers across the South Island. It is now found in over 50 rivers and 5 lakes of New Zealand. It has not yet been detected in the North Island, and there had been broad education efforts to prevent the spread within New Zealand and to the North Island. Many dramatic blooms of *D. geminata* have been observed in waters that are relatively free from development, pollution and human influence, with some waters being dam regulated. There is widespread agreement that *D. geminata* was introduced by humans, such as water recreation users. Following the discovery of *D. geminata* in New Zealand, the authoritative agency, Biosecurity, began a formal invasive species incursion response of containment and irradiation. A rigorous program of research and public education including impacts to macroinvertebrates and fisheries, disinfection techniques, and molecular analysis of *D. geminata* populations were initiated.

The recent study by New Zealand's University of Waikato has developed a new genetic testing tool that will aid in early detection of *D. geminata* and help characterize populations of *D. geminata* with molecular markers (Cary et al. 2006). Preliminary examination of DNA from populations of *D. geminata* from North America, New Zealand, and Europe suggests that *D. geminata* populations from North America and New Zealand are more closely related to each other than to other populations (Cary et al. 2006).

Impacts to Fisheries

In areas where *D. geminata* blooms have been most visual, trout populations were examined. Early data collected by New Zealand Fish and Game suggest that in areas where growth of *D. geminata* is high, fewer fish are found; whereas where growth of *D. geminata* is low, similar numbers of trout are found compared to surveys prior to *D. geminata* discovery. Snorkel survey of the number of trout >20 $cm \cdot km^{-1}$ have been conducted in various streams prior to and following the discovery of *D. geminata*. One tributary to the Waiau River, Excelsior Creek, showed a decline in the number of rainbow trout and brown trout >20 $cm \cdot km^{-1}$ after the introduction of *D. geminata* (M. Rodway New Zealand Fish and Game, Personal Communication) (Figure 4). Annual surveys of fish populations in both *D. geminata* and non-*D. geminata* rivers will continue.

Earlier examination of macroinvertebrate communities in the White River, Arkansas, and in New Zealand rivers suggested dramatic shifts in macroinvertebrates community structure and loss of diversity of macroinvertebrates (Kilroy et al. 2006, Learner 2006). A recent study examined macroinvertebrate drift dynamics and modeled the potential impacts of *D. geminata* upon fisheries. In areas with high *D. geminata* growth, the number of chironomids and smaller mayflies increased; whereas in areas of low or no *D. geminata* growth

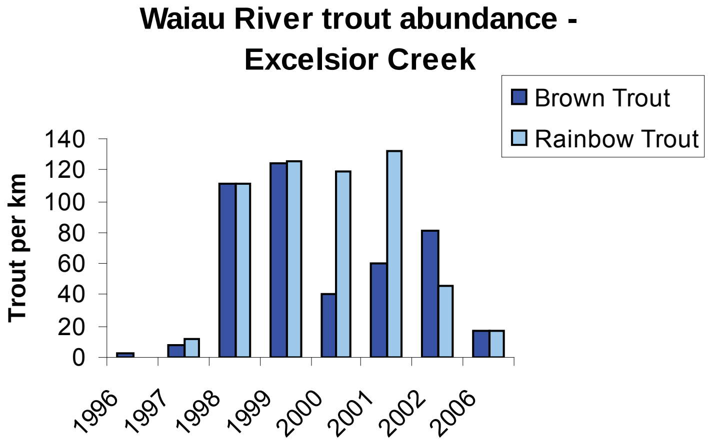

Figure 4. Number of trout greater than 20 cm per 100 km in the Waiau River tributary, Excelsior Creek, New Zealand. *Didymosphenia geminata* was discovered in 2004. Image by New Zealand Fish and Game

the greatest proportion of large macroinvertebrates such as stoneflies, a favored trout food, was found (Shearer et al 2007). However, this study also suggests that population-level impacts upon fisheries were not detected in areas with moderate growth of *D. geminata* (Shearer et al. 2007). Results of the study suggest that suggest further examination of macroinvertebrates, *D. geminata* and trout dynamics by examining additional sites and during additional seasons are necessary (Shearer et al. 2007).

Management Response

New Zealand has taken a very proactive response to the discovery of *D. geminata* since 2004. Over US$4.5 million dollars has been spent on research and another $5 million on an outreach campaign. The successful outreach campaign resulted in over 90% of New Zealand population recognizing *D. geminata* and proper cleaning techniques.

The discovery of *D. geminata* prompted a large-scale incursion by Biosecurity New Zealand in an attempt to minimize the spread of the diatom. At least eleven separate research studies have examined the distribution, control, and ecological impacts within New Zealand Rivers. Three years following the discovery, Biosecurity is finalizing their incursion response and future actions will be in a management and monitoring capacity conducted by New Zealand Fish and Game. *Didymosphenia geminata* has not yet been detected in the North Island of New Zealand; however an incursion response by Biosecurity will take place, if invasion occurs in the future.

Generalizations

Didymosphenia geminata has spread to new locations and expanded its historic range dramatically in the last 5 years. Often when *D. geminata* is first detected in a new location, this river is frequently is a popular angling destination

Figure 5. Example information flyer on *Didymosphenia geminata* for international distribution used in outreach and educational efforts.

(i.e. Waiau River, New Zealand, Rapid Creek South Dakota, White River Arkansas, or Batten Kill Vermont). Certainly the aesthetic impact of *D. geminata* on recreation activities, such as angling and swimming, has a dramatic effect on recreation satisfaction. Conversely, the ecological impact of *D. geminata* algae blooms upon fish populations is not well understood. Long-term observation and data collection will be necessary to understand the effects of this exotic species on native fauna.

The invasion of other exotic species may serve as a model for long-term research required to understand complex community interaction of invasive species. For example, one of the most studied invasive organisms *Myxobolus cerebralis* (the parasite that causes whirling disease in trout) caused dramatic declines in trout populations in western U.S. Despite decades of research on the biology and epidemiology, M. cerebralis studies to understand ecological interactions are only now being thoroughly addressed. Another invader, *Dreissena polymorpha*, the zebra mussel, continues to impact vegetation, water quality and fauna throughout the U.S. Introduced in late 1980s to the Great Lakes and Hudson River via international trade traffic, *D. polymorpha* reached huge densities and blanketed aquatic substrate. Zebra mussels have caused huge economic impacts by clogging pipes that transport water to cities and factories; attaching to ship hulls, and marine structures; and covering recreation beaches with mussel shells. The biological impacts of *D. polymorpha* suggest that high densities of filter-feeding mussels increased water clarity, created shifts in fish assemblages, decreases in primary productivity and increases in zooplankton (Karatayev et al. 1997). The complex interactions among invasive species and the native organisms are often difficult to detect and the duration of observed interactions is important is important to consider.

Recommendations

The advent of dramatic blooms of *D. geminata* has generated extensive discussion about a once rare diatom. A host of poorly understood basic biological characteristics, ecological conditions and impacts, and social aspects of transport have been identified. The following are some of the recommendations developed in response to the changing behavior of *D. geminata* (Spaulding and Elwell 2006): (1) determine ecological conditions under which excessive biomass is produced in low nutrient stream and rivers over a short period of time, (2) determine the unique stalk structure, signal, and regulatory pathways of stalk production, (3) determine habitat use of fish in areas affected by *D. geminata*, (4) adequately assess condition of fish in *D. geminata* and non-*D. geminata* waters, and (5) determine the role of angler habits and river closures on *D. geminata* and fisheries interactions. Further study is necessary to understand the interactions among *D. geminata,* native algal communities, macroinvertebrates, and fish.

The need for broad outreach campaigns that address invasive species and engage anglers and river users are critical for protecting our natural resources. A recent program called the Clean Angling Pledge was developed to engage individuals in the issue of invasive species (www.cleanangling.org). Additional studies that determine the most effective outreach methods to communicate with river users and effectively engage those users are recommended.

Acknowledgements

Many thanks to Sarah Spaulding with the U.S. Geological Survey and U.S. Environmental Protection Agency for providing feedback and data on *D. geminata* occurrence distribution; A gracious thank you to South Dakota Parks, Fish and Game, South Dakota Department of Environment and Natural Resources, Arkansas Department of Natural Resources, Biosecurity New Zealand and New Zealand Fish and Game for information and unpublished data.

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Movement of Sediment by Anglers and the Implications for Transporting Aquatic Nuisance Species

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Abstract

Movement of anglers among rivers presents a potential network for the spread of whirling disease *Myxobolus cerebralis* and other aquatic nuisance species (ANS). The objective of this study was to quantify the movement of anglers and the quantity of sediment they carry on angling equipment. High-use fishing access sites were randomly selected for surveying on six rivers in southwestern Montana. Survey questions focused on dates and locations of angling trips in the past 30 d, equipment cleaning practices, and aquatic nuisance species awareness. In addition to the questionnaire, sediment samples were collected from boots and waders with a pressure sprayer. Median number of fishing access sites used during the previous 30 d by resident and non-resident anglers was three. Non-residents fished in more states in the previous 30 d than residents and traveled farther distances to fish in the previous 30 d than residents. Mean quantity of sediment carried on one boot-wader leg was 8.39 g (± 1.5, 95% CI). Integration of angler movement patterns, angler numbers, and mean quantities of transported sediment suggests that anglers in southwestern Montana are potentially moving tons of sediment among fishing access sites every year, thereby making transport of ANS highly likely.

Introduction

Falling under the names alien, nonnative, and exotic, invasive species have captured attention around the world as a major force in ecosystem degradation (Sala et al. 2000). The impetus for our research developed from the following observations: preliminary research conducted by Montana Fish, Wildlife and Parks indicated that anglers in southwestern Montana were highly mobile, anglers are in contact with benthic sediment, and some aquatic nuisance species (ANS) are resilient, tolerant of environmental stresses, and are deposited in benthic sediment. Anglers have been documented transporting species such as New Zealand mud snails (NZMS) in other areas of the country. This led us to question ‘are anglers in southwestern Montana unknowingly transporting ANS?’

Whirling disease *Myxobolus cerebralis* presents a good example of an ANS that could potentially be transported by anglers. *Myxobolus cerebralis* is a two-host metazoan parasite that alternates between an oligochaete worm host and a salmonid fish host in a presporogonic and sporogonic myxospore stage, respectively (Brinkhurst 1996). The myxospore stage is highly resistant to environmental stresses such as freezing, exposure to low pH, digestion by fish-eating birds and fish, and desiccation (Hoffman and Markiw 1977; Wolf and Markiw 1982; El-Matbouli and Hoffman 1991; El-Matbouli et al. 1992; Hedrick et al. 1998; Kerans and Zale 2002). These resilient features of the myxospore stage make it likely that it will persist in an environment and make the inadvertent transport of viable myxospores by humans among water bodies feasible.

The incidental transfer of *M. cerebralis* and other ANS among drainages by anglers is poorly understood. The objectives of this project were to identify the movement patterns and profile of anglers in southwestern Montana, assess angler knowledge of ANS and preventative cleaning practices, and to quantify the amount of sediment carried by anglers on boots and waders.

Methods

Anglers were surveyed at access sites on the Beaverhead, Bighorn, Gallatin, Madison, Missouri, and Yellowstone rivers in October of 2004 and between June and August of 2005 and 2006. Survey questions focused on dates and locations of fishing trips in the previous 30 d, planned fishing trips in the coming week, and their cleaning practices for angling equipment. In addition, sediment samples were taken from boots and waders with a hand-held pressure sprayer and a mild detergent (sodium hexametaphosphate). Each boot was rinsed for 30 s at 2.11 kg/cm^2 (30 psi). One of the two boot samples taken from each angler was dried in an oven and weighed to determine the amount of sediment carried by anglers. The other boot sample was frozen and assayed for the presence of *M. cerebralis* myxospore DNA with polymerase chain reaction testing (PCR).

Results

Forty percent of the surveyed anglers were Montana residents, whereas 60% where non-residents (n = 487). Mean distance traveled by Montana residents from their home was 115 km (± 17, 95% CI) and mean distance traveled by non-residents was 1,738 km (± 74, 95% CI). Median number of drainages in which they fished during the past 30 d by resident and non-resident anglers was 2. Number of fishing access sites used in previous 30 d varied from 0 to 12 (Figure 1). Distance traveled to fish 30 d prior to the survey also differed significantly between residents and non-residents ($t_{289} = 7.44$, $P = < 0.0001$) (Figure 2).

Fifty-one percent of Montana residents and 49% of non-residents reported occasionally, rarely, or never cleaning their boots and waders in between uses. Mean quantity of soil carried on one boot-leg was 8.39 g (± 1.50, 95% CI).

Integrating angler movement data, cleaning practices, and sediment quantity carried with fishing license sales data from the six counties where surveys were conducted provides an estimate of the potential soil carried by anglers in southwestern Montana. The result is approximately 2,866 kg of dry soil being moved by resident and non-resident anglers every 30 d during the summer months in southwestern Montana.

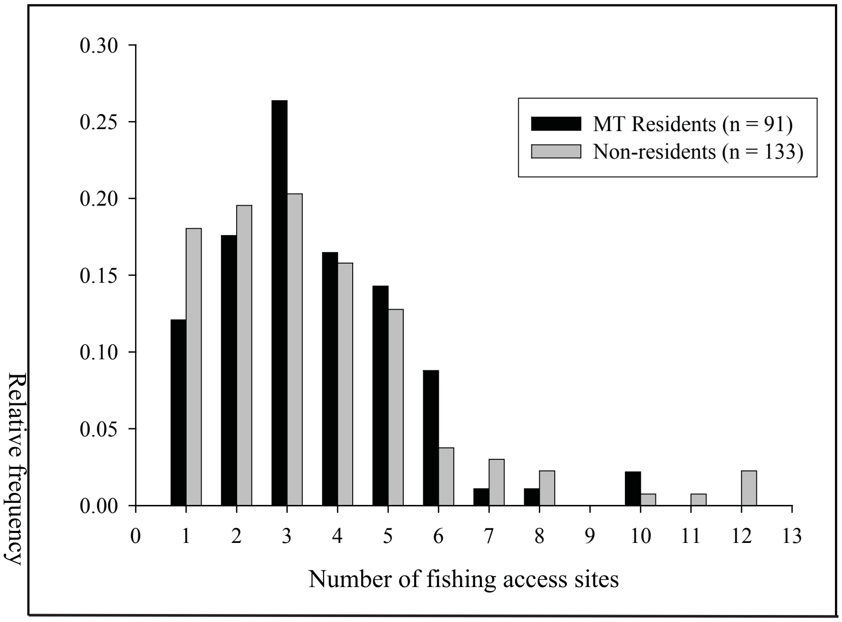

Figure 1. Relative frequency of number of fishing access sites used by Montana resident and non-resident anglers 30 days prior to being surveyd, including the survey site. Surveys were conducted during October of 2004 and between June and August of 2005 and 2006.

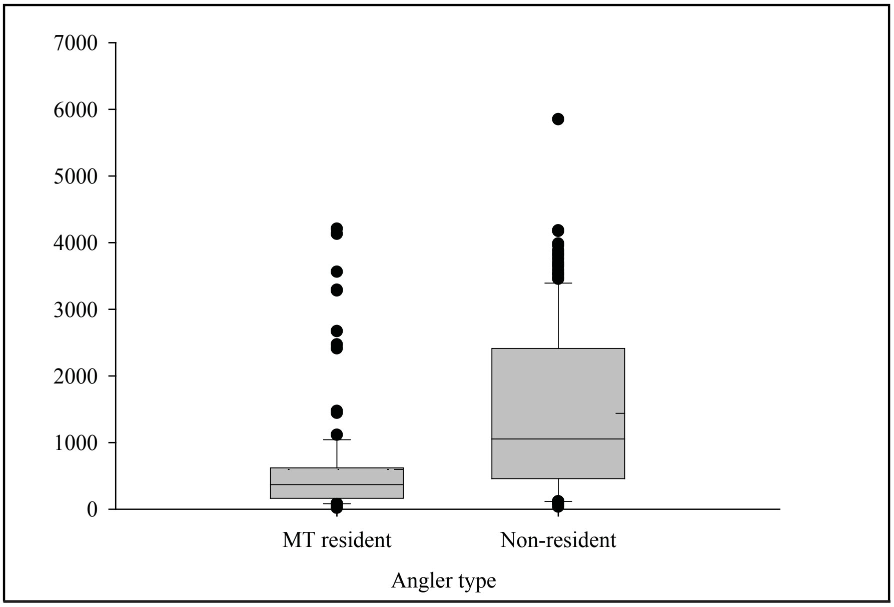

Figure 2. Distance traveled to fish by Montana reside (n=109) and non-resident anglers (n=188) during 30 days prior to being surveyed. Surveys were conducted during October of 2004 and between June and August of 2005 and 2006. Boxplots indicate interquartile range (25%, median, and 75%) and mean (dashed line). Dots indicate outliers.

Discussion

In summary, we documented frequent movement of anglers in southwestern Montana and the transport of significant quantities of sediment on boots and waders. We also documented that anglers are familiar with ANS yet, despite past educational campaigns by state agencies (i.e. Montana Fish, Wildlife and Parks) and environmental organizations (i.e. Federation of Fly Fishers), the survey revealed a departure between everyday fishing practices and aquatic disease prevention. Our research suggests that future ANS education campaigns must address sediment transport by anglers to be effective.

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WILD TROUT
SYMPOSIUM

Posters Presenters

Primary Author	***Other Authors***	***Title***
Anderson, Mike	Coleen Caldwell, Robert DuBey	Effects of Riparian Grazing on Growth Rate and Movement of Brown Trout in the Valles Caldera National Preserve, New Mexico
Bahn, Leslie	Alexander V. Zale, Christopher G. Clancy, Mark Lere	Losses of Wild Trout to Irrigation Diversions on Tributaries of the Bitterroot River, Montana
Baker, Gretchen	Margaret A. Horner, Tod B. Williams	Reintroduction of Small Native Fishes into Bonneville Cutthroat Streams in Great Basin National Park
Bangs, P.D.	J. J. Nagler	Non-lethal Techniques for Determining the Reproductive Status of Female Coastal Cutthroat Trout in Alaska
Besler, Doug	Mallory Martin, Mark Duda	North Carolina Trout Angler Opinion Survey
Bigelow, Patricia E.	Philip D. Doepke, Brian D. Ertel, Todd M. Koel	Lake Trout Suppression in Yellowstone Lake, Wyoming - an Update
Boyd, J.W.	C.S. Guy, T.B. Horton, S.A. Leathe	Effects of Fly-fishing on Mortality of Salmonids During Varying Water Temperatures in Montana Streams
Cromwell, Kara J.	Dean E. Holecek, Brian P. Kennedy	Relating Density of Juvenile Chinook Salmon to Microhabitat Availability in a Wilderness stream
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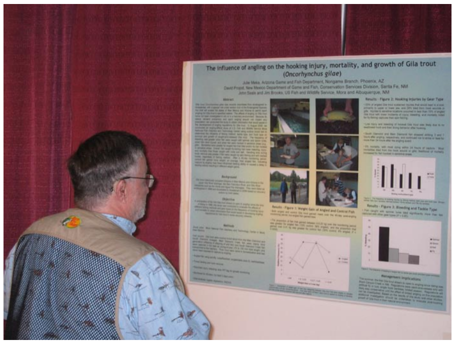
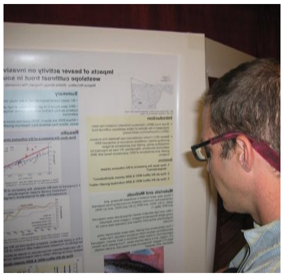
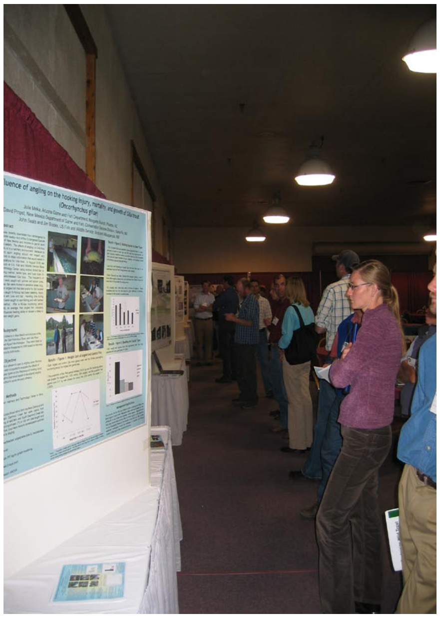
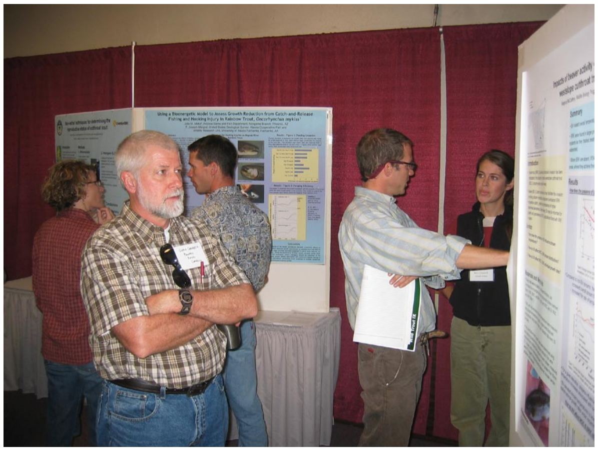
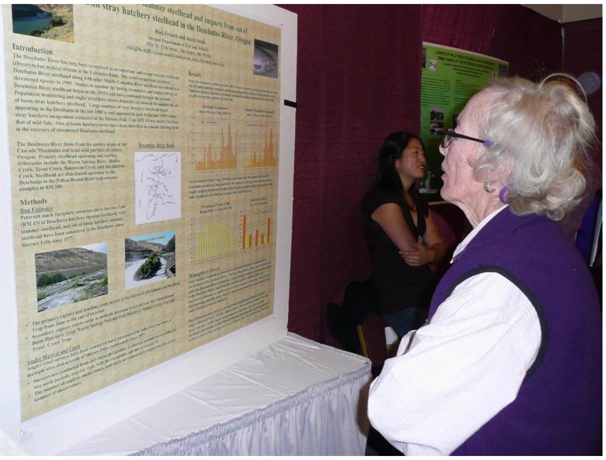

The influence of angling on the hooking injury, mortality, and growth of Gila trout (Oncorhynchus gilae)









Poster Abstracts

(in alphabetical order)

Effects of Riparian Grazing on Growth Rate and Movement of Brown Trout in the Valles Caldera National Preserve, New Mexico

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Abstract: The objective of this research is to characterize the effect of riparian grazing on growth rate and movement of brown trout *Salmo trutta* throughout San Antonio Creek, Valles Caldera National Preserve, New Mexico. Along San Antonio Creek, three sites were established in longitudinal arrangement at upper, middle, and lower reaches. Each site consisted of three grazing treatments: (1) closed to grazing, (2) open to elk grazing, and (3) open to elk and cattle grazing,. Within each treatment at all three sites, 25 to30 fish were implanted with passive integrated transponder (PIT) tags during fall 2006 and spring 2007. Recapture sampling was conducted every 6 to 8 weeks between April and November. Variation in growth rate due to grazing treatment has been minimal. To date, growth rate (g/d) among age-2 brown trout was 0.19 ± 0.234 (mean ± 1 SD) in treatments closed to grazing, 0.14 ± 0.212 in treatments with only elk grazing, and 0.13 ± 0.127 in treatments open to grazing. Seasonal movement has been minimal with a mean distance of 7.65 m in treatments closed to grazing, 2.68 m in treatments with only elk grazing, and 3.67 m in treatments open to grazing. Data collected during fall 2007 will provide insight into grazing pressure throughout riparian areas bordering San Antonio Creek.

Losses of Wild Trout to Irrigation Diversions on Tributaries of the Bitterroot River, Montana

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Abstract: Withdrawals of surface water for irrigation and stock water leave the Bitterroot River and its tributaries chronically dewatered during the irrigation season. These water withdrawals affect local trout populations by entraining migratory trout into irrigation diversion canals at multiple life stages. Irrigation losses may be responsible in part for the low abundances and restricted distributions of migratory, native, westslope cutthroat trout *Onchorhyncus clarkii lewisi* and bull trout *Salvelinus confluentus* in this system. Information about entrainment of fish into irrigation diversions is limited. Our objectives were to quantify entrainment of fish into irrigation diversions on Lost Horse and Tin Cup creeks, two tributaries of the Bitterroot River, and to identify characteristics of these diversions that correlate with entrainment. Minimum annual entrainment estimates were 5,505 in 2005 and 5,349 in 2006 in Lost Horse Creek diversions. Concurrent entrainment estimates for Tin Cup Creek were 1,922 and 1,457. These numbers represent a significant proportion of the fish populations present in creeks of these sizes. The highest entrainment of fish occurred in canals diverting the greatest amounts of water.

Reintroduction of Small Native Fishes into Bonneville Cutthroat Streams in Great Basin National Park

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Abstract: Bonneville cutthroat trout (BCT) *Onchorynchus clarki utah* are successfully expanding in five streams in Great Basin National Park, Nevada, after a 5-year reintroduction effort. However, BCT were not the only native fish in these streams; speckled dace *Rhinichthys osculus*, mottled sculpin *Cottus bairdi*, and redside shiner *Richardsonius balteatus* also lived here. These small fish were extirpated due to non-native fish predation, competition, and habitat alterations. Since the National Park Service mission is to preserve native communities, the park is attempting to complete the native fish assemblage by reintroducing these three species into BCT streams. The timing is critical. The only source stock is located in the bottom of adjacent Snake Valley where a large-scale groundwater pumping project is proposed near the headwaters of the stream the fishes occupy. In addition, while the BCT populations are still small, these small fish have a better chance to find appropriate habitat in the streams. In 2005 and 2006, fish from Lake Creek in South Snake Valley were introduced to Strawberry Creek and South Fork Big Wash in cooperation with the Nevada Department of Wildlife and Utah Division of Wildlife Resources. Monitoring will be done in 2007 to evaluate the success of these reintroductions.

Non-lethal Techniques for Determining the Reproductive Status of Female Coastal Cutthroat Trout

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Abstract: In southeastern Alaska, length-at-maturity relationships for female coastal cutthroat trout *Oncorhynchus clarkii clarkii* are a key biological consideration in the management of the sport fishery. Current maturity sampling procedures are lethal to fish, which precludes sampling in many populations because of conservation or management concerns. The goal of this project was to evaluate non-lethal techniques for assessing the reproductive status of female coastal cutthroat trout. We evaluated two approaches: ultrasound technology and the measurement of vitellogenin (VG), an egg yolk protein precursor, in blood plasma.

A portable ultrasound machine was used to visualize the gonads of 63 coastal cutthroat trout collected from Florence Lake in April 2005, just prior to the onset of spawning. Florence Lake is located on Admiralty Island, approximately 60 km southwest of Juneau, Alaska. The machine used was a Sonosite 180PLUS, which was smaller than a laptop computer, weighed about 2.3 kg, and ran on a rechargeable lithium-ion battery pack. One person handled the fish and the ultrasound transducer while a second person (the ultrasonographer) viewed the images without seeing the fish. Thus, the ultrasonographer interpreted the images without bias from fish coloration or morphological characteristics. Based on the ultrasonography, each fish was categorized as a spawning female or “other” (i.e., they did not distinguish between non-spawning female and males). Following the ultrasound exam, we euthanized and dissected each fish to evaluate our predictions of reproductive status. We found that we had correctly identified all

of the spawning females ($n = 21$) as well as the remaining 42 fish (15 non-spawning females, 27 males), which were correctly classified simply as "other".

Our second method of sampling consisted of measuring VG levels in the blood plasma of coastal cutthroat trout collected during periodic sampling trips at Florence Lake conducted between April and October 2006. We collected a blood sample from each fish, used a centrifuge to isolate the plasma, and then dissected each fish to ascertain the sex and maturity status. We measured the plasma VG concentrations by using a commercially available salmonid VG enzyme-linked immunosorbent assay (ELISA) kit (Biosense, Cayman Chemical). Our results suggest that the spring and fall months may be the optimal period for inferring sex and reproductive status based on vitellogenin concentrations. In samples collected during the spring and fall months, the concentration of VG in blood plasma ranged from 0.05 to 654.9 $\mu g \cdot ml^{-1}$ in non-spawning females ($n = 31$) and from 5,310 to 19,608 $\mu g \cdot ml^{-1}$ in spawning females ($n = 29$). In males sampled during the spring and fall, VG was not detected in the blood plasma in 26 of the 28 fish sampled, and was measured at low levels in the remaining two fish (0.08 and 0.13 $\mu g \cdot ml^{-1}$). Thus the preliminary results suggest that spawning females could be distinguished from non-spawning females and males in the spring and fall months, and that non-spawning females could be distinguished from males, albeit with a small amount of error.

While both of these approaches would be useful in reducing the lethality of future maturity studies, we suggest a combined approach to maximize efficiency and minimize costs. While the initial cost of a portable ultrasound machine can be high (e.g., US$5,000 or more), there are no subsequent operating costs and spawning females could be quickly and accurately identified in the field. For the remaining fish with unknown sex and reproductive status (i.e., males and non-spawning females), blood plasma samples could be collected for the VG ELISA. In the ELISA procedure, the plasma sample from a fish must be diluted in a series of decreasing concentrations due to the wide range in the potential VG concentration (e.g., up to 19,608 $\mu g \cdot ml^{-1}$). However, the exclusion of spawning females from the samples would greatly reduce the upper extent of the potential VG concentration (e.g., to approximately 654.9 $\mu g \cdot ml^{-1}$), thereby reducing the extent of the serial dilutions required. This streamlining of the laboratory procedures would lead to reduced labor and supply costs.

North Carolina Trout Angler Opinion Survey

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Abstract: Freshwater fishing in North Carolina is popular and has substantial economic impact. More than 1 million people fished approximately 12 million angler-days in North Carolina in 2001, spending an estimated US$1.1 billion. Of those anglers, an estimated 173,000 fished for mountain trout. The North Carolina Wildlife Resources Commission is interested in the views of its angler constituencies; however, a program-wide opinion survey of our trout anglers had never been conducted prior to this survey. To address this need, an angler survey detailing the opinions, behaviors, and desires of trout anglers was conducted in April 2007. A telephone survey of approximately 1,500 licensed anglers resulted in documentation of trout anglers' opinions regarding the current trout management and solicited opinions on program changes. By measuring the user's opinions, we will have information necessary to support changes resulting in improved trout fisheries management. In addition, survey information will also provide a baseline by which we can detect trends in angler sentiments about proposed changes and lessen the likelihood that minority groups can defeat or unduly influence program changes. Anglers will

benefit from this project because it will allow them the opportunity to input their ideas for consideration in adapting the trout program to their desires. The agency will also have the information necessary to implement changes consistent with what the anglers' desires are, but within the constraints of what the agency can provide and the habitat can support.

Yellowstone Lake Cutthroat Trout – Last Gasps of Life or Beginnings of renewal: Will Non-native Species Removal Efforts Aid Yellowstone Cutthroat Trout?

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Abstract: Yellowstone Lake cutthroat trout *Oncorhynchus clarkii bouvieri*, an icon of western trout fishing, and once the bright spot in a dim outlook for native cutthroat trout populations throughout the west, are seriously threatened by a nonnative lake trout population. Soon after discovery, Yellowstone National Park initiated an intensive gillnetting program aimed at suppressing the lake trout *Salvelinus namaycush* population to levels that would allow the cutthroat trout to sustain a healthy population. From 2001 to date, we have removed almost 250,000 lake trout from the system. Despite this effort, lake trout in Yellowstone Lake are still present in high numbers and evidence suggests that the population is continuing to expand. A new spawning site was discovered in 2006; in 2004 the highest number of mature lake trout was removed from the lake to date; and increasing numbers of smaller, immature lake trout have been removed for the last 5 years.

That said, suppression efforts are improving each year. Experienced crews have been able to use their knowledge of the lake, lake trout habitat and habits, and operations to both deploy more nets and deploy them more efficiently each year. Crews are able to maximize catch by targeting areas of the lake producing high catch rates based on recent and past catches, by rotating mesh sizes at each site, and by moving nets to new sites throughout the season. By improving operation efficiency, crews have been able to increase the amount of net fishing eight-fold over initial years of the project. Catch-curve total mortality estimates, based on spawner net catches, have averaged over 50% for both males and females for the last three years, and the number of larger, older lake trout is greatly reduced from what would be expected without removal efforts. These efforts are surely slowing the rate of expansion of lake trout in Yellowstone Lake, but will the program be able to decrease lake trout enough to provide adequate protection for native cutthroat trout?

The Yellowstone cutthroat trout population has been slow to respond, but is beginning to show signs of regaining strength. Spawner counts this spring were again extremely low, but for the first time in several years, a few small, first-time spawners were seen in several streams. The overall count of spawners in Clear Creek, the one stream we make a complete count in, was slightly up from 2005, and more importantly, also had an increase in first-time spawners. Our annual lake-wide assessment, although not designed to target juveniles, has shown a moderate increase in these size classes over the last few years concurrent with a very slow increase in spawning-aged size classes since 2002.

By far, however, the strongest signal to date of positive effects has been seen as bycatch during lake trout removal efforts. Despite employing the same basic strategies, the number of cutthroat trout incidentally caught in our smallest-meshed (25 mm) nets increased dramatically in 2006. This bycatch, a 3.5-fold increase in number over any year since the program was initiated, indicates a much stronger year class of cutthroat trout present in the lake than has been seen since the late 1990s. Indications that this year class has persisted into 2007 is evident from increased bycatch in our next largest mesh size used (32-mm bar-mesh) thus far this year. Furthermore, 2007 bycatch in the 25-mm mesh to date is slightly higher than at this time in 2006, a hopeful sign of another strong year class recruiting to the lake.

At the same time, resources dedicated to this project are becoming stretched. Time available for program monitoring and evaluation is limited, and efforts to explore new methods of removal outside of conventional gillnetting are difficult to incorporate into an already packed work schedule. Although the National Park Service remains dedicated to the protection of Yellowstone Lake cutthroat trout, limited resources could undermine this program. Current catches of immature lake trout suggest we will see a large increase in the number of spawning fish in future years. As numbers increase, in order to maintain the current level of pressure, efforts will also have to increase. If resources to accomplish this are unavailable, the Yellowstone Lake cutthroat trout population may become so reduced as to require virtually the elimination of lake trout from the ecosystem to allow recovery.

Effects of Fly Fishing on Mortality of Salmonids in Varying Water Temperatures in Montana Streams

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Abstract: There is a lack of scientific information regarding the effects of catch-and-release angling on salmonid mortality in elevated (>20°C) water temperatures. Thus, our objectives were to quantify post-release salmonid mortality in elevated summer water temperatures and cooler (<20°C) fall water temperatures, and quantify mortality from morning and evening angling events. Fly fishing occurred on the Gallatin and Smith rivers. Summer water temperatures varied from 14.5 to 23.6°C in the Gallatin River and 15.5 to 25.3°C in the Smith River, while fall water temperatures varied from 5.2 to 10.1°C in the Gallatin River and 7.9 to 14.9°C in the Smith River. Mean mortality of rainbow trout *Oncorhynchus mykiss* during summer varied from 7 to 9%, while brown trout *Salmo trutta* mortality varied from 0 to 8% in the two study rivers. Mean mortality of mountain whitefish *Prosopium williamsoni* varied from 2 to 21% in the study rivers. No mortalities for any species occurred in either river during fall sampling. No significant differences in mortality were detected between morning and evening angling events. Results indicate that trout mortality rates associated with catch-and-release fly fishing are higher at elevated (>20°C) water temperatures.

Relating Density of Juvenile Chinook Salmon to Microhabitat Availability in a Wilderness Stream

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Abstract: Performance during the juvenile rearing stage has been identified as a critical determinant of population success for stocks of wild spring/summer Chinook salmon *Oncorhynchus* tshawytscha in the Salmon River watershed. The effects of density dependent regulation on juvenile survival have received particular attention, although the presence of density dependent mechanisms has not been clarified, and it seems counterintuitive that habitat space regulates juvenile populations at their current diminished densities. Here, we test for habitat space limitation on age-0 Chinook salmon by relating local densities to available rearing habitat in a wilderness tributary to the Middle Fork Salmon River.

We conducted snorkeling surveys to evaluate microhabitat use by juvenile salmon and characterized available microhabitat through measures of depth, velocity, distance to cover, and cover complexity at the reach scale. Local fish densities were estimated by three-pass removal electrofishing surveys. Principle Component Analysis (PCA) of used and available microhabitats was employed to detect habitat space limitation. Finally, we used correlation analysis to assess the relationship of local fish density to the reach-scale proportion of preferred available habitat.

Effects of Managing Riparian Vegetation to Increase the Length of Suitable Trout Water

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Abstract: Summer water temperature limits the length of streams providing suitable trout habitat in central Wisconsin. The heating of streams is the result of complex interactions of air temperature, relative humidity, wind speed, ground water input, solar radiation, stream width, depth, and velocity. Shade, provided by riparian vegetation, reduces solar radiation and may promote opportunities to decrease water temperatures in thermally marginal habitats. One trout stream management technique used in Wisconsin removes riparian trees and shrubs in exchange for managing riparian grasses. This is done to increase primary production, decrease stream width, and increase stream depth. However, these manipulations may also result in increased solar radiation and subsequent downstream warming. A key research gap involves understanding how much downstream trout habitat is being lost due to increased summer water temperatures. The purpose of this study is to fit a stream temperature model to central Wisconsin streams based on varying riparian vegetation treatments and subsequently use this model to predict the amount of stream capable of supporting trout populations based on known thermal preferences. This model will be used to predict potential trout habitat gains or losses due to manipulation of riparian vegetation and shade.

Habitat Enhancement on Wild Trout Streams in Pennsylvania

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Abstract: During the past two decades, the Pennsylvania Fish and Boat Commission (PFBC) has developed a habitat enhancement and restoration program that uses low cost and low disturbance techniques to improve habitat in wild trout streams. In streams with good water quality, limited physical habitat, especially deeper pools and overhead cover, is one of the major factors that limits the productivity of wild trout populations in Pennsylvania streams. To address these habitat limitations, the PFBC uses habitat enhancement structures constructed of logs and stone to increase overhead cover, water depth, and habitat diversity while reducing bank erosion. These structures include overhead cover deflectors, log vane deflectors, log cross vanes, and mud sill cribbing. The typical lifespan of the structures is about 20 years, with many lasting for considerably longer periods. Significant improvements in the abundance and size structure of wild trout populations have been documented in reaches where monitoring has occurred. For example, a 12-fold increase was documented in both total catch-per-unit effort (CPUE) and CPUE of legal-size ($\geq$ 178 mm long) wild brown trout *Salmo trutta* in a reach of Little Lehigh Creek 5 years post treatment compared to a pre-treatment survey. Pennsylvania also has an active dam removal program that often uses habitat enhancement structures following dam removal to help improve instream habitat and aid in the restoration of previously impounded reaches. These restoration techniques have also been shown to considerably enhance wild trout populations in the restored reaches. This poster focuses on the evaluation of habitat restoration techniques and results of fishery monitoring in response to installation of habitat enhancement structures.

Bioelectrical Impedance Analysis: A New Field Technique for Estimating Condition of Salmonids

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Abstract: While there are many methods to accurately measure growth, a method to quickly and accurately evaluate body composition is lacking. Most of the present condition indices rely on morphological measures rather than internal assessments. There are several methods used to estimate body composition such as total body electrical conductivity and proximate analysis, but they are not viable options for field studies or cost efficient for large samples. Bioimpedance analysis (BIA) is an effective method for estimating proximate composition in some fish. Bioimpedance analysis is a quick, inexpensive and, most importantly, nonlethal method to estimatebody composition of fish. The procedure is noninvasive and nonlethal, which is vital when examining valuable subjects, such as endangered species and cultured populations of fish. The need for an accurate and reliable nonlethal method for estimating body composition has become increasingly important as many of our salmonid populations have become threatened or endangered. This study evaluated the usefulness of BIA in determining the effects of nonnative salmonids on the condition of native brook trout *Salvelinus fontinalis* in Virginia.

Managing Wild Summer Steelhead and Impacts from Out-of-basin Stray, Hatchery Steelhead in the Deschutes River, Oregon

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Abstract: The Deschutes River has long been recognized as an important and unique summer steelhead *Oncorhynchus mykiss* stream in the Columbia Basin. Studies to monitor the health, abundance, and angler harvest of Deschutes River steelhead began in the 1950's and have continue through the present. Population monitoring and angler creel surveys have shown dramatic increases in the number of out-of-basin stray, hatchery steelhead in recent years. The number of stray hatchery steelhead captured at the Sherars Falls salmon and steelhead trap (river mile 44) increased during the late 1990's when in some run years the rate of stray hatchery steelhead was nearly ten times that of wild steelhead. The final disposition of most stray steelhead that enter the Deschutes River is unknown, as fish may reside temporarily for short periods of time before continuing their journey up the Columbia River, be harvested in fisheries, or remain in the Deschutes River to spawn naturally, which poses a threat to the uniqueness of native Deschutes River summer steelhead.

Implementation of a Catch-and-release Brook Trout Regulation on a Watershed Scale

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Abstract: Maryland's upper Savage River watershed is the state's last remaining contiguous brook trout system, supporting 130 miles of interconnected streams; 85% of the stream miles are on publicly-owned land. While historically remote, recent anthropogenic changes in the watershed have increased angler access and pressure. Analysis of 2006 sampling to assess brook trout *Salvelinus fontinalis* population attributes relative to ease of angler access showed that sites with the lowest angler access always had significantly more large fish than more accessible sites. High access areas had both fewer and smaller fish. The 2006 results in conjunction with a three-decade decline in population density and the number of larger brook trout led to the adoption of a catch-and-release, artificial-lures-only brook trout regulation for the upper Savage River watershed. Primary objectives of this regulation are to (1) increase the number of larger fish (>8 inches) in the system for biological and angling value; (2) improve overall trout population densities; (3) reduce angler related mortality, particularly of larger fish; and (4) protect the only intact brook trout system in Maryland, while still optimizing angler use. Monitoring was initiated in 2006 and will continue annually through 2011 to assess the effectiveness of the regulations.

Evaluating the Effects of Flow Regulation on Snake River Cutthroat Trout Below Jackson Lake Dam

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Abstract: Flow regulation has the potential to alter the physical template upon which fish depend. Changes in the timing and magnitude of flood pulses can affect channel morphology, flood-plain inundation patterns, and sediment-transport capacity. Although flow regulation may produce similar physical effects in different streams, the response of fishes is much more variable. We were interested in identifying the specific effects of flow regulation from Jackson Lake Dam on the movement patterns of Snake River cutthroat trout *Oncorhynchus clarkii ssp.* in Grand Teton National Park. To this end, radio transmitters were implanted in 50 cutthroat trout that were captured between Jackson Lake Dam and Moose Junction, and movement patterns were monitored from July to September. This information was integrated with a long-term database of Snake River cutthroat trout population demographics (collected by Wyoming Game and Fish) to gain insight into annual movement patterns and associated habitat use. Ultimately, by evaluating how and when Snake River cutthroat trout use different portions of the stream network (main stem, tributaries, and spring creeks), we can identify flow release strategies that may be most favorable to the long-term persistence of this native cutthroat trout.

Increase Base Flow Using Catch and Release

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Abstract: Adequate base flow is the necessity for healthy fisheries. Fish do not survive without it. Base flow is dependent on weather systems delivering moisture to the watershed. Unfortunately, mankind has decimated watersheds and crippled the hydrologic cycle, flushing water into streams, discarding it before it can become base flow or watershed cooling evapotranspiration. The discarded water is not available to be delivered to the headwaters or to an adjacent watershed as precipitation. This paper proposes the means and opportunities to recover base flow.

The Wild Fish Habitat Initiative

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Abstract: In recent years, many techniques regarding fish habitat restoration have been implemented, but project results generally have not been shared or exist only in “gray literature,” where they are difficult to access. The Wild Fish Habitat Initiative is a regional program, funded by the U.S. Fish and Wildlife Service (USFWS), whose purpose is targeted research and technology transfer to provide technical information to project managers and professionals in the fields of stream and riparian restoration science. Our focus is on restoration specific to recovery of wild fish populations. Our research addresses information gaps, which inhibit resource managers and professionals from making informed decisions regarding native fish habitat restoration techniques. Our outreach is intended to augment the success of the USFWS Partners Program and other restoration efforts by providing useful, highly-technical bibliographic and case history information through a web-accessible database (http://wildfish.montana.edu). In addition to an extensive resource database, our Web site showcases a collection of case histories on stream restoration projects completed in the western U.S.. Projects selected: (1) are well-designed, based on investigation of the causes of degradation of fish habitat and/or stream hydrologic, geomorphic, and ecological processes, and (2) have an effectiveness monitoring component assessing the "success" of the restoration project.

Conversion of an Industrial Dam on Spearfish Creek, South Dakota, to Natural Rock Rapids

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Abstract: One of two low-head industrial dams constructed on Spearfish Creek, a coldwater trout fishery, in the Black Hills of South Dakota was re-constructed in 2007 using natural channel design to allow fish passage via a step-pool rapids and to provide a safer visitor experience. Upon assuming ownership in 2006, South Dakota Department Game, Fish and Parks contracted with Barr Engineering to assist with the development of plans to reconstruct the facility to allow upstream fish passage and improve the site access and safety for angler and visitor use. U.S. Army Corps of Engineers, Hydrologic Engineering Center, River Analysis System software was used in conjunction with available downstream structure hydraulics as design aids to ensure adequate pool depths, velocities to facilitate fish movement, and long term stability of the new limestone rock rapids under the designed velocities and flooding conditions. Limestone rocks, quarried from the same formations as found in Spearfish Canyon, were used to ensure an aesthetically pleasing appearance when completed. New angler and visitor facilities including a viewing platform, off-highway parking lot and wooden bridge, handicap-accessible trail, and restroom were included in the project. Brown trout *Salmo trutta* and rainbow trout *Oncorhynchus mykiss* will have free passage to reaches of stream not accessible by downstream populations since 1917.

Passage of Age-0 Trout from the Henry's Fork

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Abstract: The Buffalo River hydropower plant and dam was built in 1936. The power plant is a run-of-the-river operation diverting about one-half the base flow or 100 cfs through the powerhouse. The powerhouse is located on the Henry's Fork approximately 0.25 mi below Island Park Dam in southeast Idaho. The Buffalo River feeds into the Henry's Fork about 500 ft downstream of the dam. In 1997 a fish ladder was installed at the dam and monitored for passage of adult spawning fish. It is known that over-wintering areas for age-0 rainbow trout *Oncorhynchus mykiss* is limited in the Box Canyon reach

of the Henry's Fork. Observations indicated that age-0 trout were attempting to access the Buffalo River. The hydro project underwent re-licensing from 2000 to 2004. As part of the license, a new fishway was required that would pass 4-in, age-0 rainbow trout. The fish way was designed and built in 2004 to 2005. Parameters of the design illustrated in the poster include: total head loss 12 ft, fifty one 5 ft x 5 ft bays, 52 weirs containing a submerged orifice and slotted top weir, alignment of orifices and weirs to minimize turbulence, head loss between weirs 2.75 in, maximum designed orifice velocity 3.65 ft/s (actual 4.6 ft/s), maximum designed weir velocity 4.01 ft/s (actual 1.8 ft/s), 4 in to 6 in rounded river rock placed in bottom to provide roughness and a boundary layer between weirs, ladder length 270 ft, channel slope 4.6%, high velocity auxiliary attractant flow, ladder entrance at base of obstruction, and total flow of 10.85 cfs. Trapping and monitoring of passing fish began in March 2006. The fishway has successfully passed brook trout *Salvelinus fontinalis*, rainbow trout, whitefish *Prosopium willliamsoni*, sculpin *Cottus bairdi,* and speckled dace *Rhinicthys osculus*. Lengths of fish passed have ranged from 3 to 23 in. In the first 10 months of operation, 12,000 whitefish, 2,400 rainbow trout, and 1,500 brook trout were passed. Fish movement will be related to spawning, flows, and temperature cues. The fish way will be monitored intensely for the first 3 years and then every third year for the term of the license. The fishway has met its design criteria passing age-0 to adult trout as well as many age-0 to adult whitefish and a few dace and sculpins.

Distribution of Two Forms of Native Cutthroat Trout in the Snake River Headwaters of Yellowstone and Grand Teton National Parks

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Abstract: Within the Snake River headwaters of Wyoming, the historical distribution of native cutthroat trout *Oncorhynchus clarkii* is unknown. The Snake River fine-spotted cutthroat trout *O. c.* subsp. was thought to be sympatric with the closely-related Yellowstone cutthroat trout *O. c. bouvieri* downstream from Jackson Lake. Only Yellowstone cutthroat were believed historically present upstream of the lake. We surveyed the Snake River headwaters in Yellowstone and Grand Teton National Park to determine the current distribution of the two native subspecies by systematically sampling for them throughout the drainage. Based on their spotting patterns, captured fish were individually classified as large spotted Yellowstone cutthroat trout, the fine-spotted form, or fish that exhibited an intermediate pattern. Few of the fine-spotted cutthroat trout were collected and most were captured in the main stem river or tributaries to Jackson Lake. Typical large spotted forms were captured throughout the watershed and in the tributaries. Cutthroat trout classified as the intermediate type were the most commonly collected form in all areas. Despite the absence of confirmed barriers to upstream movement in the Yellowstone Park study section, nonnative competitive species, including brown trout *Salmo trutta* and brook trout *Salvelinus fontinalis* were restricted to the downstream portion of the main stem river there. Initial genetic analyses indicate two distinct subpopulations within the Snake River, as well as other subpopulations in most of the larger tributaries within the study area. Whether this population structuring has led to different life history strategies is unknown.

The Influence of Beaver on Brook trout Invasion and Native Westslope Cutthroat Trout Displacement in Rocky Mountain Streams of Southwestern Montana

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Abstract: Invasion of ecosystems by nonnative species is often responsible for reshaping natural biological communities. In the Rocky Mountains, brook trout *Salvelinus fontinalis* invasion has been implicated in the decline of westslope cutthroat trout *Oncorhynchus clarkii lewisi*, a native species of special concern in Montana. Although research has established that negative interactions between these species likely occur at the juvenile stage, there remain gaps in our understanding of the landscape factors that influence the extent of invasion, and resulting cutthroat trout declines. For example, beaver *Castor canadensis* are capable of altering stream habitat characteristics considerably, although it is unknown how beaver disturbance influences brook trout invasion success. To address this, our research will establish how beaver affect (i) brook trout and cutthroat trout distributions within watersheds, and (ii) species interactions between cutthroat trout and brook trout. This study is ongoing, although the first year of distribution and temperature data suggest that beaver-induced stream warming sustains brook trout invasion at higher elevations. Analyses of growth rates from scales taken in 2006, and examination of survival rates of both species during summer 2007 will lend greater insight into how beaver impact this system.

Trophic Interactions between Bull Trout and Nonnative Lake Trout in Glacier National Park, Montana

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Abstract: Lake trout *Salvelinus namaycush* have been dispersing throughout the Flathead River system since their intentional introduction in 1905. This invasion has resulted in a sympatric distribution of lake trout and adfluvial bull trout *Salvelinus* confluentus in Glacier National Park, Montana. Previous research has suggested that these species do not coexist naturally, and trophic level interactions are probable based on their ecology. We performed a stable isotope analysis (δ^{15}N and δ^{13}C) of bull trout, lake trout, and prey fishes in seven lakes in Glacier National Park to examine the relative trophic positions of these species. Lake trout were significantly enriched in nitrogen (δ^{15}N) compared to bull trout among lakes ($F_{1,115} = 23.42$, $P < 0.0001$). Bull trout and lake trout differed in δ^{13}C values within lakes, and lake trout δ^{13}C values were generally similar to those of mountain whitefish *Prosopium williamsoni*. These data provide evidence that lake trout occupy a similar trophic position relative to bull trout (δ^{15}N). This type of interaction has the potential to result in exclusion or suppression of bull trout in a significant portion of its adfluvial habitat. However, these species appear to be partitioning available resources (δ^{13}C), which may limit competitive interactions for food resources.

The Influence of Angling on the Hooking Injury, Mortality, and Growth of Gila Trout (*Oncorhynchus gilae*)

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Abstract: Gila trout were recently downlisted from endangered to threatened, with a 4(d) rule under the ESA that will enable New Mexico and Arizona to introduce angling opportunities for Gila trout in specified waters. The effects of angling on Gila trout have not been investigated in situ or in a hatchery environment. We conducted an angling mortality study using surplus brood fish to determine the influence of fishing method, tackle type, hook type, and hooking injury on the survival and growth of angled Gila trout. Mortalities were greater when fish were hooked in sensitive areas and experienced bleeding. Bleeding was greater when fish were injured, caught with lures, and hooked in sensitive areas. Overall, fish caught fly-fishing had lower bleeding, injury, and mortality rates. Handling time during hook removal was greater for fish caught spin-fishing and with barbed hooks, regardless of fishing method. After a 45-day monitoring period, control fish gained more weight on average than angled fish, indicating angling may have influenced feeding ability or caused a delay in feeding activity resulting in different weight gains. These results may facilitate regulation decisions for important recovery populations that will open to angling for the first time in decades.

Genetic Structure of Southeastern Minnesota Brook Trout Populations and the Impact of Stocking

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Abstract: Brook trout *Salvelinus fontinalis* are native to southeastern Minnesota's driftless area, but they have also been stocked extensively in the region. In the past, many of the stocked fish came from eastern U.S. hatchery sources, and the extent to which this stocking contributed to current populations is unknown. We examined genetic diversity within and among 21 southeastern Minnesota brook trout populations using seven microsatellite DNA loci. Most of the populations had little to no known stocking, although the accuracy of old stocking records is uncertain. The Minnesota populations were compared to extensive data from populations throughout the range of brook trout and from several hatchery sources. Many Minnesota populations, and one from northeastern Iowa, formed a cluster of genetically similar populations, distinct from the eastern populations. Within southeastern Minnesota, populations tended to group according to watersheds. The current genetic structure suggests that some of the brook trout populations are remnants of original populations in the region. There was also evidence of genetic impacts from successful stock transfers within the region.

Sustaining and Managing Wild Trout in a Resource-depleted World

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Abstract: A changing global energy landscape will challenge the gains that have been made in protecting and restoring wild trout populations and our ability to manage for wild trout in the future. As world oil supply and demand curves converge, we are seeing a push for expanded sources of energy to meet growing demand and to sustain economic growth. In the Midwestern USA, a rapid push towards increasing corn-based ethanol production may threaten to undo improvements in wild trout streams. Production from Canadian oil sands and increases in coal usage will likely exacerbate global climate change, which will in turn affect wild trout distributions. Rising energy costs associated with resource depletion will impact agency and angler budgets alike. Angling may become more local, thereby changing economic impacts as well as effort and harvest dynamics. Production and distribution of hatchery trout and stream restoration may become prohibitively expensive, thus underscoring the importance of preserving our quality waters and wild trout populations therein. Tools are available, however, to help fisheries managers meet these unprecedented challenges. I review how managers can make use of databases and models to guide monitoring, stream protection and restoration, and wild trout management efforts in a resource-depleted world.

Substructure of Native Steelhead in the Klickitat River and Genetic Identification of Spawning Populations

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Determining fine-scale genetic diversity and structure is critical for conservation and management of populations, especially those under heavy anthropogenic influence. We used microsatellite loci to determine local population structure of naturally produced steelhead *Oncorhynchus mykiss* in the Klickitat River of the Pacific northwest USA. Significant genetic structure among steelhead was observed in various tributaries to the Klickitat River. Genetically similar populations were used as reporting units for determining the stock composition of unknown origin adult steelhead sampled in lower Klickitat River as they migrated upstream to spawning grounds. Stock composition of both smolts and adults, as determined with genetic stock identification (GSI) methods, showed that tributaries in the lower and mid Klickitat River produced >90% of the steelhead (Table 1). Tributaries of the upper Klickitat River watershed comprised less than 2% of adult steelhead samples, suggesting that these regions primarily support resident rainbow trout populations.

Steelhead in the Klickitat River are included in the threatened mid-Columbia River Evolutionary Significant Unit and are protected under the Endangered Species Act. Plans to recover steelhead populations include restoration of fish passage to traditional spawning reaches and supplementation with locally-derived brood stock. In 2005, full passage was restored into the upper Klickitat River watershed for migratory salmonid species as a result of improvements made to the Castile Falls fishway. Prior to these improvements, passage for anadromous salmonid species attempting to negotiate the Castile Falls complex was severely constrained, if not eliminated, for the past 40 years owing to a failed attempt to improve passage around the series of cascades in the mid 1960s.

The use of artificial propagation as a means to accelerate recolonization of the upper Klickitat River watershed will be contingent upon the rate and extent of which natural recolonization has occurred. The decision to supplement the population would most likely imply that natural recolonization has been minimal or is occurring at an extremely slow rate. If this scenario occurs, anadromous individuals returning to upper Klickitat River targeted for broodstock collection would certainly be limited in number. Adhering to Hatchery Scientific Review Group (HSRG) guidelines (which suggest that no more than 25% of the natural escaping population should be taken for broodstock in a conservation program) would further constrain the number of anadromous individuals available for artificial propagation. Given these assumed conditions, use of both anadromous and resident life history types of *O. mykiss* in a conservation hatchery program targeting steelhead production and restoration may occur. It is not uncommon to have resident rainbow trout spawning with steelhead where the two ecotypes exist in sympatry, which suggests resident trout have the ability to produce the anadromous life history type. Studies have also been conducted that demonstrate the ability of both fidelity and hybrid crosses are capable of producing offspring of both life history types.

If artificially propagated stocks are released in the Klickitat River in coming years, the regional steelhead production estimates in this study provide a means to compare natural production prior to, and following artificial propagation efforts. This information will assist managers in determining if restoration efforts of steelhead to the upper Klickitat River are successful.

Table 1. Stock composition of unknown origin steelhead adults and smolts from the Klickitat River. "Res" = resident rainbow trout populations, and "Anad" = anadromous steelhead populations.

Region	2005 Adults (n=302)	2006 Adults (n=627)	2000 Smolts (n=53)	2001 Smolts (n=135)
Res_Lower Klickitat upper Little Klickitat, Fish Lake Stream	0.9%	0.5%	3.1%	5.6%
Res_Mid Klickitat upper Summit, upper White, Brush, Tepee	0.6%	0.3%	3.6%	0.6%
Res_Upp Klickitat upper mainstem Klickitat, Piscoe, Diamond	0.3%	0.1%	0.0%	1.9%
Anad_Low Klickitat lower Little Klickitat, Swale	17.2%	14.2%	13.1%	16.6%
Anad_Snyder Snyder	0.0%	0.4%	0.0%	0.0%
Anad_DeadBow Dead Canyon, Bowman	27.5%	32.4%	16.7%	30.2%
Anad_Mid Klickitat lower White, lower Summit, lower Trout	53.6%	51.9%	63.5%	44.5%
Both_MidKlickitat Surveyors, upper Trout	0.0%	0.1%	0.0%	0.7%

Rim Shoals Habitat Improvement Project, Bull Shoals Tailwater, White River, Arkansas

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Abstract: Bull Shoals Dam was authorized under the Flood Control Act of 1927 and construction was completed in 1951. The primary purposes of this project are flood control and hydropower generation, which began in 1952. Despite inconsistent water flow releases, ranging from 300 cfs. to 24,000 cfs., resulting in extreme water level fluctuations and influenced water quality, a 96-mile, world class, tailwater trout fishery developed downstream of Bull Shoals Dam. During the past 50 years, these inconsistent water flows and fluctuating water levels have significantly impacted streambanks, resulting in erosion that in turn has contributed to habitat degradation. Nine critical areas totaling 22 mi on the Bull Shoals tailwater have been identified as in need of immediate aquatic habitat improvement. The Rim Shoals area totaling 1.8 mi in length located 22 mi below Bull Shoals Dam was selected as a high priority area in need of habitat improvement.

The objectives of the Rim Shoals Project were to stabilize critical areas of eroding streambank by constructing boulder hard points, placing boulder clusters for fish cover and scour pockets, and placing large woody debris to provide habitat for fish and invertebrates, and to improve the overall quality of the fishery. Between December 18, 2006 and January 24, 2007, 3,500 tons of large boulders, 38 large hardwood tree structures, and 36 rock "Lunker Bunker" type structures were placed in this 1.8-mi area for habitat improvement. A self-propelled, self-unloading barge, 40 ft in length and 14 ft wide, with 4 ft of draft was used to place these habitat materials. The project was completed for a total cost of US$119,050. The large boulders and hardwood trees that were used in this project were obtained through donations and had a monetary value of $77,500.

One of the major objectives of this project was to improve the overall quality of the trout fishery in the Rim Shoals area. A pre-project electrofishing survey was conducted within the project area on September 27, 2006. The CPUE (fish/hr) was 80 for brown trout *Salmo trutta* was and 61 for rainbow trout *Oncorhynchus mykiss*. Brown trout ranged in size from 9 to 24 in and averaged 15.2 in total length. Rainbow trout ranged in size from 8 to 14 in and averaged 11.9 in total length. Future surveys should yield increased CPUE's and improved size distributions. Projects such as this should provide additional areas for quality angling opportunities and help disperse angling pressure over a greater portion of the tailwater. Creel survey estimates of angling pressure in more popular areas on the Bull Shoals tailwater approach 100 instantaneous angler count/m. Pre-project estimates of angling pressure in the Rim Shoals area were 1.95 instantaneous angler count/mile, which has now increased to 3.19 instantaneous angler count/mile.

In fiscal year 2005-2006, the Arkansas Game and Fish Commission sold 167,740 trout permits. From previous trout angler surveys it is estimated 25.8% of these anglers fish the Bull Shoals tailwater most often. Trout anglers spent an estimated $180 million dollars that generated over $10 million in state and local taxes. The completion of the Rim Shoals aquatic habitat improvement project will help maintain or increase the sale of trout permits that will be essential for future program funding. This, in turn, will help provide significant tourism, social, and economic benefits to the State of Arkansas.

Wolf River Brown Trout Movements and Population Characteristics with Future Management Implications

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Abstract: Little is known about the brown trout population in the Wolf River despite decades of stocking, four habitat restoration projects, and special regulations to provide for quality fishing, including a catch and release, artificial lures only section. The Wolf River has a long and well known reputation as a trout fishing destination in the Midwest, as least in part due to its large size, whitewater and wild setting, and fishing reputation. The objectives of this study are to describe brown trout population characteristics, seasonal movements, and to assess habitat restoration projects and angling regulations. The brown trout population was estimated to be 158 fish/mile, with low first year survival of stocked trout (< 2%) and low angler catch and harvest rates of stocked trout. Biotelemetry revealed significant movements outside of special regulation areas and high harvest rates of radio tagged trout. Habitat use by trout at one of the 4 habitat restoration projects was significant in fall, winter, and spring. The catch and release only section did not have significantly more trout per mile or a higher percentage of quality sized trout than the non catch and release section. Summer high water temperatures appear to be limiting the trout population throughout the Wolf River.

Adaptive Fish, Adaptive Fish Management-Redband Trout Management in the Chewaucan River Basin; Lake County, Oregon

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Abstract: The Chewaucan River contains one of the few native redband trout populations within the Oregon section of the Great Basin and is located within a relatively short commute to the towns of Lakeview, Klamath Falls, and Bend, Oregon. Historically, the Oregon Department of Fish and Wildlife stocked the Chewaucan River with hatchery rainbow trout to provide for a recreational fishery. Efforts have been taken by the Oregon Department of Fish and Wildlife to eliminate impacts on wild trout populations. The relative health of the wild redband trout population in the Chewaucan basin was investigated through the use of electro-shock sampling. Additionally, a survey was conducted to investigate angler views on the fishery. Based on results of the trout population investigations and the angler survey the hatchery trout stocking program was discontinued in 1998. During this period a major habitat project was completed which imitated river and marsh conditions more similar to the past. The Rivers End Reservoir, located on the lower Chewaucan River, was created in 1992 by a private rancher with assistance form the State, Federal Government, and Ducks Unlimited. The reservoir filled for the first time in 1993. This reservoir imitated the natural lake and marsh that had been drained in 1946. The addition of the reservoir allowed the redband trout to exhibit an adfluvial life history. All irrigation diversions currently are passable by trout. Redband trout populations are being monitored to determine effects of the removal of hatchery fish as well as improved fish passage.

Summer Movements of Large, Piscivorous Ferox Trout in Loch Garry, Perthshire, Scotland

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Introduction

Ferox trout *Salmo trutta* are the top predators in many Scottish lochs; they feed on smaller trout and Arctic charr *Salvelinus alpinus*. Although once classified as a separate species – *Salmo ferox* –ferox trout are currently considered to be members of the brown trout species complex which have switched to a mainly piscivorous diet. This trophic switch is associated with rapid growth and extended longevity – ferox can grow to over 1 m in length and live for over 20 years. The main aim of the study was to investigate the summer (May-September) movements of ferox trout in their natural habitat.

Methods

Loch Garry is an oligotrophic freshwater loch situated 406 m above sea level in the Grampian mountains. Lying at the bottom of a steep-sided glacial valley, the loch is 4.2 km long, with a maximum width of 0.5 km and maximum depth of 34.4 m. It has a surface area of 1.67 km^2.

All fish were caught by trolling a dead Arctic charr behind a boat. When hooked, each fish was played with care. Upon recovery in a large, fine mesh keep-net, each fish was anesthetized, measured, and tagged. Tags were attached externally alongside the dorsal fin. Each fish was then returned to the keep net, to recover for a minimum of 20 min, before being released from the shore as close to the original capture site as possible.

The horizontal summer movements of three ferox trout (Fish1-3) were tracked using radio and acoustic tags. Their horizontal position was recorded using a handheld GPS whenever weather and work commitments permitted. In addition, the vertical movements of five ferox (Fish4-8) were recorded every 15 min using data storage tags.

All analyses were performed using ArcGIS 8.3 and R 2.5.1. Home ranges were estimated using the Minimum Convex Polygon (MCP) method. To control for statistical non-independence, the data were analyzed using mixed models with autoregressive errors.

Results

All three tracked ferox trout had home ranges that extended over much of the loch (0.78-1.10 km^2). The dominant swimming pattern was to move slowly and undertake frequent changes in direction. The tracks for Fish2 and Fish3, which included their positions during darkness, indicate that both fish tended to move closer to shore at night ($p < 0.05$).

The DST data indicate that Fish4-8 tended to remain in the top 5 m of the water column but undertook frequent dives to depths of 5 m to 20 m. At night all five fish became less active ($p<0.05$) and, with the exception of Fish8, tended to be recorded higher in the water column ($p<0.05$).

Discussion

The results indicate that during the summer months, ferox trout cruise through the top 5 m of Loch Garry undertaking frequent changes in direction and dives to 20 m. At night the fish become less active and move into shallower water closer to the shore. We suggest that the ferox trout dive during the day to hunt Arctic charr in the deeper water but at night become less active to conserve energy.

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The Evolution of Management for Klamath Lake Redband Trout and New Management Challenges

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Abstract: The Upper Klamath Basin redband trout fishery consistently produces redband trout which exceed 10 pounds in weight and is among the finest native trout fisheries in the United States. The redband trout of the Upper Klamath Basin have evolved through time to become adapted to the often harsh environmental conditions found in Upper Klamath and Agency Lakes. The management of Klamath Lake redband trout has evolved from the early 1920's when large numbers of exotic rainbow trout were stocked to the 1990's, when management depends on natural production, habitat protection and enhancement, and conservative angling regulations to provide for trophy redband trout fisheries. This evolution in trout management was the result of evaluation of hatchery trout stocking programs, information on stock specific disease resistance, life-history investigations, genetic analysis, and changes in Oregon Department of Fish and Wildlife trout management policies which emphasize the importance native fish. Currently, managers struggle with petitions to manage Upper Klamath redband trout in the Williamson River and Agency Lake as catch and release fisheries. ODFW also has to deal with the same constituency that argued successfully for catch and release for brown trout in the Wood River (tributary to Agency Lake) despite the fact the brown trout might have negative affects on redband trout in the Wood River and Agency Lake.

Recovery of Apache Trout: Are We Finally There?

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Abstract: The Apache trout *Oncorhynchus gilae apache* was listed as endangered in 1967 and reclassified to threatened in 1975. Efforts to conserve and recover Apache trout began in 1955 when the White Mountain Apache Tribe closed all remaining streams to fishing. Fifty-plus years later, the Apache trout's status has improved to the point where it may be the first fish taken off the Endangered Species List due to recovery. We will present an overview of the Apache trout recovery program, recent setbacks and accomplishments, timelines for recovery, and management actions needed to maintain the improving trend in the status of the species.


WILD TROUT
SYMPOSIUM

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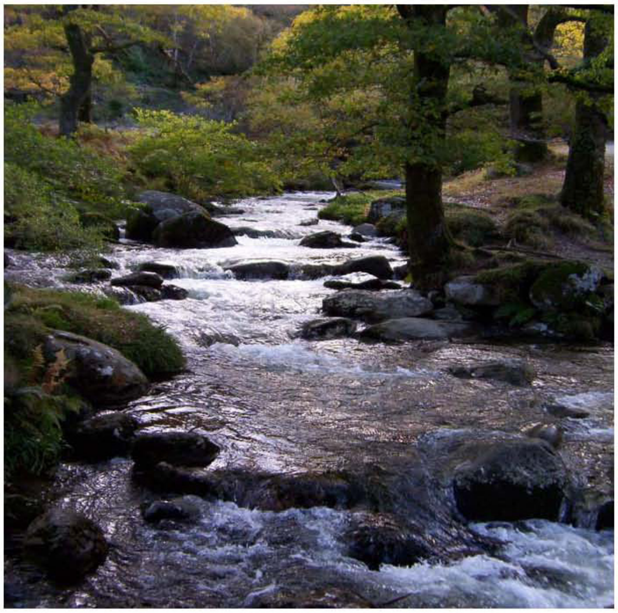
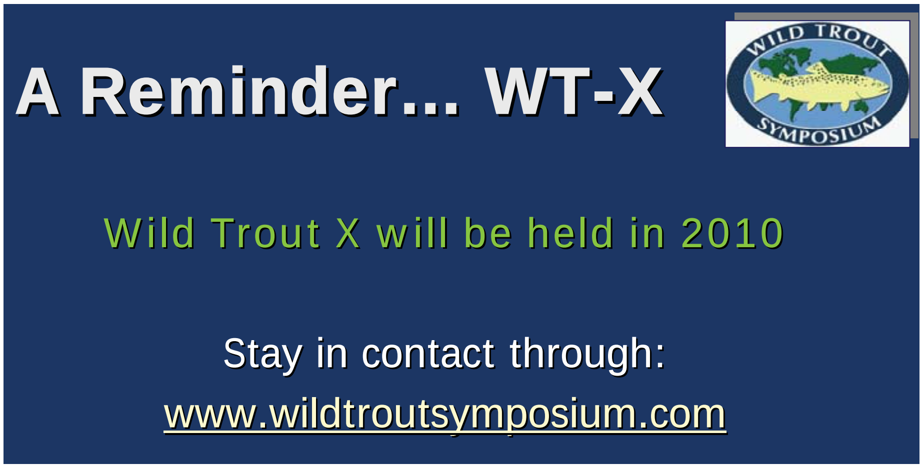


Wild Trout IX



A Reminder… WT-X

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