Effectiveness of Constructed Barriers at Protecting Apache Trout (*Oncorhynchus gilae apache*)

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ABSTRACT—Apache trout (*Oncorhynchus gilae apa*che) are a federally threatened salmonid endemic to the White Mountains of east-central Arizona. Nonnative salmonids can prey on, compete with and hybridize with Apache trout, and have thus been identified as a major threat to this species. Emplacement of fish migration barriers (primarily of gabion construction) on selected streams is one of the major recovery actions being used to isolate and protect upstream populations from nonnative salmonids; however, the effectiveness of this recovery action has not been evaluated. We evaluated the success of constructed barriers at preventing the upstream movement of nonnative salmonids. We also evaluated if barriers affected Apache trout population characteristics by examining condition and size structure above and below barriers. We examined historical survey data from eight streams following pesticide treatment and re-stocking of Apache trout, to determine if non-native salmonids reinvaded. Sixty-four percent of the barriers failed to isolate Apache trout populations. We also marked 1,436 salmonids downstream of barriers on six streams and subsequently electrofished upstream of the barriers to determine if marked salmonids had moved past barriers. We found two marked salmonids upstream of one barrier; no marked fish were found upstream of any other barriers. Failure of barriers to prevent upstream movement of nonnative salmonids was likely due to structural deterioration, design flaws, or angler transport. We suggest success might be improved if gabion barriers are filled with concrete or if solid concrete barriers are used. Barriers should be inspected biennially, repaired, or modified when necessary. We found little evidence that barriers negatively impacted population characteristics of Apache trout. Apache trout condition was higher above barriers in two of six streams, but no difference was found in any other streams. Apache trout were significantly smaller below barriers than above barriers suggesting downstream movement of fry, localized spawning.

Evaluating Single-Pass Catch as a Tool for Identifying Spatial Pattern in Fish Distribution

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Extended Abstract

One of the most critical issues currently facing wild trout managers is simply determining the distribution and relative abundance of trout, and evaluating how these parameters change through space and time. Because patterns may emerge at multiple spatial scales, a conservative approach incorporates a fine sampling grain, a large sampling fraction, and the maximum extent possible. As sampling fraction and extent increase, the application of high precision sampling techniques becomes prohibitively expensive. We assessed the efficacy of single-pass electrofishing, without blocknets, as a tool for collecting spatially continuous fish distribution data in headwater streams. Spatial patterns in abundance, sampling effort, and length-frequency distributions from single-pass sampling of coastal cutthroat trout (*Oncorhynchus clarki clarki)* were compared to data obtained from a more precise multiple-pass removal electrofishing method, with blocknets, in two mid-sized (500-1000 ha) forested watersheds in western Oregon.

Methods

After initial habitat assessment and classification of two streams (Blowout and Slide creeks), single-pass electrofishing was used to collect fish in all pools and cascades in each watershed. Subsequently, all cascades and every third pool (with a random start) were sampled using multiple-pass electrofishing, and fish abundance was estimated for each unit. A waiting period of 6 - 24 hours separated single- and multiple-pass sampling events in each habitat unit. If the waiting period was exceeded, units were discarded and replaced as follows: (a) if the unit was a pool, a new random draw was made from the next three available pools, or (b) if the unit was a cascade, sampling resumed at the next available cascade in the watershed. All fish > 70 mm that were collected during single-pass sampling were marked with a fin clip so that they could be identified during subsequent assessments. In Blowout Creek, fish received a combination of fin clips unique to the habitat unit from which they were collected. In Slide Creek, only the adipose fin was removed.

Results and Discussion

Capture probabilities for fish in individual habitat units ranged from 0.58 to 1.00 in Blowout Creek and 0.22 to 1.00 in Slide Creek, but differences among habitat units were not statistically significant ($P>0.05$) in either stream. The mean capture probability and coefficient of variation were 0.82 and 16% and 90 and 19%, for Blowout and Slide creeks, respectively. In contrast to capture probabilities, total catch from multiple-pass removal sampling was highly variable among habitat units. Mean number of coastal cutthroat trout captured was 7 (CV=113%) for Blowout Creek and 3 (CV=134%) for Slide Creek. Abundance estimates from the two electrofishing methods were positively correlated in both watersheds ($r = 0.99$ and 0.86). Differences between single-pass catch and catch from the first pass of the multiple-pass removal estimate were not statistically significant ($P > 0.05$) in either stream. Approximately 78% of the estimated population of cutthroat trout in Blowout Creek and 74% of the estimated population in Slide Creek were captured during the single-pass sample, but the effort expended was only , 7 and 10% of the total needed to make the population estimates.

Stream ecologists have been slow to recognize the role that scale may play in interpretation of observed phenomena (Fausch et al. 2002). For example, fisheries biologists commonly sample individual habitat units, or short, often arbitrarily defined lengths of a stream, and therefore, the scope of inference is generally limited to small spatial scales. However, when the scale of measurement of a variable changes, the variance of the sample also changes. This is especially applicable to the use of low-precision estimators over a large spatial extent. When grain size (sample unit) remains fixed, increasing extent results in increasing heterogeneity or variance among sample units (Wiens 1989). As variance among sample units increases, the value of precise estimates of the parameter of interest at the unit- or grain-scale declines because within-unit variance explains less of the total variation. Thus, there is an advantage to increasing the sampling fraction within the extent of the survey rather than the precision of estimate for individual sample units (Hankin 1984; Hankin and Reeves 1988).

We observed a substantial range in capture probabilities among sample units (i.e., pools and cascades); however, at the watershed scale, there was no trend in capture probability (i.e., upstream or downstream) in either stream. In addition, among-habitat-unit variation in abundance was much greater than variation in capture probabilities. Therefore, it appears that the extent of stream sampled in this study was sufficient to give an accurate depiction of relative abundance at the watershed scale. These results suggest that when compared to single-pass catch, multiple-pass removal procedures provide a more accurate estimate of coastal cutthroat trout abundance at the habitat-unit scale, but the multiple-pass method provided no additional information about the pattern of fish distribution. Because the effort expended to acquire the multiple-pass population estimates was at least seven times greater that required for the single-pass estimate of relative abundance, it appears that at the scale of intermediate sized watersheds, single-pass electrofishing is effective for detecting patterns of cutthroat trout abundance and investigating habitat relations at larger scales.

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Determining Ecologically Relevant Temperature Criteria for Salmonids: A Laboratory Approach

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ABSTRACT—Water temperature is one of the most fundamental environmental influences on fishes, particularly temperature-sensitive wild trout. However, thermal tolerances and optimal temperatures are unknown for many native North American salmonids. We have applied the Acclimated Chronic Exposure method to determine thermal optima and tolerances for bull trout *Salvelinus confluentus* and westslope cutthroat trout *Oncorhynchus clarki lewisi*, and to determine how these criteria may be influenced by competition from nonnative trout (rainbow trout *Oncorhynchus mykiss,* and brook trout *Salvelinus fontinalis*). The ACE method represents a more realistic measure of thermal tolerance than traditional methods (critical thermal maxima, incipient lethal temperature) because of slower acclimation times (1 °C/d) and long-term (60 d) exposure of test fish to elevated water temperatures while allowing simultaneous assessment of growth and survival. Our results indicate that both bull trout and westslope cutthroat trout have upper lethal and optimum growth temperatures in the lower range among North American salmonids, including other cutthroat trout subspecies. More detailed information on thermal criteria for wild trout will allow improved assessment of habitat suitability, species interactions, and response to climate change.

Colorado River Cutthroat *(Oncorhynchus clarki pleuriticus)* Habitat Restoration on the Green River Tributary Little Twin Creek

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ABSTRACT—Little Twin Creek would be an ideal spawning stream for Colorado River Cutthroat Trout inhabiting the Green River. However, salmonid spawning in general was rare due to decades of overgrazing and poor management practices. Joseph Urbani and Associates were hired to lead the restoration efforts on this creek in the fall of 2003. These efforts involved bed manipulation and the removal of many tons of fine sediment. During this process, gravels were exposed while pools and riffles were constructed. Creek passage was improved by removing some of the numerous beaver dams that blocked access to the upper section. Restoration efforts are being monitored through macro invertebrate inventories.

Declining Brown Trout in the Batten Kill

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ABSTRACT—The Batten Kill was previously considered a top blue-ribbon trout fishery in the Northeast. Stocking of brown trout (*Salmo trutta*) was discontinued in 1972 and a self–sustaining population has existed for at least a decade until the abundance of fish in all size classes began declining steadily. In response, a study team was formed to investigate potential factors that could contribute to the decline in fish numbers; e.g., habitat, water quality, contaminants, temperature, flows, nutrient enrichment, diseases, predation, forage, and conflicting recreational uses. Population modeling is a tool we used to identify events in the life cycle that impinge on population growth. Tentative indications are that the bottleneck in the population is affecting midsize trout, i.e., those ~150-200 mm (6 to 8”) long. That pattern appears to possibly be associated with at least three of the factors from the Batten Kill Study Team list: declining habitat quality due to lack of cover in the stream, increasing activity of bird and mammal predators, and introduction of pathogens. Importantly, early indications do not implicate problems at the early stages of the trout life cycle, which might be associated with water pollution or siltation.

Minimizing Effects of Piscicides on Macroinvertebrates

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ABSTRACT—Great Basin National Park minimized effects of piscicides through fish distribution surveys that reduced area treated and monitoring macro invertebrate response to rotenone and antimycin. Fish distribution surveys found 3.1 miles of Strawberry Creek and 0.9 miles of Snake Creek would not require treatment. Rotenone was dispensed into Strawberry Creek at 5 ppm for one hour and 2 ppm for seven hours over two days. Antimycin was dispensed into Snake Creek averaging eight ppb for eight hours. Under rotenone, macronvertebrate abundance declined 85% (1762/m^2 to 263/m^2) at one-month post-treatment and taxa richness was reduced 95% at one-week post-treatment. Ephemeroptera, Plecoptera and Trichoptera (EPT) group abundance declined 99% (833/m^2 to 10/m^2). Except for one sample, abundance and Taxa richness has not exceeded pre-treatment levels after three years. Five species had not returned after one year and two species are still absent after three years. Under antimycin, total abundance declined 61% (1642/m^2 to 635/m^2) while EPT abundance declined 54% (766/m^2 to 353/m^2) one-month post-treatment. Taxa richness declined less than 30%. All but one species has returned after one-year. .Macroinvertebrate abundance increased 300% 9-months post-treatment. Providing non-treated areas, all missing species are still found in non-treated areas, and using antimycin minimized impacts on macroinvertebrates.

Natural Environmental Variability and Acid Sensitivity: What Drives Brook Trout and Blacknose Dace Population Density in Shenandoah National Park, VA?

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ABSTRACT—We performed bi-annual basinwide visual estimation technique fish surveys on Paine Run, a highly acid sensitive stream, and Staunton River, a moderately acid sensitive stream in Shenandoah National Park, VA between 1993 and 2003. We estimated population density, length, and weight for blacknose dace *Rhinichthys atratulus* and brook trout *Salvelinus fontinalis*. Population density estimates for both age-0 and adult (all fish older than age-0) brook trout were highly variable in both streams, but were nearly always higher in the Staunton River. Conversely, the population density of blacknose dace was nearly always higher in Paine Run. The average size adult brook trout was similar between streams, as was relative weight (W*r*) of adult brook trout >130 mm, however the average size and condition factor (K) of age 2+ blacknose dace was lower in Paine Run. High density of age-0 brook trout in the fall generally corresponded to high density of adult trout the following spring; however, there was no relationship between density of adult trout in fall and density of age-0 trout the following spring. Natural environmental variability and acid sensitivity appear to drive fish population density in these streams by affecting blacknose dace condition and age-0 trout survival.

Salmonid Restoration Using Streamside Incubators

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ABSTRACT—Trout Unlimited (TU) and the U.S. Forest Service (USFS) are using "old refrigerators" and "ice-chest coolers" as streamside incubators to restore native salmonid populations. The "old fridge" was successfully developed by Dr. Fred Eales, Flaming Gorge-Lower Green River Chapter TU, Rock Springs, Wyoming (WY) in 1987. This TU chapter alone has proven the technique during the last 15 years by hatching over 13 million eggs of twelve (12) different species and strains of salmonids. In 1998, “old friges,” were used on the Goshute Indian Reservation, Utah, to achieve a 92% hatching success of Bonneville cutthroat trout (BCT) from green eggs to swim-up fry, and a 92% hatch of 5,000 eyed-eggs of triploid rainbow to develop tribal recreational fisheries. In Central Utah, on Trout Creek, tributary to Strawberry Reservoir, the "old frige" had a 90% hatch success of 16,000+ green eggs of BCT. In Nevada, in the Lahontan Basin, within the Truckee River drainage, TU and the Pyramid Lake Paiute Tribe used two "old friges" to hatch 225,000 Lahontan cutthroat trout eyed-eggs in 1998. This was done in cooperation with U. S. Department of the Interior Secretary Bruce Babbitt and had a resulting 92% hatching success. Sec. Babbitt was in the western U.S. to endorse the use of the "old frige" for threatened and endangered salmonid species recovery in conjunction with stream habitat enhancement and land management plans implementation for native trout. The USFS & the Shoshone-Bannock Tribe, Idaho, are using the “frige" for salmon & steelhead in the Salmon River. This effort is used on the Salmon-Challis National Forest to recruit wild salmonids into the Salmon River, a tributary in the Columbia River Basin, and has a hatching success of 85% to 99% for both eyed and green eggs to swim-up fry. The use of the "old frige" and "coolers" represents another management "tool" that fisheries managers can use for replenishing salmonid populations for recreational fisheries as well as "jump starting" native trout in stream restoration programs.

Population Characteristics of Lake Trout in Lake McDonald, Glacier National Park: Implications for Removal

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ABSTRACT—Native bull trout *Salvelinus confluentus* have suffered a dramatic population decline since the establishment of nonnative lake trout *Salvelinus namaycush* in Lake McDonald, Glacier National Park (GNP). In an attempt to prevent further decline of this population, GNP is considering a lake trout removal program. This study was conducted to examine the population characteristics of lake trout and model the effects of varying exploitation on lake trout in Lake McDonald. Saggital otoliths were aged from 154 lake trout. The von Bertalanffy growth model was used to estimate theoretical maximum length (687 mm), growth coefficient (0.103), and time when length would theoretically equal 0 mm (-0.324). Growth in length was typically lower than lake trout in Yellowstone Lake, Wyoming. Model simulations for a population of 25,000 individuals indicated that lake trout abundance decreased as the minimum size of lake trout that could effectively be removed decreased. Additionally, an exploitation of 90% was needed to reduce the number of 500 mm and larger lake trout to zero at 20% natural mortality. These data illustrate that complete removal of lake trout in Lake McDonald is highly unlikely; however, moderate levels of exploitation (30-50%) could negatively impact the population.

Wild Fish Habitat Initiative: Technology Transfer Project

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ABSTRACT—Habitat degradation is one of the principal reasons for the listing of wild fish as “threatened” or “endangered” under the Federal Endangered Species Act and can exacerbate the detrimental effects of fish predators, exotic competitors, and diseases such as whirling disease. In addition, land values are diminished by habitat degradation and the subsequent loss of wild fish populations. In recent years, many fish habitat enhancement and restoration techniques have been implemented; project results, however, have not been shared widely and their efficacy is not well understood. The technology transfer portion of the Wild Fish Habitat Initiative seeks to augment the success of habitat restoration programs by featuring selected habitat restoration techniques, and by implementing a technology transfer program to share information on project results and to provide technical information to land owners and project managers. The technology transfer program includes online bibliographic and restoration manual resources, as well as a case histories database of restoration projects implemented in the Intermountain West.

Efficacy of Fish Screens on Irrigation Diversion Canals at Skalkaho Creek, Montana

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ABSTRACT—Wild Trout Guidelines - Problem statement, issue significance, objectives, findings, and conclusions should be relayed in 200 words or less. Post-spawn adult and downstream migrant juvenile westslope cutthroat trout (Oncorhynchus clarki lewisi) are entrained, become trapped, and die in the seven irrigation canals on Skalkaho Creek, a tributary of the Bitterroot River. We quantified entrainment rates into the canals using telemetry and trapping before (2003) and after (2004) installation of fish screens at three of the canals to provide private landowners and agency personnel with an in-depth evaluation of the value of fish screens. We also examined the efficacy of the screens in returning downstream migrants to the stream. No telemetered adults were entrained in 2003, but most were residents and therefore did not migrate past the canals. Entrainment of juveniles occurred at the farthest upstream canal in 2003. Almost all age-0 juveniles encountering the canal were entrained, as it diverted most of Skalkaho Creek during the peak of summer irrigation, concurrent with peak emergence and downstream movement of age-0 juveniles. Six telemetered adults were entrained in 2004 in unscreened canals and six entered screened diversions; all six were successfully bypassed back to the creek. The screens effectively precluded entrainment.

Watershed Restoration—A Southern New Jersey Brook Trout Population at Risk

James Gracie

ABSTRACT—Mason's Run, in Camden County New Jersey is the only stream that still supports a self-sustaining population of eastern brook trout in southern New Jersey. Early settlers removed vast acreages of forest cover to engage in agriculture more than two hundred years ago, rendering most streams incapable of supporting trout. The major mechanisms for this loss were sediment loadings and loss of base flows and shade, which naturally moderated flow and summer water temperatures. With the abandonment of farms in the 1940's many areas have grown back into forest cover mitigating these past impacts. At the same time, unprecedented land development for homes, road, and businesses has dealt another severe blow to streams. In some places, there are enough mitigating factors to permit the survival and propagation of trout.

Mason's run in Camden County New Jersey, flowing through a large (approximately 560 acre) tract of relatively undisturbed land in the borough of Pine Hill still hosts a self-sustaining population of eastern brook trout. The reach of stream that supports the trout population is about 900 feet long. Downstream of the trout habitat there are two ponds in series which warm the water to lethal levels for trout in summer. The discharges from these ponds create a warm water environment downstream of the ponds as well. At the headwaters of Mason's Run, storm water runoff for a road system has created an unstable reach of ephemeral channel, which has incised delivering huge quantities of sediment downstream. This reach continues to be unstable. The sediment being delivered from the eroding reach is limiting the habitat downstream in Mason's Run by creating unstable streambed interfering with spawning success of brook trout and severely limiting macroinvertebrate populations.

This paper describes the restoration of Mason's Run, which was a part of mitigation plan for impacts on wetlands and buffers of a golf course construction project. Two ponds were eliminated and replaced with a reconstructed stream; the upstream sediment source was eliminated by restoring the ephemeral reach using the natural channel design approach to restoration. In addition, a sand trap was installed upstream of the trout habitat to remove sediment which is still stored and continues to be transported after the restoration of the unstable reach upstream. By understanding the factors limiting trout reproduction and growth in the watershed, the restoration approach created an opportunity for a watershed-wide recovery of trout habitat. The trout population may be an aboriginal strain of *salvelinus fontinalis* and was certainly at risk because of the limited gene pool and limited habitat for its survival and propagation prior to the restoration work.

Genetic Characterization of New Jersey Wild Brook Trout *Salvelinus fontinalis* Populations and Management Implications

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ABSTRACT—The brook trout *Salvelinus fontinalis* is New Jersey's only native salmonid species. Habitat alterations and widespread supplementation with cultured salmonids over the last century have likely impacted the distribution and genetic characteristics of brook trout statewide. Over the past 35 years, NJDFW surveys have documented the occurrence of 130 reproducing populations, primarily in headwater streams located in the forested hills and mountains of northwestern New Jersey. The ancestral origin of these brook trout populations is unknown, and in this study, molecular genetics is being used to assess differences in 22 of these reproducing brook trout populations. The genetic variation within and among 19 allopatric populations, and 3 populations that occur in sympatry with brown trout *Salmo trutta* and rainbow trout *Oncorhynchus* mykiss, is being examined using microsatellite DNA technology. Nuclear DNA extracted from red blood cells, and amplified at 13 gene loci using PCR, is being analyzed using a genetic analyzer. Software to score, bin, and output allelic data is being used to shed light on the genetic origin of these populations. Genetic variability is considered important in maintaining the adaptive ability of this species and its long-term survival. If unique, ancestral brook trout populations can be identified then specific management practices and conservation strategies to conserve these "heritage" populations will be developed and implemented.

Creating a Sanctuary for Wild Steelhead Trout through Hatchery Operations

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ABSTRACT—The Deschutes River basin in north-central Oregon supports a wild population of threatened summer steelhead (*Oncorhynchus mykiss*). The basin has seen large increases in the number of out-of-basin stray hatchery steelhead in recent years. Since 1987, hatchery strays have accounted for over 50% of the total steelhead returns to the Warm Springs River, a major tributary of the Deschutes River. While the large numbers of stray hatchery steelhead have contributed to making the Deschutes River one of Oregon's premier summer steelhead fishing streams, the impact of hatchery strays on the wild steelhead population is a concern for fishery managers. Warm Springs National Fish Hatchery, located on the Warm Springs River, is cooperatively managed with the Confederated Tribes of the Warm Springs Reservation of Oregon to produce spring Chinook salmon (*O. tshawytscha*) for harvest while protecting the indigenous fish populations in the river. To preserve the genetic integrity of wild steelhead populations, the hatchery is operated to allow only wild, unmarked steelhead upriver into the major steelhead spawning areas. The management and operation of the hatchery since its inception has created the only wild steelhead sanctuary in the Deschutes River basin.

Introduction

Fishery managers often use hatcheries as a tool for enhancement, mitigation, or supplementation of depleted fisheries resources. Hatchery programs, however, are often criticized for their effect on wild fish populations. In many instances, this negative criticism is warranted and hatchery programs can result in undesired ecological consequences to wild fish populations (Marnell 1986; White et al. 1995; Northwest Power Planning Council 1999). For salmon and steelhead hatchery programs in the Pacific Northwest, recent independent reviews have suggested management changes and reform measures to reduce the negative impacts of hatchery programs on wild fish populations (Hatchery Scientific Review Group 2000; Williams et al. 2003). In particular, the effect of naturally spawning hatchery fish on wild populations is receiving increased attention. In this paper, we look at the effect of stray, out-of-basin hatchery fish in the Deschutes River and how the unique management and operation of a hatchery facility has created a sanctuary for wild summer steelhead trout (anadromous form of *Oncorhynchus mykiss*).

Site Description

The Deschutes River originates on the east slope of the Cascade mountain range, flows north through central Oregon, and enters the Columbia River at river kilometer (rkm) 330. Summer steelhead historically were found in the main-stem of the Deschutes River up to rkm 214. The development of the Pelton/Round Butte hydroelectric project, a series of three dams completed between 1958 and 1964, limited the natural production of anadromous salmonids to the main-stem

Deschutes River and tributaries below Pelton Dam at rkm 166 (Oregon Department of Fish and Wildlife (ODFW) 1997). Steelhead in the Deschutes River basin are part of the mid-Columbia River Evolutionary Significant Unit that was listed as a threatened species by NOAA-Fisheries in 1999.

The Warm Springs River is the major westside tributary of the lower Deschutes River. The river flows entirely within the Warm Springs Indian Reservation and enters the Deschutes River at rkm 135. Warm Springs National Fish Hatchery (NFH) is located at rkm 16 of the Warm Springs River (Figure 1). A barrier dam, located adjacent to the hatchery blocks all upstream migrating fish and diverts them into a fish ladder. Depending on hatchery operational needs, fish can pass upstream through the fish ladder or be diverted to hatchery holding ponds. Approximately 111 rkm of stream habitat is accessible to anadromous salmonids above the hatchery barrier dam (Cates 1992).

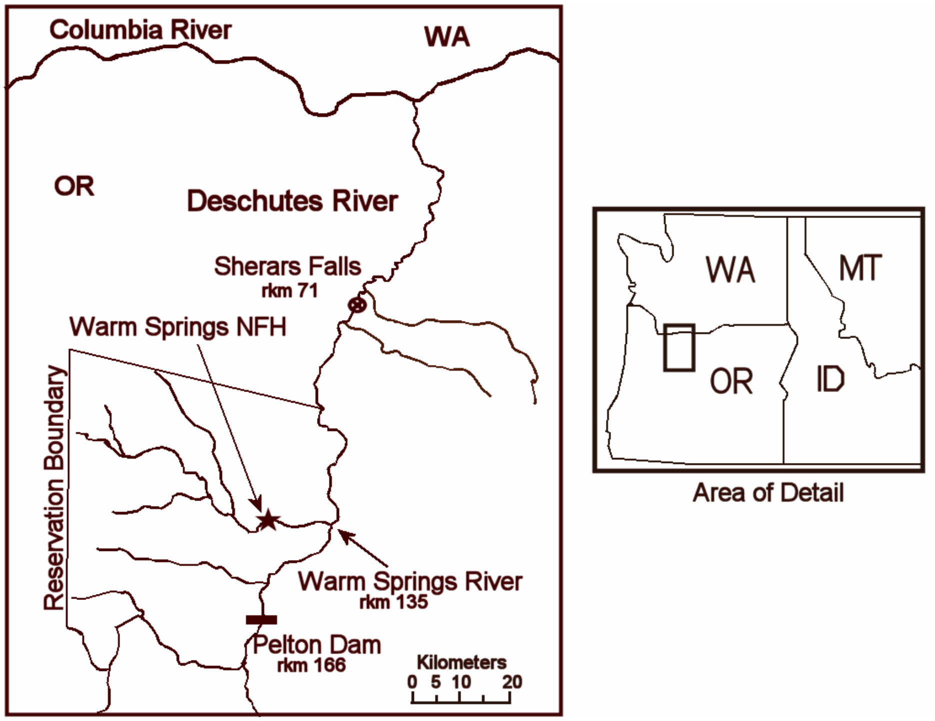

Figure 1. Map of the lower Deschutes River basin

History and Operation of the Hatchery

Warm Springs NFH was authorized by Congress in 1966 in response to a request from the Confederated Tribes of the Warm Springs Reservation of Oregon (Tribes) to establish a hatchery on Reservation land. The original purpose of the hatchery was to increase harvest opportunities of spring Chinook salmon (*O. tshawytscha*), summer steelhead, and trout (resident form of *O. mykiss*) in the Deschutes River and Reservation waters (Cates 1992). The hatchery, managed by the U. S. Fish and Wildlife Service in cooperation with the Tribes, became fully operational in 1978. The steelhead program was terminated in 1981 due to disease problems in the hatchery and the physical limitations of rearing 2-year-old smolts. Shifting priorities for the co-managers has resulted in the curtailment of resident trout production. Currently, the focus of the hatchery is on providing spring Chinook salmon for harvest in Tribal and sport fisheries in the Deschutes River. Olson et al. (1995) provide a detailed review of the spring Chinook salmon program.

Since the inception of the hatchery, federal, tribal, and state governments have worked together to develop a hatchery operational plan that minimizes the effects of hatchery operations on wild fish populations. In developing and updating the operational plan, the co-managers recognized the importance of wild steelhead populations in the Warm Springs River. When the hatchery steelhead program ended in 1981, a decision was made to try to limit the effect of hatchery steelhead on the wild fish populations in the Warm Springs River. Since any hatchery steelhead entering the Warm Springs River are straying from their hatchery release location, the operational plan was updated in 1984 to specifically exclude these strays from the spawning grounds upstream of the hatchery. During the steelhead spawning migration in the Warm Springs River, generally between February and May, all fish passing upstream through the fish ladder are diverted into holding ponds at the hatchery. Hatchery personnel hand sort the fish and pass wild, unmarked steelhead upstream of the fish ladder while hatchery steelhead, identified by marks applied at a hatchery prior to juvenile release, are removed from the stream and distributed to the to the Tribes for food. Prior to distribution to the Tribes, hatchery steelhead are checked for the presence of a coded-wire tag in the snout to determine their hatchery of origin. Coded-wire tags are small (<1.5 mm) identification tags that are implanted into juvenile hatchery steelhead prior to release and used to evaluate hatchery programs.

Steelhead in the Deschutes River Basin

Juvenile summer steelhead in the Deschutes River basin spend between one and four years rearing in freshwater before smolting and migrating downstream to the ocean (Northwest Power and Conservation Council 2004). After spending one to two years in the ocean, steelhead migrate back to freshwater and enter the Deschutes River as early as June and continue to enter the system throughout the summer and fall. Returning adults over-winter in the main-stem Deschutes River before moving onto the spawning grounds in the following spring. Based on limited spawning ground surveys in the main-stem and tributaries, main-stem spawning is believed to account for between 30% and 60% of the natural production in the basin (ODFW 1997). Spawning in eastside tributaries and lower sections of the main-stem generally occurs between January and April. Spawning in westside tributaries, such as the Warm Springs River, can begin as early as February, with peak spawning usually occurring in mid-April and continuing into May (Olson et al. 1995). Round Butte Hatchery, located at the hydroelectric project, is the only hatchery in the Deschutes River basin that currently produces summer steelhead. The hatchery, operated by the state of Oregon as part of a mitigation program for the hydroelectric project, annually releases around 160,000 summer steelhead smolts into the Deschutes River.

Reliable estimates of the number of adult steelhead entering the mouth of the Deschutes River are unavailable. A fish trap operated by ODFW, located at Sherars Falls on the Deschutes River (rkm 71), is used to sample steelhead as they pass upstream. Since the fish trap captures only a portion of the steelhead passing upstream, a Peterson mark-recapture method, with fish recaptured at

Pelton Dam and Warms Springs NFH, is used to estimate the total steelhead population. Fish are classified as either wild, Round Butte Hatchery, or stray (out-of-basin) hatchery steelhead based on fin marks. Sherars Falls steelhead numbers in this paper are derived from unpublished ODFW-Mid Columbia Fish District mark-recapture estimates.

The average number of wild and Round Butte Hatchery steelhead passing the falls between 1979 and 2002 was 5,030 (SD=2,769) and 4,959 (SD=2,571) adults, respectively. Large numbers of stray hatchery steelhead began passing the falls in the early 1980's, with an even more pronounced increase in numbers beginning in 1995 (Figure 2). Between 1995 and 2002, stray steelhead accounted for an average of 62% (SD=10%) of the total number of adult steelhead passing upstream of Sherars Falls. A large number of wild and hatchery steelhead migrating to other streams in the Columbia River basin enter the lower sections of the Deschutes River for a period of time before exiting back out to the main-stem Columbia River and continuing their migration to their natal streams for spawning (ODFW 1997). Based on recoveries of tags applied to stray hatchery fish and a radio-telemetry study, an estimated 50% of the stray hatchery steelhead passing upstream of Sherars Falls eventually exit the Deschutes River (Rod French, ODFW, personal communication). Since the origin of wild fish cannot be determined without genetic analyses, the number of stray wild fish that migrate up and down the river is unknown.

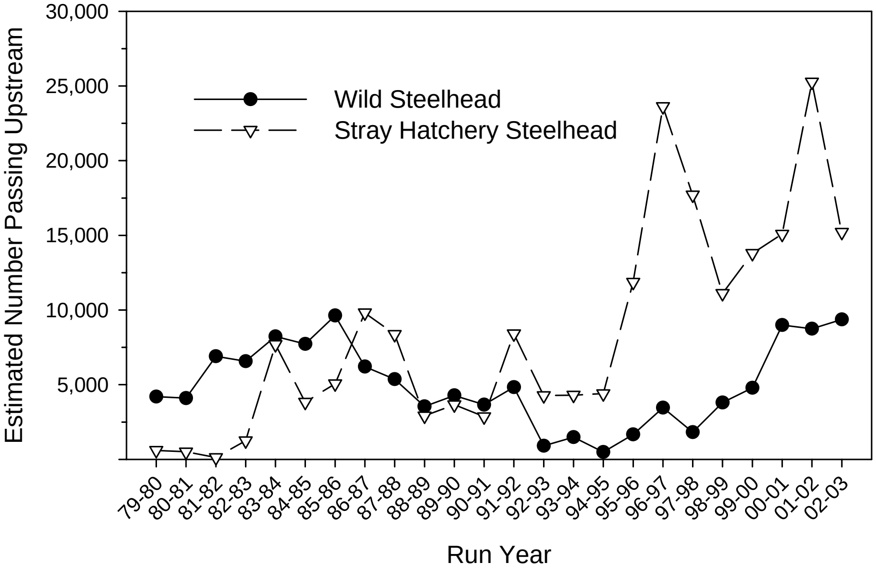

Figure 2. Peterson mark-recapture estimates of the number of steelhead passing upstream of Sherars Falls (ODFW unpublished data). Round Butte Hatchery fish are not included in this figure.

While 50% of the stray hatchery steelhead may eventually leave the basin prior to the spawning period, the large overall number of strays in recent years means that in many years the number remaining can equal or exceed the number of wild steelhead in the basin. The reasons for the large number of stray steelhead migrating up and remaining in the Deschutes River are unknown. Fish transportation operations, in which a proportion of juvenile smolts are artificially transported around main-stem Columbia and Snake river dams, may influence the straying rate of returning adults (Olson et al. 1995; Quinn 1997).

Some of the stray hatchery steelhead that remain in the Deschutes River move onto the wild steelhead spawning grounds. Based on spawning surveys conducted by ODFW on Buckhollow and Bakeoven creeks, major eastside tributaries that enter the Deschutes River at rkm 68 and 84 respectively, hatchery steelhead accounted for a yearly average of 42% (SD=25%) of the total number of steelhead on the spawning grounds between 1991 and 2003 (ODFW unpublished data). Shitike Creek, a westside tributary entering the Deschutes River at rkm 155 just downriver of Pelton Dam, also has stray hatchery fish moving onto the spawning grounds. Between 2001 and 2003, out-of-basin stray hatchery steelhead have accounted for an average of 28% (SD=7%) of the adult steelhead trapped at a weir located near the mouth of the creek (Confederated Tribes of the Warm Springs Reservation of Oregon, unpublished data).

Warm Springs River

The only tributary in the Deschutes River basin where stray hatchery steelhead are actively excluded from the wild steelhead population is the Warm Springs River. If strays were not excluded, the steelhead population in the Warm Springs River would have been heavily influenced by hatchery steelhead in recent years. The number of stray hatchery steelhead trapped and removed at the barrier dam at Warm Springs NFH increased substantially in 1987 (Figure 3). Between 1980 and 1986, stray hatchery steelhead accounted for a yearly average of 13% (SD=5%) of the total steelhead in the Warm Springs River. Between 1987 and 2003, an average of 51% (SD=10%) of the yearly steelhead run was composed of stray hatchery steelhead. The timing of upstream migration differed between wild and stray hatchery steelhead. The median day of migration to the barrier dam for stray hatchery steelhead was 14 days (SD=7 days) earlier than for wild steelhead.

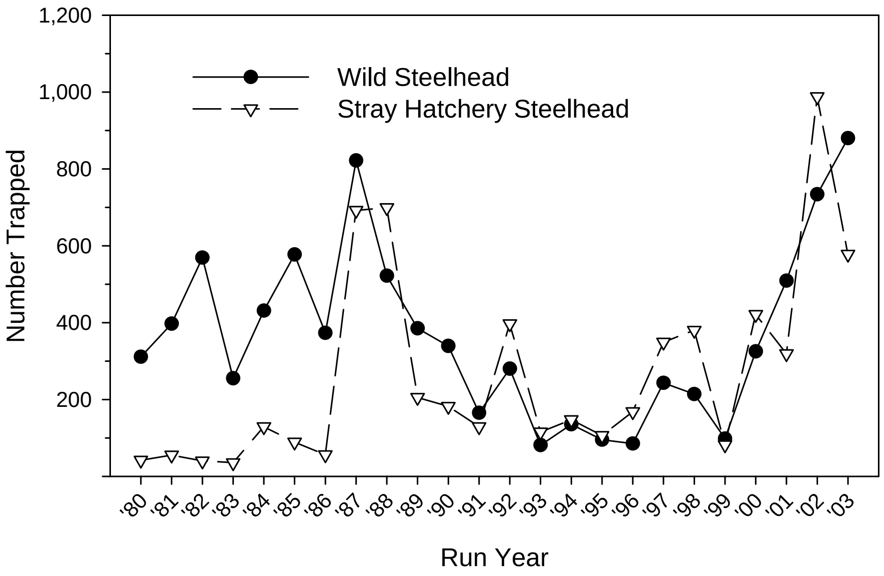

Figure 3. Number of steelhead trapped at the barrier dam at Warm Springs NFH (rkm 16).

Currently, the only way to determine the origin of stray hatchery steelhead in the Warm Springs River is to rely on the recovery of coded-wire tags. Analysis of stray steelhead is complicated by the fact that most hatcheries in the Columbia River basin do not coded-wire tag all of their juvenile steelhead releases. For example, in 2003 a total of 6.1 million juvenile steelhead were released from hatcheries in the Columbia River basin above Bonneville Dam (rkm 235). Of this total, only around 10% were coded-wire tagged (RMIS Database). To determine the straying rate of fish released from hatcheries that coded-wire tag at least a proportion of their juvenile steelhead releases, an expanded recovery number is estimated. The expanded recovery number is calculated based on the ratio of the number of coded-wire tagged fish released from each hatchery to the total number of fish released from that hatchery.

Between 1987 and 2002, expanded coded-wire tag estimates could account for 37% of the stray hatchery steelhead in the Warm Springs River. Of the strays that could be accounted for, most came from hatcheries or release locations in the Grande Ronde, Imnaha, Wallowa and other rivers in the Snake River basin (Figure 4). These rivers are over 450 rkm upriver from the confluence of the Deschutes and Columbia rivers. Since the origin of over 60% of the strays cannot be accounted for based on expanded coded-wire tag recoveries, a complete analysis of the straying phenomenon in the Warm Springs and Deschutes rivers cannot be completed. Strays from hatcheries that do not coded-wire tag any of their releases may be a source of a large number of strays trapped at Warm Springs NFH. In addition, although most hatchery steelhead are externally marked with an adipose fin-clip, making them easily recognizable to hatchery staff who are sorting fish, some fish are released without an adipose fin-clip as part of restoration efforts in the Upper Columbia and Snake rivers. For example, over 2 million non-adipose clipped juvenile steelhead were released from hatcheries in the Snake River basin in 2003 (U.S. Fish and Wildlife Service, unpublished data). If fish have no easily recognizable external marks and they do stray into the Warm Springs River they could be misidentified by hatchery staff as wild fish and be passed upstream into the spawning grounds.

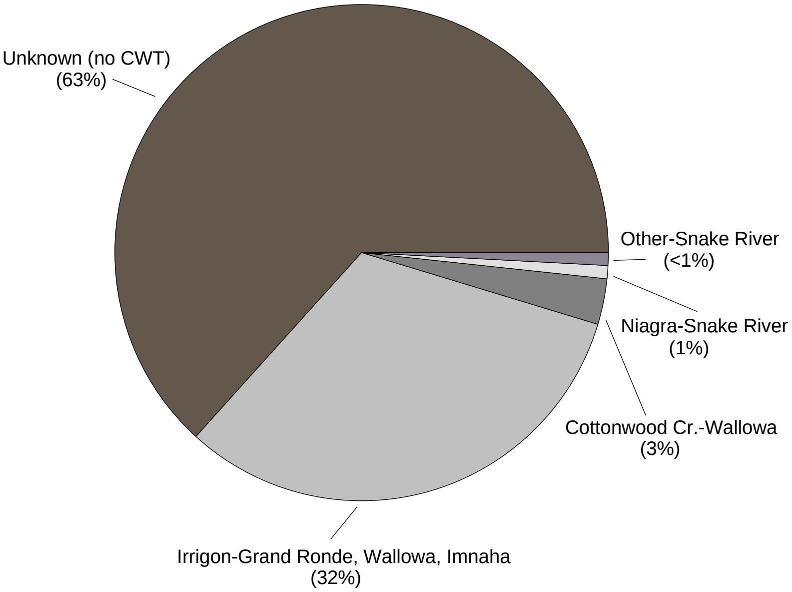

Figure 4. Origin of stray hatchery steelhead (n=4,910) at Warm Springs NFH 1987-2002 based on expanded coded-wire tag recoveries. Hatchery and release river are listed.

Impact of Stray Steelhead

The Deschutes River is a popular summer steelhead fishing stream for sport and tribal fisheries (ODFW 1997). A large portion of the sport fishery for steelhead occurs from the mouth of the river up to Sherars Falls and a tribal dipnet fishery is primarily focused on the area just below the falls. In 1979, in an effort to protect wild steelhead populations, sport harvest of summer steelhead was limited to hatchery fish. Sport anglers are allowed to keep adipose clipped hatchery steelhead, regardless of the hatchery of origin. The tribal dipnet fishery is regulated by the Tribes and harvest of a limited number of wild summer steelhead is allowed during years when wild steelhead populations are abundant. While Round Butte Hatchery produces steelhead specifically for harvest in the Deschutes River, stray out-of-basin hatchery steelhead make up a large component of the sport harvest. Based on a statistical creel survey, between 1987 and 1995 a yearly average of 1,907 (SD=590) hatchery steelhead were harvested in the sport fishery below Sherars Falls. During this time, stray hatchery steelhead accounted for an average of 83% (SD=7%) of the total sport harvest (ODFW 1997).

While stray hatchery steelhead are an important and valuable component of the Deschutes River sport fishery, the potential impact of the strays on the wild steelhead population is a major concern for fishery managers (Northwest Power and Conservation Council 2004). Fish straying from one basin to another have the potential to introduce diseases that are not endemic to the receiving basin. *Myxobolus cerebralis*, the causative agent of whirling disease in salmonids, has been shown to infect juvenile hatchery steelhead held at acclimation sites in the Wallowa and Imnaha rivers in the Snake River basin (Sollid et al. 2004). While whirling disease does not appear to be established in the Deschutes River basin, the presence of *M. cerebralis* has been detected in adult stray hatchery steelhead sampled at Warm Springs NFH since 1987. In 2003, 81 stray hatchery steelhead collected at Warm Springs NFH were tested and 15 were found to be infected with *M. cerebralis* (U.S. Fish and Wildlife Service, Lower Columbia River Fish Health Lab, unpublished data). All of the infected adults in 2003 were released as juveniles from acclimation sites in the Wallowa River. While the adults do not exhibit clinical signs of the disease, if they die in the stream they could potentially release myxospores into the water column. The removal of stray hatchery steelhead from the Warm Springs River reduces the likelihood of whirling disease or other non-endemic diseases being introduced into the drainage. Given the large number of strays that are in the Deschutes River, the potential for introduction of non-endemic diseases to areas downstream of Pelton Dam on the Deschutes River and downstream of Warm Spring National Fish Hatchery on the Warm Springs River is a concern and needs to be evaluated.

The impact of stray hatchery steelhead on the genetic integrity and productivity of wild steelhead populations in the Deschutes River is not known. Chilcote (2003) used data from the Deschutes River steelhead population as part of his analysis of mixed spawning populations of wild and hatchery steelhead. In that analysis he found a reduced level of productivity in populations that had a higher proportion of hatchery fish on the spawning grounds. Other studies have also described reduced productivity in mixed hatchery and wild steelhead populations (Chilcote et al. 1986; McLean et al. 2003). The actual mechanisms for the reduced productivity are not known, but the incorporation of genetic material from out-of-basin fish into the Deschutes River stock may reduce the ability of the wild stock to respond to environmental extremes (Northwest Power and Conservation Council 2004). Wild steelhead are locally adapted to the environmental conditions in the Deschutes River. Steelhead reared in hatcheries in the Snake River basin do not have these local adaptations and therefore may have reduced reproductive success when spawning in the Deschutes River. If hybridization between wild and stray hatchery steelhead occurs, introduction of non-locally adapted traits may reduce the overall reproductive success of the wild population. For example, the difference in timing of migration to the barrier dam on the Warm Springs River may indicate a difference in spawn timing between wild and stray hatchery steelhead. In areas of the Deschutes River basin where wild and stray hatchery steelhead are intermingled, some level of hybridization has likely occurred. McLean et al. (2003) suggested that altered timing of reproduction resulting from hybridization of wild and hatchery stocks could lead to a reduction in productivity.

Conclusion

The removal of stray hatchery steelhead from the Warm Springs River is an example of how the operation and management of a hatchery facility can play a role in the conservation of wild fish populations. The hatchery program has limited the potential mixing of wild and stray hatchery steelhead stocks and likely preserved the biological and genetic integrity of the wild steelhead population in the Warm Springs River. As such, the Warm Springs River may serve as a useful “control” stream for further investigations into the effects of stray hatchery steelhead on wild steelhead populations in the Deschutes River. We are currently developing plans to use mixed-stock genetic analyses to determine the origin of non-coded-wire tagged fish in the Warm Springs River, but the costs involved make it unlikely that this technique can be used on a basin-wide scale. A comprehensive marking and coded-wire tagging program for all hatcheries in the Columbia River basin will allow fishery managers to more effectively monitor and evaluate the straying problem in the Deschutes River.

Acknowledgements

Policy and biological support staff from the Confederated Tribes of the Warm Springs Reservation of Oregon have been leaders for the conservation of wild fish in the Warm Springs River. We thank on-the-ground work by U. S. Fish and Wildlife Service staff from Warm Springs National Fish Hatchery, the Lower Columbia River Fish Health Lab, and the Columbia River Fisheries Program Office, as well as policy support from our Regional Office. Rod French of the Oregon Department of Fish and Wildlife provided helpful information on steelhead populations in the Deschutes River and Jen Stone of the U. S. Fish and Wildlife Service provided an insightful review of this paper.

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Catch and Release Runoff to Cool the Watershed

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ABSTRACT—Cooling a watershed requires restoring natural processes that were in place for centuries prior to human intervention. The grazing, timbering, mining, and irrigated agriculture industries of the West have disrupted the natural processes. Unaided recovery would take centuries even if mankind did no further harm. Managing recovery involves catching runoff and releasing the water on an assigned portion of the watershed. The release system, a nominal "irrigation" system, is designed to assure that the water will evaporate (cooling) or infiltrate. The released water can be caught again further downstream and re-released. It is more valuable than trout.

A group of sites sized to catch and release a total of 10 AF per day would have a daily environmental value received of $216,630 to $284,420 depending on site evaporation to infiltration ratio. A hundred day season would be worth $21.6 million. The impact on neighboring areas would be worth an additional $20.7 million per season to them. Every mile of stream should be evaluated for possible implementation.

Influence of Fish Origin and Stream Discharge on Movements of Coastal Cutthroat Trout in a Headwater Stream

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Extended Abstract

Headwater streams on the western slope of the Cascade Mountains represent dynamic environments subjected to frequent natural perturbations. These streams account for a majority of stream length in forested areas and are easily altered by management practices (Chamberlin et al. 1991). Most studies of stream fish movement and habitat use involve spatially discontinuous sampling during discrete time intervals (Fausch et al. 2002). Although results may accurately depict localized phenomena, ecological patterns acting across multiple scales cannot be discovered (Levins 1992). Electrofishing censuses of 40 randomly selected headwater basins in western Oregon has suggested that populations of coastal cutthroat trout exhibit an aggregated spatial pattern at a variety of spatial scales (Gresswell et al. 2001). Subsequent continuous spatial sampling of the South Fork Hinkle Creek watershed documented a non-random, aggregated pattern of relative fish abundance in that system. In order to understand effects of variable stream discharge on spatial and temporal variation in relative abundance of coastal cutthroat trout, constant monitoring of tagged individuals is being conducted in contiguous sections of South Fork Hinkle Creek that exhibit diverse abundance patterns.

Methods

The South Fork of Hinkle Creek is a 3rd-order tributary of Calapooya Creek located in the Umpqua River basin in southwestern Oregon. The watershed is about 1100 ha and contains 7 km of fish-bearing stream with an average active channel width of 4 m. Fish species include anadromous steelhead (*Oncorhynchus mykiss*), resident sculpin (*Cottus* spp.) and potamodromous coastal cutthroat trout (*O. clarki clarki*). The watershed is located primarily in a second-growth Douglas-fir forest that is managed for industrial timber production.

A total of 17 mainstem and 6 tributary habitat patches were identified during a watershed-scale electrofishing census of coastal cutthroat trout. Distribution patterns were used to identify habitat patches with high and low relative fish abundance. Habitat patches ranged in size from 30 m to 230 m and consisted of multiple channel units (i.e., pool, riffle, and cascade). A total of 296 coastal cutthroat trout $\geq$ 100 mm (fork length) were marked with 23-mm half-duplex PIT-tags and continuously monitored using data-logging PIT-tag readers.

In addition to 7 antennas located at tributary junctions, 24 additional stationary PIT-tag antennas were installed to completely encompass the habitat patches. Antennas were positioned perpendicular to stream flow and located in high-velocity habitats to minimize multiple PIT-tag readings related to fish holding behavior. Censuses of the study area using mobile PIT-tag antennas were conducted about every 1.5 months, and basin-wide censuses occurred seasonally (i.e., every 3 months). Stage-logging capacitance rods were installed at tributary junctions, and temperature loggers were located at 6 points in the study area.

Results and Discussion

From October 13, 2003 through June 1, 2004, continuous monitoring with PIT-tag readers and data loggers was achieved 90% of the time. Approximately 87% (116/133) of PIT-tagged fish that were originally tagged in the intensively monitored section were relocated by mobile and stationary antennas at least once. Fifteen percent (6/41) of fish from downstream origin and 7% (3/44) of fish from upstream origin immigrated into the intensively monitored section. Median extent of movement (i.e., difference between most upstream and downstream locations) and variation in the extent of movement were significantly different between fish of main stem and tributary origin (Mann-Whitney U-test $P < 0.01$; modified Levine Test for Equal Variance $P < 0.01$). In addition, differences in the median extent of movement and variance for fish originating below and above Tributary 2 were statistically significant (Mann-Whitney U-test $P < 0.01$; modified Levine Test for Equal Variance $P < 0.01$). Two fish tagged in Tributary 2 during the spawning season subsequently moved > 190 habitat units and were detected in the mainstem South Fork of Hinkle Creek (Figure 1).

Most coastal cutthroat trout moved during periods of low to moderate discharge levels (Figure 2). Approximately 57% (270/452) of longer distance “between-habitat patch” movements occurred at moderate stage heights, and 55% (353/640) of shorter distance “within-habitat patch” movements occurred during periods of low stage height. Sixty-one percent (279/457) of stationary behavior events (i.e., maintaining position within the detection field of an antenna for a minimum of 15 minutes) occurred during moderate stage levels. There was a two-fold increase in the median duration of stationary behavior events during times of high stage height (median =3.8 h) as compared to similar events at moderate (median = 1.6 h) or low (median = 1.9 h) stage heights. Movements from mainstem habitats to tributaries increased during periods of high stage height.

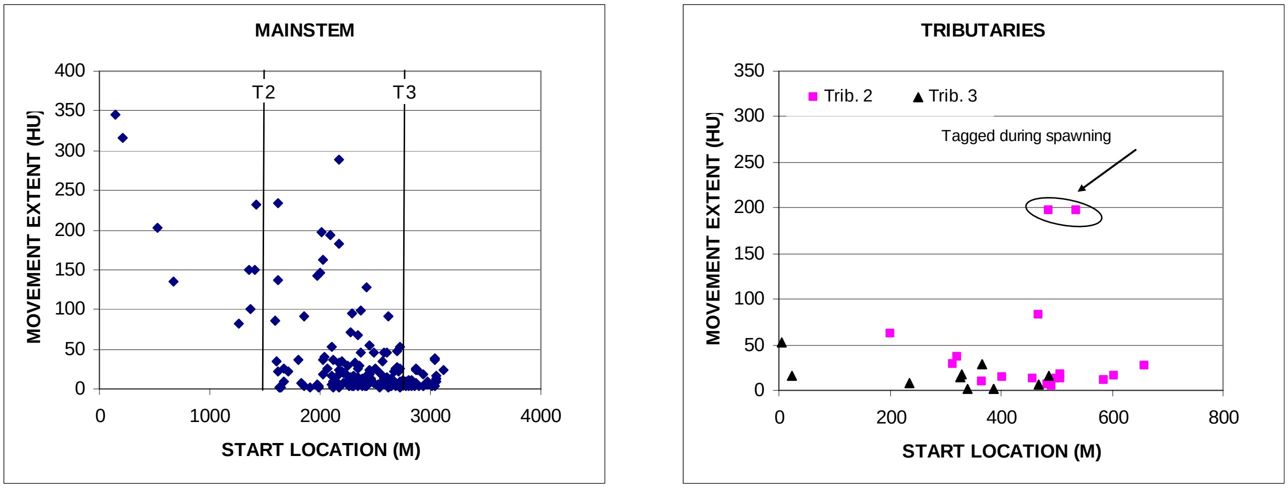

Figure 1. Movement extent (i.e., difference between most upstream and downstream locations in habitat units) for individual fish based on starting location from the mouth of South Fork Hinkle Creek. Lines labeled T2 and T3 show tributary locations.

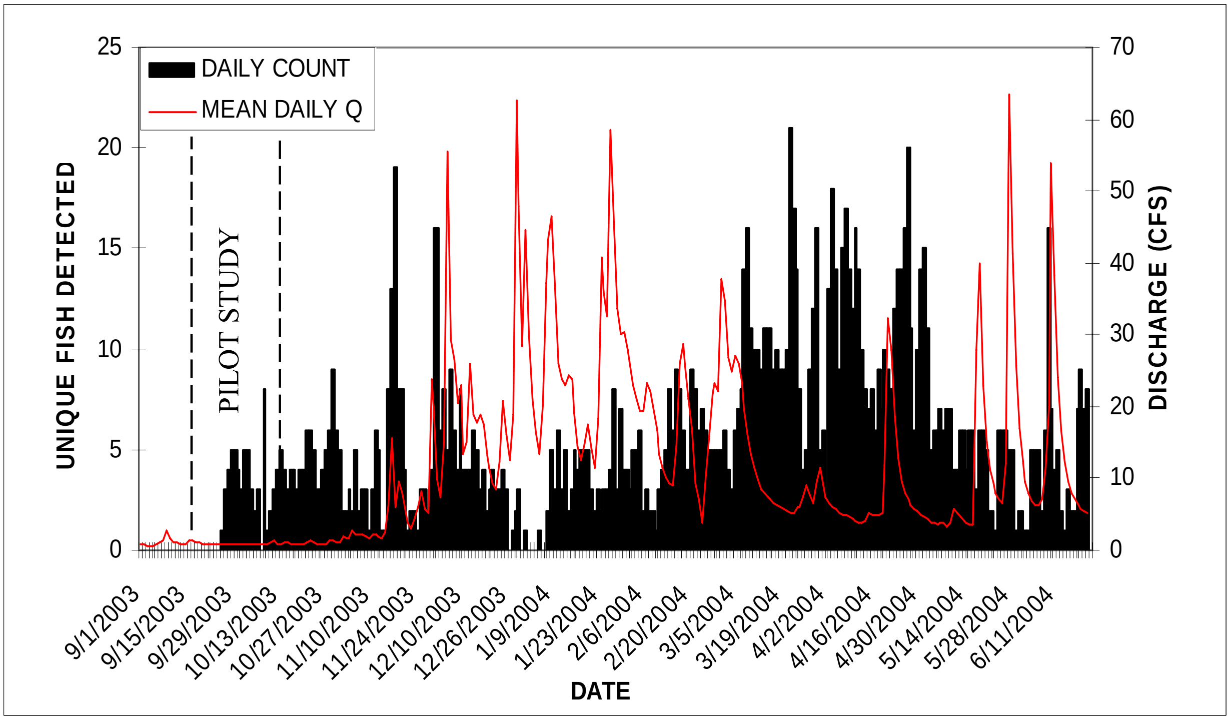

Figure 2. Time series plot of stream discharge superimposed on a frequency distribution of unique fish detections at stationary antenna sites. Detections are based on only the first detection of individual fish for each day. Both mainstem and tributary detections are represented.

Recognizing factors influencing distribution of coastal cutthroat trout in the context of the watershed-scale variables that constrain them may be critical for management of headwater ecosystems. Preliminary evidence suggests differential use of the stream network by fish of different origin. Decreased frequency of stationary behavior events at high and low stage levels may be indicative of reduced use of riffle and pool tail-out habitats (i.e., antenna locations); however, increased duration of stationary behavior events during high stage shows some locations become refuge habitats. The observation of more movements from mainstem habitats to tributaries during high stream stage may be related to refuge or spawning movements. Understanding movement patterns within a watershed can provide insight into the demographic, genetic, and recolonization processes maintaining coastal cutthroat trout populations in headwater streams.

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Genetic Variation Maintenance in Rio Grande Cutthroat Trout

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ABSTRACT—Recovery plans for salmonids frequently discuss the need to maintain the genetic diversity of the 'species' in recovery efforts and the development of hatchery stocks. For many types of salmonids, there is also the problem of hybridization between various species and subspecies. For west-slope cutthroat trout (*Oncorhynchus clarki lewisi)* there have been various opinions presented about whether hybridized populations should be considered as part of the sub-species under the Endangered Species Act. Intuitively, the more stringent the requirement for genetic purity the fewer the number of populations that will be included within the sub-species. Exclusion of slightly hybridized populations, however, may also exclude a significant proportion of native genetic diversity. Populations of Rio Grande cutthroat trout (*O. c. virginalis*) have been characterized using microsatellite markers and compared against known rainbow trout populations (*O. mykiss*) to give an index of hybridization. Alleles have been characterized as either cutthroat specific, rainbow specific, shared, or unclassified. Cutthroat trout and shared alleles are well represented in populations with low or no introgression, while the unclassified alleles are more variable and less likely to be represented with fewer populations.

Evaluation of Large Trap Nets for Lake Trout Removal in Lake Pend Oreille, Idaho

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ABSTRACT—We assessed the use of large trap nets to suppress the exotic population of lake trout *Salvelinus namaycush* in Lake Pend Oreille, Idaho. While trap netting we also monitored the mortality rates of non-target species and estimated the abundance of lake trout. The nets varied in lead heights and mesh size as part of the assessment to identify the most effective gear. Using the Schnabel multiple-census population estimator, we estimated that Lake Pend Oreille contained 6,376 lake trout > 52 cm after handling 1,183 lake trout (marked and unmarked) during the six month study. Based on the population estimate, we caught 16% of the population > 52 cm in length. Our catch rates ranged from a high of 3.0 lake trout/net/day (during spawning season) to a low of 0.13 lake trout/net/day (during the winter season). We captured a total of nine species with the trap nets and found the catch and mortality of most non-target species was relatively low. Due to lake bathymetry (steep shorelines and few shallow areas), these nets could not be set in many of the lake trout habitats found within the lake. Data indicated that the large trap nets alone may not be a suitable way to suppress the lake trout population in a short period of time, since they caught only $^1/_6$ ($^1/_5$ to $^1/_8$ based on the confidence interval) of the population. However, they may have utility as part of a long-term program of lake trout control. Trap nets also proved to be a valuable research tool for collecting lake trout for population estimates and sonic tagging projects without causing high mortality to non-target species.

Seasonal Movements and Habitat Use Patterns of Fluvial Trout Populations in the Upper Salmon River Basin, Idaho

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ABSTRACT—Information on the movements, behavior, and critical habitats of fluvial salmonid populations native to the Salmon River basin, Idaho is minimal. The upper Salmon River basin provides a unique study area due to its diversity of lotic habitats. Many tributary streams have been negatively impacted by various land use activities, while others found in wilderness areas have been relatively undisturbed. The goals of this study are to identify migration patterns, critical spawning, and seasonal habitats of fluvial trout populations within the Salmon River drainage. In 2003 and 2004, 67 bull trout (*Salvelinus confluentus*), 39 westslope cutthroat trout (*Oncorhynchus clarki lewisi*) and 43 rainbow trout (*O. mykiss*) were monitored using radio telemetry. Movements were monitored by ground relocations and fixed telemetry stations located at major tributaries. Fish were relocated on a weekly basis, allowing for the observation of migration timing and movement corridors, as well as the identification of spawning areas and seasonal habitats. During the first year of study, previously unknown spawning and over wintering areas have been identified for fluvial trout populations in the upper Salmon River basin. This information will aid in future management decisions by agencies working in the upper Salmon River basin and help guide habitat conservation and improvement projects.

The Effects of Non-Native *Salmo Trutta* (Brown Trout) on Growth and Fitness of *Oncorhynchus Clarki Virginalis* (Rio Grande Cutthroat Trout) in Stream Enclosures on the Rio Cebolla, Jemez Mountains, New Mexico

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ABSTRACT—The purpose of this study was to examine the effects of interspecific competition between juvenile brown trout and Rio Grande cutthroat trout. One 28-day manipulative experiment was conducted on the Rio Cebolla, Jemez Mountains National Recreation Area, New Mexico in August of 2004. Sixteen temporary barriers were placed in the stream, effectively blocking 8 twenty-meter sections, and fish were stocked at a constant biomass within each section. Four of the blocks consisted of a sympatric treatment combination of 10 Rio Grande cutthroat trout and 10 brown trout. The remaining four blocks were used as allopatric controls. Two of the control treatments consisted of 20 Rio Grande cutthroat trout, and the other two consisted of 20 brown trout. In order to record growth rate and change in body condition, fish were recaptured at weekly intervals from their respective treatments using electrofishing techniques. Our analyses found that Rio Grande cutthroat trout growth significantly declined ($p < .001$) in sympatric treatments when compared to allopatric controls. In contrast, we found that brown trout growth significantly increased ($p < .005$) in combined-species treatments when compared to controls. These results suggest that brown trout displace Rio Grande cutthroat trout from optimal foraging habitats, and the subsequent decrease in Rio Grande cutthroat trout body condition suggests the former is accomplished through direct aggressive interactions.

Introduction

Worldwide, biological invasions are second only to that of habitat loss and destruction as a cause of the loss of biodiversity (Williamson 1996). The invasion of nonnative species into new ecosystems is accelerating as the human population continues to grow. Species of plants, animals, and microbes have been introduced for reasons ranging from agriculture to recreation. Only a small percentage of nonnative introductions result in conspicuous environmental impacts (Lodge 1993, Williamson 1996), however each introduction holds consequences for populations, communities, or ecosystems. Throughout North America, freshwater systems have proven particularly vulnerable to invasion from nonnative species. In the United States alone, over 100 aquatic invertebrate species and 138 nonindigenous fish species have been introduced (Courtenay et al. 1991, Courtenay 1993). Isolated freshwater desert systems, such as those found in New Mexico, experience relatively rapid effects from nonnative fish introductions. Consequently, there is a need for research to identify deleterious effects of these nonnative introductions, and mechanisms by which nonnatives may be affecting populations and communities.

Because Rio Grande cutthroat trout (*O. c. virginalis*) has been reduced to 5-7% of its historic native range, there is a need to determine the underlying mechanisms of this reduction. Contemporary data suggest declines in most of these species, particularly Rio Grande cutthroat trout, and possible relationships among these declines with introductions of nonnatives such as *O. mykiss* (rainbow trout), *Salvelinus fontinalis* (brook char), brown trout (*S. trutta*), and *Catastomus commersoni* (white sucker) (NMDGF 2002). The mechanisms by which these nonnatives species may be affecting native populations include hybridization, resource competition and predation.

Researchers in both academia (Trotter 1987, Wang and White 1994), and government agencies (Stefferud 1988, NMDGF 2002) have suggested that brown trout outcompete cutthroat trout through higher recruitment rates and increased food–resource acquisition as a result of heightened aggressive behavior (Nillson and Northcote 1981). Wang and White (1994) conducted laboratory competition experiments between brown trout and *Onchorhynchus clarki stomias* (greenback cutthroat trout), and discovered greenback cutthroat trout were displaced into upstream riffles (areas of scarcest food), when in sympatry. Additionally, the researchers found that brown trout solely occupied pool habitats (areas nearest food and most energy efficient) when the two species were in sympatry. In northern and central New Mexico streams where brown trout were introduced or invaded, Rio Grande cutthroat trout appear to be more abundant in headwater streams and brown trout are more abundant downstream. A similar pattern is seen in the northeastern United States between native brook char and brown trout. In many of the northeastern streams brown trout will force populations of brook char to retreat further upstream each year (Nyman 1970). Fausch and White (1981) presented data suggesting that brook char and brown trout compete for preferred resting positions, a critical and scarce resource, and that brown trout were dominant competitors suggested by the ecological release observed in brook char when brown trout were removed. Because brown trout and Rio Grande cutthroat trout evolved separately in similar environments they might be expected to exhibit a high degree of niche overlap, and possible competition for resources. If invading species interact with natives primarily through competition for limited resources, removal of the exotic should produce a compensatory increase in native populations (D’Antonio et al. 2001).

In general, superior competitors gain better foraging opportunity and increased protection from predators with concomitant increases in fitness, especially in species with variable growth patterns such as fish (Metcalfe et al., 1995). Growth in fishes is a sensitive index of resource availability and acquisition, and is generally positively related to fitness (Hall et al. 1970; Werner and Hall 1976). Bromage et al. (1992) reported positive correlations between body size, egg size and number of eggs produced in hatchery-raised salmonids. Jones and Bromage (1987) documented a 25% decrease in salmonid egg production associated with a 25% decrease in daily food ration. Therefore, competition for food resources can be expected to have direct effects on growth and body size and indirect reproductive consequences that decrease overall fitness.

The purpose of this study was to examine interspecific competition between Rio Grande cutthroat trout and nonnative brown trout. The experiment described here evaluates the consequences of competition on growth and body condition. Niche shifts in sympatry indicated by effect on growth is considered evidence of competition (Werner and Hall 1976; Diamond 1978; Gatz et al. 1987), but overlap in resource use alone does not indicate that species are competing (Sale 1979). In this study, growth in body mass and length was used as an indication of competition and effects on body condition was used as an indirect measure of its effects on fitness.

Materials and Methods

This study was conducted within the Rio Grande basin on the Rio Cebolla in the Jemez Mountains National Recreation Area, New Mexico (N 35.97011º W 106.66127º) (Figure 1). The Rio Cebolla is a first-order, cold-water trout stream with a substrate dominated by sand and gravel. It drains an approximate area of 35 km^2. The Rio Cebolla is a tributary of the Rio Guadalupe, which joins the Jemez River, a direct tributary to the Rio Grande. Its relatively small size made it an excellent site to conduct experiments within constructed enclosures.

Historically, the Rio Cebolla was within the native range of Rio Grande cutthroat trout. At the time of this study, the upper reach contained a restored population protected by a migration barrier (McKinney Pond). The barrier provides the restored population with protection from invasion of nonnative brown trout and rainbow trout. Because this study used nonnative brown trout, it was conducted downstream from McKinney Pond to ensure protection of the restored population of Rio Grande cutthroat trout. The fish community in this reach of the Rio Cebolla included brown trout, rainbow trout, Rio Grande sucker, and Rio Grande cutthroat trout.

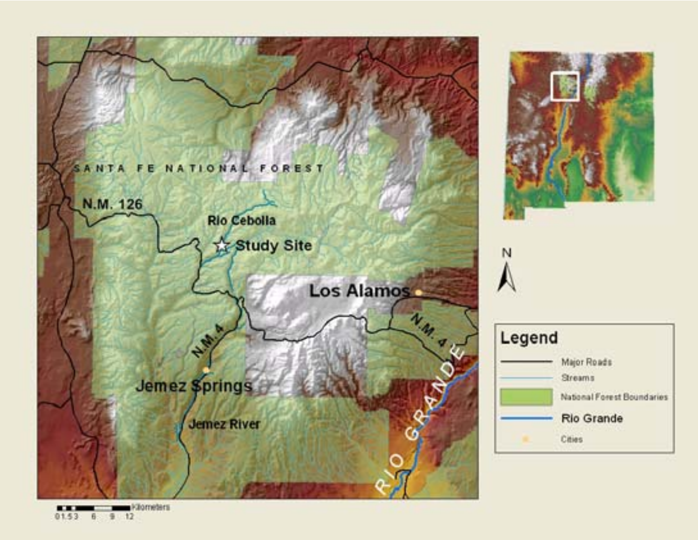


Figure 1. The study site on the Rio Cebolla is located in north-central New Mexico. It is a tributary to the Jemez River and part of the Rio Grande drainage basin.

A total of eight 20 m sections of the Rio Cebolla were selected as experimental sites. Each end of the experimental enclosures was delimited by a panel of 6.35 mm (1/4 in) expanded metal screen, reinforced with angle iron and reinforcing bar. Each screen spanned the entire width of the stream and provided complete enclosure from the stream substrate to 75 cm above the surface of the water. After the eight treatment enclosures were adequately blocked, all fish within them were removed using a Smith-Root LR-24 backpack electroshocker.

Total fish biomass was estimated and fish were placed downstream of all experimental enclosures. Mean biomass per unit area was subsequently used as a target for stocking each experimental enclosure. All enclosures were surveyed by electrofishing twice in the following two days in order to test the effectiveness of the temporary barriers and total removal of fish.

Data Collection and Analyses

The experimental design for the experiment consisted of a one-way classification analysis of variance with 3 treatments in a completely randomized design with two replicates of each treatment. The three replicated treatments consisted of allopatric Rio Grande cutthroat trout, allopatric brown trout, and two sympatric Rio Grande cutthroat trout and brown trout treatments (Table 1). Each treatment (allopatric or sympatric) began with a total of 20 like-sized fish, which yielded a total biomass consistent with that supported by the stream prior to the experiment This type of experimental design for testing interspecific competition was described by Underwood (1986). The abundance of wild brown trout in the Rio Cebolla allowed for the selection of equal sizes. Individual fish within each enclosure had a mass equal to 35 g ± 5 g, yielding a total biomass of 700 ± 50 g per 20 m enclosure. Each enclosure was randomly assigned a treatment. The fixed effects model (completely randomized hierarchical) was:

$$Y_{ijk} = \mu + T_i + R_{j(i)} + e_{ijk}$$

where μ is the overall mean, Y_{ijk} is the k^{th} observation (length or mass) in the j^{th} replicate ($R_{j(i)}$) of the i^{th} treatment (T_i = allopatric Rio Grande cutthroat trout, sympatric Rio Grande cutthroat trout – brown trout, or allopatric brown trout), and e_{ijk} is the residual error. Analyses were conducted using the general linear models procedure of SAS (SAS Institute, Inc. 1989). Significance in the ANOVA was judged by the Type III (partial) sums of squares because sample sizes were unbalanced. Least squares means for treatments were obtained from the ANOVA (Goodnight and Harvey 1978) and used for pairwise comparisons of treatments.

Table 1. Experimental treatments of Rio Grande cutthroat trout (RGCT) and brown trout (BT) selected to examine interactions.

Species	BT	RGCT
BT	BT * BT (allopatric)	BT * RGCT (sympatric)
RGCT	RGCT * BT (sympatric)	RGCT * RGCT (allopatric)

All Rio Grande cutthroat trout used in the experiment were obtained from the Seven Springs Fish Hatchery. Fish used in the experiment were hatchery produced progeny of fish that originated from the wild population in the Rio Las Vacas in 2002. All brown trout used for the experiment were collected from the Rio Cebolla using electrofishing techniques. Fish within individual treatments were uniquely marked using colored elastomer (Northwest Marine Technology, Inc.) injected subcutaneously utilizing combinations of four anatomical locations and two colors.

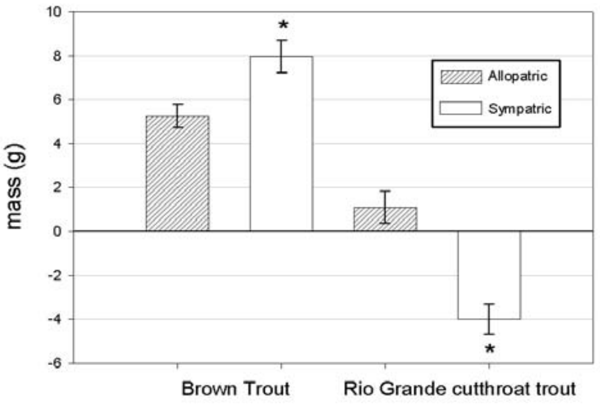
The experiment took place over a 28-day period between 08/13/03 and 09/09/03. This experiment was initially designed to span a 30-day period but heavy rainfall forced termination of the experiment two days early. Fish were recaptured from every enclosure at day 7, 18, and 28 using a backpack electroshocker (Smith-Root Inc.). Length and mass were recorded for each fish. All individuals were then released back into their respective enclosures. Temperature was recorded at five minute intervals using two water temperature loggers (HOBO), which were placed at the upper and lower enclosures. At the completion of this experiment all fish were euthanized and returned to the laboratory for examination of gut contents, assessment of fat deposition (Goede 1993) and measurement of fin condition. Fat deposition was qualitatively assessed through examination of the amount fat surrounding the pyloric caecum. Each individual was assigned a body condition ranking of 0, 1, 2, 3, or 4, which represented no fat, < 50% fat, approximately 50% fat, >50% fat, and 100% fat, respectively. In order to determine any significant differences between treatments, a Chi-square test of homogeneity was conducted on the body condition rankings. Fin condition was assessed by incidence of caudal fin damage or removal, which was either partial or complete. The proportions of fin damaged individuals were used to make comparisons within species and between treatments using t-tests.

Results

We surveyed four of eight enclosures to obtain an accurate estimate of the naturally occurring fish biomass throughout the study site. The four enclosures used were 1, 3, 4, and 8 all of which were randomly selected. Mean total biomass across all four enclosures was 716.64 g (SE = 62.75), which was used throughout the experiment for individual treatment biomass.

Due to flood flows that occurred on the final day of the experiment a total of 18 of 40 allopatric Rio Grande cutthroat trout and 19 of 40 sympatric Rio Grande cutthroat trout were recovered on the final recapture day of the 28-day manipulative experiment, whereas a total of 27 of 40 allopatric brown trout and 22 of 40 sympatric brown trout were recovered. No unmarked individuals were recaptured throughout the experiment. By including temperature as a fixed affect in the ANOVA model it was determined that temperature had no significant effect on growth of fish (P > .4). Overall significance of treatments was assessed with Type III sums of squares. The model was significant (ANOVA, $F_{(3, 82)} = 60.10$; P < .0001) with the dependent variable being difference in mass at the end of the experiment and start of the experiment, hereafter referred to as growth in body mass (g), and body length (mm). A Shapiro-Wilk test for normality was conducted on growth in body mass and total length, and was found to be normally distributed (P = .8291). Because ending sample sizes were unequal, least squares means were used to make individual comparisons between the three treatments.

Fish growth in body mass in all three treatments were found to be significantly different from zero (P < .05), and significantly different from each other using a Bonferonni adjustment to account for type II errors. Sympatric brown trout gained significantly more body mass than allopatric brown trout (P = .0027), however sympatric Rio Grande cutthroat trout displayed negative growth, which was significantly less than allopatric Rio Grande cutthroat trout growth (P < .0001), which was positive (Figure 2).



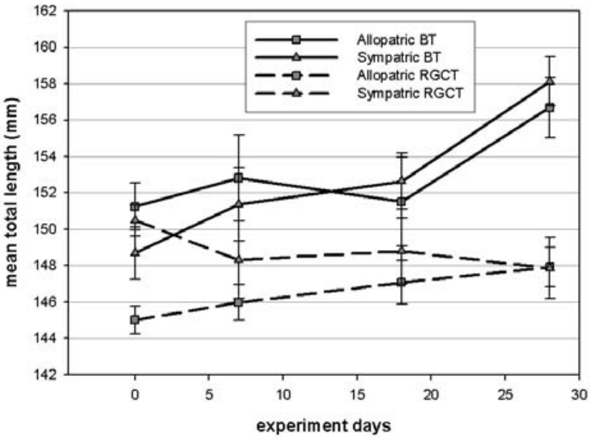


Figure 2. Mean 28-day change in mass (g) of Brown trout and Rio Grande cutthroat trout in allopatric and sympatric treatments in experimental enclosures throughout the experiment. An asterisk indicates a significant difference at p < 0.0083.

Figure 3. Mean 28-day change in body length (mm) of Brown trout and Rio Grande cutthroat trout in allopatric and sympatric treatments in experimental enclosures throughout the experiment.

Additionally, we found a significant effect of treatment on growth in body length (ANOVA, F $_{(3, 82)}$ = 14.47; P < .0001). Allopatric and sympatric brown trout did not grow significantly different from each other (P = .5), but both grew significantly more than allopatric and sympatric Rio Grande cutthroat trout (P < .001, and P < .0001), respectively. Interestingly, there was a negative mean growth in body length of -.91 mm in sympatric Rio Grande cutthroat trout, which was significantly less than allopatric Rio Grande cutthroat trout, which displayed positive growth in body length (pP = .003) (Figure 3).

Post-mortem fat content and fin lossin brown and allopatric Rio Grande cutthroat trout (X^2 = 5.48, P = .139) and no difference was found between allopatric and sympatric brown trout (X^2 = 4.65, P = .199). A significant difference was found between sympatric brown trout and sympatric Rio Grande cutthroat trout (X^2 = 28.11, P < .001). The incidence of Rio Grande cutthroat trout caudal fin damage was significantly higher in sympatry (88.8%) with brown trout as compared to allopatric treatments (11.1%) (t $_{(.01, 37)}$ < 3.042).

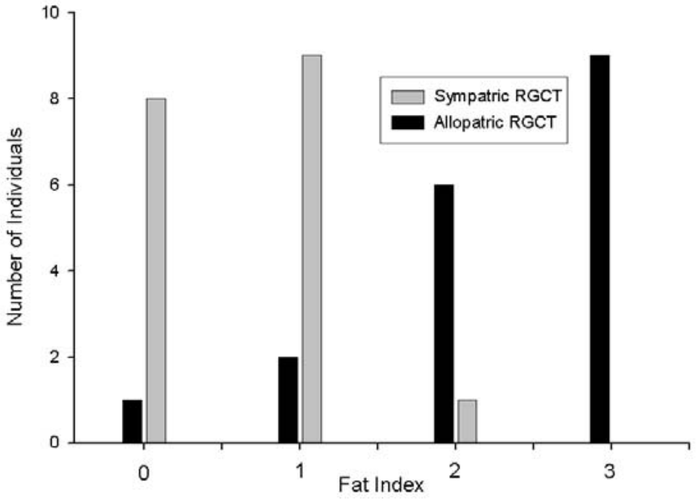


Figure 4. Post mortem fat analysis, using a standardized health condition profile, of Rio Grande cutthroat trout in allopatric and sympatric (w / S, trutta) treatments from Experiment 1 where a value of 0 represents 0% fat present on the pyloric caecum, 1 represents < 50%, 2 represents 50%, and 3 represents > 50%.

Discussion

This experiment supports our prediction that in unnatural sympatry nonnative brown will have significant effects on the growth of Rio Grande cutthroat trout. Using equal-sized fish in a natural setting, brown trout were clearly dominant competitors over Rio Grande cutthroat trout. In nature fall-spawning brown trout would have a size advantage over the spring-spawning Rio Grande cutthroat trout, but our experiments controlled for fish size. We found symmetrical competition between juvenile brown trout and Rio Grande cutthroat trout. Rio Grande cutthroat trout growth was lowest in the presence of brown trout, whereas brown trout growth was highest in the presence of Rio Grande cutthroat trout (Figure 5). In addition to demonstrating negative growth in sympatry with brown trout, Rio Grande cutthroat trout displayed significantly less fat deposition (Figure 9), suggesting displacement into less profitable stream habitat. One possible explanation is that Rio Grande cutthroat trout were displaced into high velocity riffles where the ratio of net-energy-gain / net-energy-loss was very low resulting in the observed fat loss.

Fausch and White (1981) conducted a study to examine resting positions of brook char and brown trout in allopatric versus sympatric conditions. The researchers found that brook char were displaced into less favorable resting positions when in sympatry with brown trout, and demonstrated a niche shift to more favorable, energy efficient positions when brown trout were removed. Fausch and White (1981) postulated that in small headwater streams with gravel and sand dominated substrates, such as that found on the Rio Cebolla, resting positions can be a scarce and aggressively defended resource. Competition for resting position in concert with competition for feeding position, are two possible factors responsible for the observed negative growth of Rio Grande cutthroat trout in sympatry with brown trout.

Wang and White (1994) set out to examine microhabitat shifts, particularly feeding position, in greenback cutthroat trout and brown trout when in sympatry as compared to allopatry. Most notably, they discovered that in sympatry greenback cutthroat trout held feeding positions twice the distance from the food source than when in allopatry. In contrast brown trout were found to hold positions closer to the food source when in sympatry. While the above studies provide valuable information regarding habitat shifts in sympatric conditions, to infer competition from their results may prove erroneous. If the authors were to demonstrate effects on growth, survival, or fecundity as a result of these niche shifts competition may be invoked. Our study directly addressed effects of sympatry on growth and body condition, allowing greater confidence in the declaration of the presence of competitive interaction.

Additionally, the present study discovered strong evidence of aggressive interaction between brown trout and Rio Grande cutthroat trout. In sympatry, 52% of Rio Grande cutthroat trout recovered at the end of the experiment exhibited varying levels of caudal fin loss, wherein allopatry only 11% of Rio Grande cutthroat trout exhibited caudal fin loss. These data confirm levels of active interaction between the two species, and suggest yet another explanation for the documented weight loss of Rio Grande cutthroat trout in sympatry. Aggression and territoriality in brown trout has been well documented (Hardwood et al. 2002; Johnsson et al 2000; Johnsson et al 1999; Wang and White 1994; Griffith 1988). Aggressive bouts and extensive chasing can be metabolically expensive resulting in the loss of fat stores, unless the interaction allows the dominant competitor to exploit additional resources. In our study, the significant loss of fat in sympatry ($p < .0001$) coupled with significantly higher incidence of caudal fin loss ($p < .01$), lend support to the aggressive nature of brown trout Rio Grande cutthroat trout interactions, and a causal mechanism for the observed loss in body mass of Rio Grande cutthroat trout in sympatry with brown trout. Based on our results, we recommend complete removal of nonnative brown trout prior to Rio Grande cutthroat trout repatriation attempts.

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Exotic Trout Effects on Pennsylvania Headwater Stream Food Webs

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ABSTRACT—We held native *Salvelinus fontinalis* (brook trout) and naturalized *Salmo trutta* (brown trout) in enclosures (1.14 m^2) during spring and summer 2003 in central Pennsylvania streams (Tomtit Run, Lingle Run) to measure their effects on benthic communities and detritus processing. Treatments (brook trout, brown trout, and no trout) were replicated at four sites in each stream; all enclosures had an upstream, fishless control section. After a two-week benthos colonization period, one trout (representative of the resident populations' average length) was placed in each enclosure (except for controls). Trout were held in enclosures for three consecutive weeks; subsequently, benthos samples (artificial substrates, leaf packets, and cobble) were collected from all enclosures. Brown trout were larger (18.0 ± 1.8 cm) than brook trout (13.5 ± 2.0) but biomass of the populations were similar within streams. Trout fed actively during trials as evidenced by observation and presence of stomach contents in most individuals at trial termination. Although total biomass of benthic organisms was slightly lower in the presence of trout, there were no significant ($p < 0.05$) differences among treatments on leaf loss, invertebrate abundance, richness, or biomass. Experiments are being performed again in Tomtit Run and Lingle Run from May to October 2004.