

General Session Papers: Western Division American Fisheries Society, Boise ID

(alphabetical order by session and by author)

Beyond Fish

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River ice disturbance: effects on organic matter & feeding ecology of aquatic insects

Disturbance is a critical factor shaping the structure and function of aquatic communities and ecosystems. Disturbances from ice, however, often are not considered within the natural disturbance regime of rivers. We investigated the effects of a river ice regime on organic matter dynamics and the feeding ecology of aquatic insects during winter. We collected monthly samples of organic matter (biofilm and seston) and aquatic insects from Big Creek, a 6th-order tributary of the Middle Fork Salmon River in central Idaho, USA. We documented patterns of river ice via direct observation and use of digital-interval cameras. Our results indicate that river ice affects both the quantity and quality of organic matter available to consumers. Specifically, scour from December and February ice-out events reduced periphyton biomass (ash-free dry mass and chlorophyll-a) by one-third and one-half, respectively, while quality (chl-a:AFDM ratio) increased. Diets of scrapers, Rithrogena (*Heptageniidae*) and Bibiocephala (*Blephariceridae*), collector-gatherer Baetis (*Baetidae*), and the collector-filterer, Simulium (*Simuliidae*), appeared to follow the patterns of organic matter in response to disturbance by river ice. These taxa consumed greater proportions of diatom frustules following ice-out events. In contrast, other taxa, such as collector-gatherer, non-Tanyptodinae (*Chironomidae*), and the collector-filterer, Arctopsyche (*Hydropsychidae*), did not follow patterns observed in organic matter. Rather, these insects consistently consumed high proportions of diatom frustules and insect material, which have been reported to be higher quality food resources than amorphous detritus and diatom stalks. The shredder, Pteronarcys (*Pteronarcyidae*), exhibited the greatest variability in its diet, and followed patterns observed in algal resources. Our study indicates that ice regimes in rivers affect dynamics of organic matter and the feeding ecology of aquatic insects in a trait-mediated fashion. Understanding the ecological consequences of river-ice is important in the context of a changing climate. Furthermore, predicting the net effects of global climate change is hindered because of the lack of aquatic research conducted during winter.

Beyond Fish

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Fishing for scientists: engaging the next generation using fish in the classroom

Scientists recognize our responsibility to communicate to the public including policymakers, managers and the press, but do we also have a responsibility to communicate science to the next generation? Over half of Colorado fifth-graders cannot pass the statewide science aptitude test and scores are even lower in schools with large proportions of low-income Hispanic students. It is critical that elementary students have positive, confidence-boosting experiences with science since attitudes towards science become fixed as early as fifth-grade. I argue that fish biologists are in a unique position to provide positive science experiences since we work with charismatic animals that have easily observable behavior. We should consider K-12 outreach an opportunity rather than someone else's responsibility. I also make the case that a significant impact can be made in only two hours. Here I present a program that I developed and implemented as a proof of concept. In just two hours, I helped 30 low-income, Hispanic fifth-graders design and conduct a one-month experiment on predator-prey interactions using live guppies and cichlids. The students collected data, analyzed the data using Microsoft Excel, and created a poster that they presented at a local scientific conference for ecologists in Colorado. If every fisheries biologist used their study species to engage K-12 students for just two hours, imagine the pivotal role we might play in increasing scientific literacy in the United States.

Beyond Fish

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Three common errors from using bioassessment methods to sample macroinvertebrate communities for non-bioassessment purposes

Macroinvertebrate surveys are useful for fisheries management because invertebrates are important as forage, in ecosystem processes and as environmental indicators. Regionally calibrated biocriteria provide managers with pre-packaged standard methods for the collection and analysis of macroinvertebrate samples. However, inappropriate uses of these methods produce data that are irrelevant to the intended study. Well-meaning reviewers often recommend these standard methods universally under the auspices of protecting the public's interest, but in so doing, they introduce errors and biases that are often overlooked. I present three examples of problems caused by using bioassessment methods for non-bioassessment applications. The first limitation is one of design and application. Bioassessment designs use a regional model and regional replication. Thus, the null-hypothesis tested is H_0 : the sample collected is not significantly different than the reference population. This is the only hypothesis that may be tested without replication, but because of the calibration measures, it is irrelevant for most fisheries investigations. The second problem results when sample units are combined in the field to produce a large single "composite" sample. The goal is to homogenize variance by increasing the area sampled, but I have found that high variances in metrics are common because fixed count subsampling protocols use only a very small portion of the sample. Composite samples stymie most useful forms of reach-scale/riffle-scale statistical modeling, reduce power and increase cost, but fail to homogenize variance; they should usually be avoided. The third problem relates to the effect of fixed-count subsamples and estimates invertebrate densities; a common need for fisheries studies. When fixed-count subsampling methods are used and small invertebrates become very abundant, they actually control how much of the sample is processed in the laboratory. This causes a bias error because some samples only require 0.5% subsampling, whereas others may use close to 100% to reach the subsampling target. Thus some densities will be estimated from a sample area of 0.0004 m², whereas others are estimated from >0.1m². Although these errors are common, they rarely addressed in aquatic resource reports, and they may lead to misinterpretation of results.

Beyond Fish

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Effects of reservoir operations on aquatic macroinvertebrate community composition and production in the Deadwood River, Idaho

We evaluated effects of reservoir operations on aquatic invertebrates in the Deadwood River below Deadwood Dam in central Idaho. The montane field sites included four sites in the regulated river and six reference sites located upstream of the dam and in nearby rivers. Macroinvertebrate, stream habitat, and water chemistry data were collected every 4 – 6 weeks from June through October in 2010 and 2011. Macroinvertebrate production was estimated over intervals between sampling dates. River temperature, discharge, and wetted streambed area were modeled for alternative scenarios of reservoir operations using a one-dimensional flow model and a high-resolution digital elevation model of the streambed. Results from the flow model were used to simulate effects of reservoir operations on macroinvertebrate production using an empirical mass- and temperature-dependent growth model for macroinvertebrates. Regulated and reference sites had similar physical habitat and water quality with the exception of periphyton abundance and organic matter, which were elevated at sites closest to the dam. Sites immediately below the dam differed in community composition and had lower richness and diversity; however, these effects attenuated quickly with distance from the dam. Annual production of benthic invertebrates was similar in regulated and reference sites. Production was at levels expected for arid montane rivers, and should provide a sufficient prey base for fish. Flow and temperature simulations suggested that the range of reservoir operations being considered by managers would not alter invertebrate production dramatically. The largest negative effect on invertebrate production occurred in simulations of wet water years, when there is little operational flexibility to increase water temperatures in the river.

Beyond Fish

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Using Simulation Modeling to Inform Forest Practices Regulations in Idaho

In Idaho, the Forest Practices Act Advisory Committee (FPAAC) has been working in conjunction with forest industry representatives, Idaho Department of Environmental Quality (IDEQ), and the US Environmental Protection Agency (EPA) to revise minimum stocking rules guiding timber harvest activities in stream management zones along fish-bearing streams. In revising the rules, FPAAC is responding to Forest Practices Water Quality audits conducted by the IDEQ which cited the need to better quantify rules to insure that stream temperatures are not adversely impacted as a result of harvest. In this presentation, we report on how FPAAC has been using these models to inform recommended revisions to Idaho Forest Practice Rules for streamside harvest. We show how these models were useful for understanding a) similarities and differences in the response of LWD recruitment and shade to forest management across the range of stand conditions encountered on commercial forests and b) tradeoffs in active management of streamside management zones and the conservation of aquatic habitat. As a “real-world” example, this case study not only has scientific value regarding prediction of LWD recruitment and shade in response to forest management, but it has social value demonstrating how a transparent decision-making process informed by subjective scientific evidence can counterbalance—to some extent—diverse interests and values represented by FPAAC members and participating state and federal agencies. The outcome—recommended riparian prescriptions—serve as hypotheses about the effects of forest management to be tested via effectiveness monitoring in an adaptive management framework.

Fish Interactions

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Stock Characteristics of Lake Whitefish in Lake Michigan

Lake whitefish (*Coregonus clupeaformis*) support important recreational, commercial, and tribal fisheries in the Great Lakes, including Lake Michigan. Genetic analyses indicate at least six distinct lake whitefish stocks exist in Lake Michigan resulting in a mixed-stock fishery. Biological characteristics could vary among these stocks, which could result in stock-specific responses to exploitation. The objectives of our study were to determine if capture location in October is an accurate identifier of genetic stock and to determine if stocks differ in terms of growth, maturation, age structure, condition, and fecundity. Initial results indicate that some biological differences exist among stocks; continued analysis will determine if these differences are meaningful from a management standpoint.

Fish Interactions

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Salmon vs Bass: An unreconcilable conflict?

This presentation will be a discussion of why fisheries managers should try to reach a middle ground in managing recreational fisheries that consist of both native and long established non-native species. In western aquatic systems like the Columbia River, and many reservoirs, where introduced sport fish, e.g., black bass and walleye, have existed for many decades and have become recreationally and economically important, does it make sense to target these fishes for elimination, even if that could be achieved?

Fish Interactions

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Status of the Wind River drainage, Wyoming sauger population

The Wind River drainage in Wyoming currently supports one of the most unique sauger populations throughout the range of the species. Saugers within the Wind River drainage occupy the highest known elevation, and are the slowest-growing and longest lived of any other population. Electrofishing population estimates conducted in 2009 and 2010 showed a 73% decline in sauger numbers since 2002. The decline was caused by a recent lack of recruitment, as 27% of the captured saugers were age-10 or older and juveniles were rarely observed. The cause of the decline in recruitment over the past decade is currently unknown because attempts to correlate environmental variables to catch curve residuals were unsuccessful. In an attempt to increase recruitment, the Shoshone and Arapaho tribes, U.S. Fish and Wildlife Service, and Wyoming Game and Fish Department began a supplemental stocking program in 2012. Additionally, studies are currently underway to learn more about the ecology of juvenile saugers and the environmental factors that influence sauger year class strength in the Wind River drainage.

Fish Interactions

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Agonistic behavior between three species of commonly stocked salmonids in Utah reservoirs

The potential for nongame fish species to explode with detrimental effects on sport fisheries in Utah has prompted managers to shift some stocking programs from exclusively rainbow trout, to include tiger trout and/or Bear Lake cutthroat trout as potential biological controls. However, inter-specific interactions among this unusual complex of predatory species are not well understood, and there is concern that the overall effect may be a decrease of overall trout condition. In Scofield Reservoir rainbow trout niche space overlaps substantially with Utah chub (nongame), indicating a similar trophic position. Large tiger trout and cutthroat trout occupy top trophic positions indicating considerable niche overlap and possibly direct competition for food and space. To evaluate the potential for negative interactions among these three species, we designed laboratory experiments to assess agonistic behavior. Differences in agonistic behavior between rainbow, cutthroat, and tiger trout were determined with replicated, pair-wise treatments of one fish of each species together in a tank. We then observed the number of chases and contacts occurring between species. In all treatments rainbow trout initiated significantly ($p < 0.000$) more aggressive interactions (primarily chases) than tiger or cutthroat trout. Feeding (pre-post) did not have a significant effect on agonistic behavior for any species; however relative differences in fish size did appear to influence the outcome of the interaction for tiger trout. Understanding agonistic behavior provides important information for determining niche overlap between, and resource availability for, these sympatrically stocked species.

Fish Interactions

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Attempting to purify a Yellowstone cutthroat trout stream by removing rainbow trout and hybrids via electrofishing

Backpack electrofishing removals of rainbow trout and hybrids were conducted during 2010 and 2012 to evaluate whether a hybridized population of Yellowstone cutthroat trout could be reverted back to a pure or nearly pure Yellowstone cutthroat trout population. Removals of rainbow trout and hybrids were conducted from an electric weir that blocks upstream migrating non-native salmonids from spawning in Palisades Creek (a South Fork Snake River tributary), upstream approximately 10 km to a cascading section of stream that appears to be a complete fish barrier. In 2012, phenotypic characteristics of the sampled fish were recorded for comparison against genetic identifications. Capture efficiency was surprisingly high at 51%, and was especially high for spawning fish (\geq about 250 mm TL) at 73%. Thus far, the removal effort has only slightly altered the salmonid composition in the stream, with Yellowstone cutthroat trout comprising 68% of all fish captured in 2010 and 81% in 2012. Total phenotypic accuracy for all fish was 89%, and nearly half the error was rainbow trout misidentified as hybrids. Thus $< 1\%$ of the Yellowstone cutthroat trout that were captured were mistakenly killed, and only 6% of the rainbow trout alleles that were captured were accidentally released. Our results suggest that, combined with an efficiently operated electric weir preventing rainbow trout and hybrids from accessing Palisades Creek, using electrofishing removals will be successful at reducing rainbow trout alleles in Palisades Creek to well below 10% in only a few more years.

Fish Interactions

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Non-native invasive fish....Should they be managed for the public to the detriment of native fish conservation?

It's not just about the 4 H's (hydropower, habitat, hatcheries & harvest) anymore. Now we have non-native invasive fish that have contributed to the decline of native fish and impaired our conservation efforts. Non-native invasive fish are a significant contributor in their decline and only recently have invasive fishes gained in our understanding and awareness. Non-native invasive fish are typically defined as species that establish and reproduce outside their native range and threaten the diversity and/or abundance of native fish species through competition, predation, parasitism or hybridization. Some non-native game fish (i.e., smallmouth bass, walleye and northern pike) fall into this category. However, they do provide for recreational fisheries. These invasive fish have spread and thrived throughout the Columbia River Basin due largely to the development and operation of hydroelectric dams. These dams have turned free flowing rivers into a series of pools and reservoirs, creating slow backwaters and warmer temperatures which benefits many non-native invasive species like bass and walleye. Coupled with intentional and unintentional introductions of non-native species, the future conservation of native fish is at risk. Management of non-native invasive fish needs to be evaluated in locations where they overlap with native fish conservation and especially when implementing provisions in the Endangered Species Act.

Fish Interactions

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Suppression of Nonnative Salmonid Species to Benefit Migratory Bull Trout in an Open System: Lessons Learned from an Effort Performed on the Lower East Fork Bull River, Montana.

During relicensing of its Clark Fork River dams, Avista Corporation cooperatively developed the Native Salmonid Restoration Plan (NSRP). In part, the NSRP recommended addressing impacts that nonnatives have on native salmonids (principally bull trout and westslope cutthroat trout). Due to documented impacts on bull trout of brown trout redd superimposition and brook x bull trout hybridization, a nonnative suppression effort was authorized for the lower East Fork Bull River (EFBR). This suppression effort employed electrofishing, selective passage at fish traps, and brown trout redd excavation to create a more favorable biological condition for native species in the lower EFBR. Specifically, the objective of a 90% reduction in one or more indices (numbers, density, or biomass) of nonnative salmonids at monitoring electrofishing sections was established. To assuage public concern, nonnatives greater than 150 mm were transported and released downstream in the lower Bull River. Concurrent programs included upstream passage of adult bull trout and limited habitat improvements. From 2007 through 2009, 10,938 salmonids were captured; of which 5,480 were nonnative brown, brook, and rainbow trout (4,665 fish smaller than 150 mm were euthanized, while 815 larger fish were released in the Bull River). Comparison of indices at monitoring electrofishing sections after three years of suppression efforts showed that while nonnatives were significantly reduced for most comparisons, the targeted 90% reduction was generally not achieved. Positive responses from native species included a significant increase in native species' percent composition and an overall increase of 280% for juvenile bull trout density. Suppression efforts were reduced to trapping and brown trout redd excavation beginning in 2010. From 2010 through 2012, annual monitoring via electrofishing depicted that the large increase in juvenile bull trout apparently facilitated by the three years of intensive suppression was short lived. Difficulty in maintaining closure from adjacent sources of nonnatives allowed a degree of recolonization through 2012; although nonnative indices largely remained below 2007 levels.

Fish Interactions

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Response of wild trout to stream restoration over two decades in the Blackfoot River Basin, Montana

Anthropogenic degradation of aquatic habitats has prompted worldwide efforts to improve or restore stream habitats for fisheries. However, little information exists on the long-term responses of salmonids to restoration in North American streams. To recover wild trout populations in the Blackfoot River in western Montana, a collaborative approach to stream restoration began in 1990 to improve degraded stream habitats primarily on private land. To assess the efficacy of various restoration techniques (channel reconstruction and placement of instream habitat structures, restoration of natural instream flows, installation of fish ladders and screens at irrigation diversions, and modification of grazing practices) in the recovery of wild trout, we examined long-term (>5 years) trends in trout abundance on 18 tributaries treated between 1990 and 2005 and monitored between 1989 and 2010. At pre-treatment conditions, average trout abundance was significantly lower in treatment versus reference sites (0.19 versus 0.62 trout/m; $P=0.0001$). By three years post-treatment, trout abundance had increased significantly to an average of 0.47 trout/m across treatment sites ($P=0.01$) and was no longer significantly different from the reference average ($P=0.12$). These initial rapid increases were sustained over the long-term (5-21 years) in 15 streams. However, trout abundance declined below pre-treatment levels on three streams presumably due to the return of human impacts from heavy riparian grazing and detrimental irrigation practices. Although long-term (12-year) average response trends were positive, trends varied spatially with native trout responding more strongly in the upper portion of the basin. Study results indicate that restoration should focus in the mid- to upper-basin and emulate features of natural channels to promote life history diversity and the recovery of native trout. Finally, long-term monitoring led to adaptive management on most (10 of 18) projects, and thus proved vital to the overall sustainability of wild trout fisheries throughout the basin.

Fish Interactions

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Smallmouth bass abundance and dietary habits at three mainstem Columbia River dams: are tailrace and forebay environments 'hotspots' of salmonid predation?

For several decades, much investigation has been devoted to understanding and managing predation by fish on juvenile salmonids in the Columbia River Basin. Non-native species such as smallmouth bass have become a higher profile species of concern for which past studies have identify their potential impact to be insignificant in some areas while other areas have identified severe impacts to be probable in localized areas. One such area of concern involving smallmouth bass impacts on migrating juvenile salmonids is near three lower Columbia River dams. Beginning May 2011, Oregon Department of Fish and Wildlife implemented a hook-and-line sampling study to quantify smallmouth bass abundance and to assess dietary habits in the restricted tailrace and forebay zones of The Dalles, John Day, and McNary dams. Findings after two seasons of study (May—August, 2011 and 2012) will characterize spatial and temporal characteristics of smallmouth bass abundance and their dietary habits during the period.

Fish Interactions

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Population Dynamics of Northern Pike and Smallmouth Bass in Lake Coeur d'Alene, Idaho

Cutthroat trout (*Oncorhynchus clarkii*) in Lake Coeur d'Alene, Idaho have declined in recent years. The decline is thought to be largely due to predation by northern pike (*Esox lucius*) and smallmouth bass (*Micropterus dolomieu*), two important sport fishes in the system. To better understand factors influencing cutthroat trout in Lake Coeur d'Alene, this study was conducted to describe the population structure and dynamics of northern pike and smallmouth bass. Fishes were sampled from March 2012 to November 2012 from four bays using experimental gill nets and pulsed-DC electrofishing. A total of 480 northern pike varying in length from 170 to 1,080 mm and in weight from 26 to 9,628 g was collected. A sample of 1,032 smallmouth bass was also collected varying from 37 to 492 mm in length and 1 to 1,604 g in weight. Proportional size distribution was used to evaluate size structure and relative weight was used to evaluate body condition of northern pike and smallmouth bass. Pelvic fin rays and cleithra were used to estimate age structure and growth of northern pike. Smallmouth bass age structure and growth was evaluated using dorsal spines and saggital otoliths. Results of this study will be used to compare population dynamics of northern pike and smallmouth bass in Idaho with other populations in North America. In addition, these data will provide information useful for cutthroat trout conservation efforts.

Fisheries Techniques

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Evaluations of Artificial and Natural Markers for Monitoring Hatchery Releases of Juvenile Burbot (*Lota lota*)

A distinct population of burbot (*Lota lota*) native to the lower Kootenai River (located in Idaho, USA and British Columbia, Canada) has been categorized as functionally extirpated as a result of physical alterations to the river. In response, an international conservation strategy has incorporated supplementation as one of several approaches to restore this population to historical levels. Stock enhancement programs often rely on marking or tagging of juvenile fish to monitor and evaluate stocking success. However, limited information is currently available on marking juvenile burbot. Our objective was to evaluate a variety of marking options compatible with burbot conservation and population-level rehabilitation. We established six criteria as guides for marker selection prior to conducting our evaluations. In a 1-month trial of artificial marks applied to fingerling burbot (fin clips, freeze brands, visible implant elastomer (VIE) tags, passive integrated transponder (PIT) implant), we observed no adverse tagging effects on fish survival and growth. A follow-up 2-year trial determined that only 3 (anterior dorsal fin clip, pectoral fin clip, PIT implant) of 17 tested artificial marks showed long-term retention rates exceeding 90%. Aging, fish growth, tag color, and mark location were significant factors affecting retention of either VIE tags or freeze brands. A separate 1-year trial comparing surgical insertion and needle injection of PIT tags found that both methods resulted in excellent tag retention (99%) and no adverse long-term effects on juveniles. Additionally, we conducted a 1-month trial of coded wire tags (CWTs) implanted in six body locations and observed high average tag retention (98%) and no adverse effects on fingerling survival and growth. Post-trial investigations determined that fingerling burbot can be mass-marked with PIT tags, anterior dorsal fin clips, and CWTs at tagging rates averaging 280, 470, and 550 fish/h/station, respectively. Lastly, we examined genetic markers as a natural means to identify hatchery-reared burbot. We determined that microsatellite loci previously developed for studies of burbot phylogeography can be optimized for parentage-based tagging. Results from these investigations will have broad implications for understanding the economy and ecology of future burbot stock enhancement strategies.

Fisheries Techniquess

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Efficacy of mobile electrofishing equipment for inducing lake trout embryo mortality

Suppression is an important tool in management of invasive lake trout populations across the Intermountain West. Evaluation of these programs indicates that population growth is highly sensitive to reproductive vital rates. Suppression efforts often use targeted gillnetting of spawning adults to affect reproductive success. To supplement the targeted gillnetting, natural resource agencies are looking for ways to further decrease early survival. We evaluated the efficacy of a towed electrode array for inducing mortality in lake trout embryos. To confirm the results of pilot trials, we exposed rainbow trout embryos to 2, 5, and 10 v/cm for 0.1, 0.5, and 1.0 s in a laboratory. Embryo mortality was 100% when exposed to 10 v/cm for 1 s, and was not different than control exposures at 2 v/cm. To test the array in situ, and to determine the effect of burial on embryo mortality, a prototype electrode array was mounted to tracks moved across the lake trout spawning area in Swan Lake, Montana. In situ, the mean proportion of eggs killed at the surface of the substrate was 0.79 (SD, 0.21), where the mean was 0.13 (SD, 0.13) when eggs were buried 20 cm deep. The electric field of the mobile unit was lower at deeper substrate depths, allowing embryos to survive a short duration exposure in areas of low voltage gradient. These results suggest a towed electrode array will not be effective in reducing embryo survival. An array that is still mobile but much more sedentary is being developed and tested.

Fisheries Techniquess

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Graduated-Field Fish Guidance Technology: A Review of Successes, Limitations and New Concepts for Hydropower and Other Applications

Various technologies have been developed for fish guidance at hydropower and water diversion projects. Historic attempts to guide fish with electricity used alternating current (AC) for deterrence. This paper highlights an innovative approach to fish guidance, one that combines recent developments in the use of pulsed DC fields to achieve fish guidance success: the Graduated Field Fish Barrier (GFFB). There are 49 GFFB electric arrays in use around the world for fish guidance and deterrence. GFFBs have demonstrated an ability to guide fish away from areas where fish injury potential is greatest. We review published data on the efficiencies of GFFBs and other bottom-mounted, electric guidance arrays (which can be up to 100% effective) from results in peer-reviewed literature. Published accounts primarily address deployments to block the movements of invasive species (e.g. Asian carp; Chicago Ship Canal). Hydropower facilities using GFFBs include a tailrace barrier for a power plant in Vessy, Switzerland, a tailrace barrier at a hydro facility in Beeston, U.K., and a cooling water intake barrier in Canada. This paper outlines “the lessons learned” in applying electric barrier technology ... addressing its successes, challenges, limitations and design modifications to enhance effectiveness. One of the highest priorities for hydropower development is the need to safely guide downstream-migrating fishes away from water intakes. An innovative GFFB concept will be presented to address this need. The key may be in combining graduated electric guidance fields with other technologies that promote sensory avoidance stimuli.

Fisheries Techniquess

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Development of a tool to evaluate outplanting strategies and prespawn mortality of Upper Willamette River spring Chinook

Willamette River spring Chinook salmon represent an economically and culturally important species of conservation need. Access to many Willamette River basin spawning areas are blocked by dams, and fish are trapped, hauled, and outplanted into upstream spawning habitats to supplement natural production. However efficacy of outplanting efforts has been limited by high prespawn mortality (PSM) levels, especially in years with elevated water temperatures. Experimental adult holding in cool water has resulted in decreased PSM relative to fish experiencing natural environmental conditions. Ongoing experimental and observational studies indicate that limiting accumulated degree days limits PSM via effects on energetic status, and pathogen development and expression. Evaluating management alternatives that minimize PSM in outplant basins within the Willamette River system is difficult since accumulated degree days of migrating adults depends on entry to and duration in the migratory corridor and management alternatives are constrained by conservation hatchery operations (e.g., brood stock quotas). We developed a model to objectively evaluate management alternatives hypothesized to reduce PSM of spring Chinook within system constraints for outplanted spring Chinook in upper Willamette River basins. The model was developed using data from passage counts at Willamette Falls, radio telemetry studies, and upstream dam captures to simulate accumulated degree days in the migratory corridor and subsequent capture at dams. Among scenarios evaluated, outplanting fish from throughout the run minimized total accumulated degree days of directly outplanted fish while providing sufficient fish for hatchery needs.

Fisheries Techniquess

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30 Years of Weir Operations on the Imnaha River: the Effect of Logistics on Salmon Management and Biology

Hatchery supplementation programs have goals and/or objectives that guide program management and protocols that direct the daily operation of the program. Weir protocols often direct when the weir will be operated, which fish are to be collected for broodstock, which are to be released above or below the weir and which are to be removed from the population for other uses (e.g., outplant to another stream or tribal subsistence/foodbank). Such protocols may be designed to insure that goals are met, such as broodstock collection and hatchery:natural and/or age class ratios of spawners in nature or the hatchery. However, events and logistical constraints that are beyond the control of managers often affect their ability to follow protocols and meet the underlying goals and objectives. This talk will present the goals/objectives and protocols of the Imnaha River Chinook Salmon Supplementation Program, its logistical constraints and our ability to follow its weir operation protocols. The Program began in 1982 with the collection of 28 natural Imnaha River salmon for broodstock. Weir restrictions have constrained the program from its inception, the most influential being that 1) the weir is located in the middle of the spawning range, so some salmon never encounter the weir, and 2) the weir cannot be installed until stream discharge decreases to $28 \text{ m}^3/\text{s}$ - the mean date of weir installation has been 30 June, well after the first salmon have arrived in the river. As a result, means of only 42% of the total run and no more than 60% of the run that reaches the weir location are captured. In addition to limiting our achievement of Program goals, these constraints may also affect the biology of the Chinook salmon population that we are trying to support with this supplementation program.

Fisheries Techniques

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Counting Salmon in California: A Return on Investment for Effective Salmon Conservation

A significant legislative milestone was reached this year when the Governor signed Assembly Bill 1961 (Huffman – Coho HELP Act of 2012). The Act, also known as Assembly Bill (AB) 1961, aims to remove burdensome permitting obstacles that inhibit private landowners, particularly timber companies, from implementing high priority salmon recovery actions for the streams that run through their properties. Once AB1961 takes effect and timber companies and other landowners begin salmon habitat restoration projects on their properties, a critical question will arise: how do we know these projects are successful and are resulting in more fish? Currently, the scientific and regulatory community do not know how many salmon come back to spawn in California coastal rivers. Without population data, it is difficult to correlate salmon population changes to specific restoration projects. We are thus hamstrung in our ability to measure the cost effectiveness of recovery actions and to adjust our actions accordingly. Measuring progress and end results is a common practice in business and is viewed as a best practice in conservation. However, tracking progress and results in salmon conservation, particularly in California, is rare. State and federal agencies do monitor salmon populations that continue to support commercial fishing, but spend little in the way of resources (technical and financial) to monitor wild coastal salmon and steelhead, which are no longer part of a commercial fishery in California due to their low numbers. Government agencies and conservation organizations spend tens of millions of dollars on salmon restoration actions annually in California; however they spend only minor amounts on monitoring returning spawners. Therefore, the salmon restoration community has little understanding of how cost-effective recovery actions have been. TNC will compile current and historic adult salmon spawning population data, organize it and publish it in a user-friendly, web-based format and in annual snapshot documents, alongside watershed specific restoration accomplishments to demonstrate the value of metrics to support an increase in funding from both public and private sources. TNC will share this Salmon Snapshot with a broad range of stakeholders in order to advocate for the establishment and funding of a coast-wide monitoring program.

Fisheries Techniquess

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Electrofishing with spheres, rings and rods: electrical fields of three common electrodes

Electrofishing has evolved to the point where spheres, rings and rods are the shapes most commonly used for electrodes. The effects of size and shape of these electrodes on electrical fields have not been adequately studied under controlled conditions. In a concrete hatchery raceway, I compared electrical fields in terms of voltage gradient (V/cm) for 15-cm (6-inch) and 30-cm (12) diameter rings and spheres and 48-cm (19-inch) and 96-cm (38) long rods. Rings and rods consisted of four stock diameters: 3 (1/8-inch), 6 (1/4), 10 (3/8) and 13 mm (1/2). Identical pairs (e.g., two 15-cm spheres) were suspended 300 cm (rings and rods) or 500 cm (spheres) apart and energized with 120-V AC. In-water voltage was measured between each of the 18 electrode pairs and converted to voltage gradients after adjustment to 100 applied volts as a standard. Voltage gradients were compared at 1 cm (hazardous to fish) from electrodes and at distances to 1.0 and 0.1 V/cm (inner and outer edges of the effective electrical field). Gradients at 1 cm were lowest for the 30-cm sphere (4-5 V/cm) and increased with decreasing stock diameter; 3-mm stock produced the highest gradient (18-21 V/cm). Distances to 0.1 V/cm were longest for the 30-cm sphere and 96-cm rods (up to 83 cm), followed by 30-cm rings (55-64 cm) 48-cm rods (46-61 cm) and 15-cm rings (40-47 cm). All electrodes produced 1.0 V/cm at about 10 cm. Small stock diameters (3 and 6 mm) produced very high voltage gradients near the electrode, a greater hazard for fishes. Contrary to conventional wisdom, field size was more affected by electrode size and shape than stock diameter. Rings, compared to rods of equal stock diameter, produced smaller fields. Electrofishing-based projects aimed at small and juvenile fishes in shallow water will be more effective with smaller rings and rods made of smaller stock. Those aimed at larger fishes in deeper water should use larger rings or rods with larger stock diameter, or spheres.

Fisheries Techniquess

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Comparison of techniques for sampling juvenile burbot in lotic systems

Burbot *Lota lota* in the Kootenai River have declined in abundance over the past 60 years. Consequently, conservation efforts (e.g., habitat restoration, conservation aquaculture) have been initiated by a multiagency coalition. Despite increased monitoring efforts, few juvenile burbot have been sampled in the system. Our research compares three sampling techniques (i.e., boat-mounted electrofishing, benthic trawls, small-mesh hoop nets) for sampling burbot with a particular focus on juveniles. Due to low burbot densities in the Kootenai River, the Green River of Wyoming was selected as a secondary sampling location and used to compare sampling techniques in a system with higher burbot densities. In the summer and fall of 2012, 26 reaches were surveyed two to six times in the Kootenai and Green rivers. Comparisons of catch by sampling technique and river system were investigated. Burbot were predominately captured using electrofishing in the Kootenai River and hoop nets in the Green River. Results of this research will help identify the best sampling technique(s) for juvenile burbot in large river systems.

Fisheries Techniquess

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Evaluation of sampling designs to assess status and temporal change for salmonids in Yellowstone Lake

Fisheries management works best when the sampling design clearly matches the evaluation of the management action of interest. The management action in Yellowstone Lake is to decrease non-native lake trout *Salvelinus namaycush* catch per unit effort (C/f; number of fish per 100-m net night) 15% per year through 10 years to 0.1 and elicit a positive response in Yellowstone cutthroat trout *Oncorhynchus clarkii bouvieri* C/f. The National Park Service desires the ability to detect a 15% annual change in C/f for Yellowstone cutthroat trout and lake trout through 1 year at $\alpha = 0.05$. We used variance components to quantify sources of variation with existing C/f data and simulations to assess the statistical power of various sampling designs to detect temporal change in C/f. We assessed accuracy for estimation of mean C/f in a given year (i.e., status) to determine whether a tradeoff existed between ability to estimate temporal change versus status. We evaluated sampling designs where all sites were fixed through time, all sites were selected randomly each year, and half of the sites were fixed through time while half were sampled randomly each year or revisited with a frequency of 2 or 3 years. Power to detect change was lowest when sites were sampled randomly each year and highest when all sites were revisited each year or every 2 or 3 years. Power increased when t-tests were used for detecting temporal change rather than linear models and was greater for lake trout than Yellowstone cutthroat trout. Change in lake trout C/f could only be detected with 0.80 power at $\alpha = 0.05$ after 5 years when annual change was 15%. Sampling designs had similar accuracy for estimating status. Our results provide a useful case study for managers optimizing sample allocation for assessing temporal change and status with C/f data.

Fisheries Techniques

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Assessing the predictive ability of a process-based net rate of energy intake model for drift-feeding salmonids

Ecologists often use habitat suitability models to assess habitat quality and availability for fishes, but these preference-based approaches have been criticized for neglecting important habitat characteristics like food availability. Recently, foraging models that include considerations for depth, velocity, temperature, and food availability demonstrated success identifying profitable foraging locations for drift-feeders and suggested a link between model predictions and habitat quality. Despite promising results, application of these models remains limited. We used a process-based net rate of energy intake (NREI) model (Hayes *et al.* 2007) to determine if observed steelhead trout (*Oncorhynchus mykiss*) density and biomass were related to model-predicted steelhead density, biomass, and area of suitable habitat in 22 stream reaches in Washington and Oregon. We used information from the Columbia River Habitat Monitoring Program (CHaMP) and the Integrated Status and Effectiveness Monitoring Program (ISEMP) including streambed and floodplain topography surveys, drift samples, temperature information, and fish abundance estimates calculated using mark-recapture methods. Observed fish density and biomass were weakly correlated with predicted density and biomass respectively, but observed fish density and biomass were not well correlated with area of suitable habitat. Challenges associated with widespread application of this modeling approach involve the use of cross sections to discretize stream space and issues related to the introduction of drifting invertebrates into the water column. Despite these challenges, results suggest that this process-based NREI model may synthesize multiple variables collected in CHaMP and help describe salmonid habitat quality.

Ocean

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Finfish catches in tropical estuarine systems: How to manage multispecific fisheries?

Small scale fisheries in tropical and subtropical areas have high importance for hundreds of families. In Mexico this kind of fishery accounts for approximately 108000 tones/year. However, information related to these fisheries is scarce, although it is known that the landings have decreased and the effort has increased, and there are evidences of possible changes in the specific composition of the species, which could have effects on the economic revenue if the species are replaced for others with less economic importance. Therefore there is a need for a proper management program of the artisanal finfish fishery in order to achieve long term sustainability. But a problem with this fishery is that this is a multi-specific fishery that catches more than 200 species. The objective of this work is to analyse the landings together with data from experimental surveys in different estuarine systems along the SE Gulf of California, to propose a management program that considers the problem of multispecificity.

Ocean

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How the hydrological changes associated to human activities impact mangroves and fisheries

Mangrove-estuarine complexes in the Pacific coast of Mexico comprehend the largest mangrove region in the Pacific coast of America, and it has been an important region for artisanal fisheries since 3000 A.C. Since the 1970's this region has been strongly affected by human activities. It is estimated that 8,000 hectares of mangrove have been depleted, but the new marine conditions and the absence of mangroves from some areas has apparently improved the local shrimp and finfish fisheries. In this work we attempt to understand why.

Ocean

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Diagnosis and Treatment of the Bay Delta Ecosystem

Numerous stressors on the Bay-Delta ecosystem have resulted in impaired habitat conditions for many delta fish species. Ecosystem-based management of the Bay-Delta is a policy and management goal that requires an understanding of the ecological requirements of managed species. We examined the health of the Bay-Delta ecosystem through the eyes of delta smelt (*Hypomesus transpacificus*) using the Ecosystem Diagnosis & Treatment approach. We developed spatio-temporal trajectories for delta smelt based on previously published descriptions of their life history. Potential performance along these pathways was described in terms of population potential based on Beverton-Holt stock-recruitment parameters. Actual performance for current (patient) and historic (template) conditions was estimated in terms of degradation of the benchmark Beverton-Holt performance across each life stage based on environmental conditions and a set of straw-man rules defining sensitivity to the environment. The approach allows us to diagnose limiting factors, limited life stages, and priority restoration areas for treatment planning. The impacts of water exports, expressed as entrainment and changes in velocity, showed a substantial impact on productivity of delta smelt for all life stages. However, the long-term primary environmental drivers of delta smelt performance appear to be a ten-fold degradation of capacity due to loss of food quality and healthy spawning habitat. The existing set of species-habitat rules and performance benchmarks require review and refinement from the scientific community. However, we believe the overall approach will be of considerable utility to planning, conservation, and restoration efforts in the California Bay-Delta ecosystem.

Resident Fish Issues

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Lake hypolimnetic oxygenation influence on a brook and rainbow trout fishery

Lake eutrophication can threaten deep lake coldwater fisheries by causing a summertime temperature and dissolved oxygen habitat squeeze. Anthropogenic eutrophication in North Twin and South Twin Lake, Washington has apparently degraded brook (*Salvelinus fontinalis*) and rainbow trout (*Oncorhynchus mykiss*) habitat, reducing trout condition, growth, and survival. To address these concerns, external nutrient inputs have been limited and hypolimnetic oxygenation was implemented throughout the summer stratification season in North Twin Lake beginning in 2009. South Twin Lake has been used as a non-oxygenated reference lake. Trout in North Twin Lake immediately expanded their habitat use and began to occupy the oxygenated hypolimnion. We compared trout condition, growth, and survival in oxygenated North Twin Lake to South Twin Lake. Our results suggest oxygenation has not had a significant short-term influence on brook or rainbow trout condition assessed as relative weights. Both lakes continue to see significant reductions in rainbow and brook trout relative weights during early summer and stabilize at lower relative weights in later summer. Some years, brook trout relative weights remain stable throughout the summer in both lakes. Growth rates for rainbow and brook trout are also similar between lakes throughout the summer. However, catch per unit effort data from 2010 revealed that North Twin may have a higher annual carryover of rainbow trout stocking classes compared to non-oxygenated South Twin. Although trout condition and growth appear not to have been influenced by oxygenation in the short-term, hypolimnetic oxygenation may offer long-term benefits by increasing trout survival necessitating fewer stocked trout to support the fishery.

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Estimating the Ages of Black Hills Mountain Sucker from Four Calcified Structures: Precision, Population Dynamics, and Management Implications

Mountain sucker (*Catostomus platyrhynchus*) has declined in parts of its range and is listed as a species of greatest conservation need in South Dakota. Little is known about mountain sucker population dynamics and an assessment of population metrics may benefit from identifying structures that provide reliable age estimates. To address this need, we evaluated the relative precision of scales, sectioned fin rays, whole otoliths, and polished otoliths to estimate mountain sucker ages. We then described age structure, recruitment, growth, age and size at maturation, and mortality for one population of mountain sucker in the Black Hills of South Dakota. Polished otoliths had the highest precision of the four structures used, followed by sectioned pectoral fin rays. Multiple year classes were present, indicating consistent recruitment, and the population contained individuals up to age-6. Individuals grew to 100 mm total length during the fourth growing season and reached an average maximum attainable size of 219 mm total length. Mountain sucker matured as early as age-3, and nearly all were mature by age-5. Natural mortality was estimated to be 25% in the Black Hills. These data increase the understanding of mountain sucker ecology in the Black Hills and may improve its range-wide conservation. These metrics indicate that mountain sucker might respond quickly to management actions due to its relatively short life span. In other mountain sucker populations, we recommend using polished otoliths to estimate age, but sectioned pectoral fin rays provide a suitable non-lethal structure.

Resident Fish Issues

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Metadata Analysis of Wild Cutthroat Trout Trap Data from Utah

Data from eight wild trap sites in Utah which are used for obtaining eggs from wild cutthroat trout were analyzed to determine possible effects on egg survival. Variables examined included 1) size of the water body, 2) use of electrofishing to capture brood fish(yes/no), 3) distance of travel between site and receiving hatchery, 4) time of year (Julian day), 5) egg-take order (e.g, 1st take versus 2nd, 3rd, or 4th take), travel on dirt road from site (yes/no), 6) strain (Bear Lake Bonneville ([CTBL], Bonneville[CTBV], Colorado River [CTCR] cutthroat trout), 7) trap site, 8) number of eggs in a take, and 9) site elevation. Two overlapping data sets were used, one which had data from all years (1973 to 2012), and a second which had data from 2008 to 2012. Several trap sites began within the last five years, so the second data set is more balanced across all sites and minimizes the effects of earlier years; it also has data at the egg-take level, rather than for the year (average of all egg takes). In addition, since 2008, all wild cutthroat trout eggs have been sent to one hatchery for incubation. Analysis of the first data set indicated significant differences in egg survival to eye-up among trap sites and among the three cutthroat trout strains: CTBL (83.3%) >CTCR (54.0%) or CTBV (69.8%). There was a weak ($r = 0.35$), but significant ($p = <0.001$), positive correlation between the number of green eggs taken (log scale) and the resulting eye-up. The eye-up was not significantly influenced by elevation or reservoir area or travel distance in the first data set, but in the second data set, reservoir area was the most significant variable in the multiple regression. Travel distance was also significant. However, site elevation, electrofishing, dirt road travel, and Julian day were poor predictors of survival to eye-up. There were no significant differences among takes for any of the cutthroat trap sites; however, when all years for the Dougherty Basin Lake trap were analyzed, there was a significant drop in eye-up from the second to the third egg-take.

Resident Fish Issues

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An In Situ Egg Box Experiment to Assess Kokanee Shore-Spawning Incubation Success in Lake Pend Oreille, Idaho

Kokanee (*Oncorhynchus nerka*) are an important prey and sport species in many western lakes and reservoirs. Kokanee spawn predominantly on the shoreline in Lake Pend Oreille (LPO). Winter water level drawdowns are thought to decrease kokanee recruitment by reducing the availability of wave-washed spawning gravels, which primarily exist above the minimum winter lake elevation. In 1996, the Idaho Department of Fish and Game adopted a lake level manipulation strategy to increase kokanee recruitment by holding the winter lake elevation at a higher level to provide more gravel for kokanee to spawn in. The lake level manipulation strategy assumes that shoreline spawning habitat is limiting and that kokanee only spawn in shallow areas. Recent observation and underwater videography has challenged this premise with the discovery of large numbers of kokanee spawning in suboptimal gravel (e.g., silt and sand) and at depths in excess of 10 m. The goal of this study was to evaluate the influence of a suite of abiotic variables on shore-spawning kokanee incubation success in LPO. The validity of the lake level hypothesis was addressed in the experiment by assessing the viability of eggs deposited at depths greater than 4 m and measuring the relationship between substrate size composition and egg-to-fry survival. Egg incubation boxes were buried in substrate by divers in a 4 × 4 matrix at shallow (1-4 m) and deep (10-15 m) isobaths within three major lakeshore spawning reaches. Habitat variables that were measured included depth, substrate composition, intragravel dissolved oxygen, shoreline slope, and groundwater influence. Egg survival was not related to the depth of boxes and substrate composition alone was a poor predictor of egg survival. At several sites, dissolved oxygen and egg survival appeared to be enhanced by downwelling. These results suggest that spawning habitat on the shoreline of LPO is not as limited previously thought and that groundwater may play a role in spawning site selection.

Resident Fish Issues

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Basis of Design for the Kootenai Tribe of Idaho's proposed Twin Rivers Hatchery - Burbot Aquaculture

Since 2001, the Kootenai Tribe of Idaho has been collaborating with the University of Idaho; British Columbia Ministry of Forests, Lands and Natural Resource Operations; and Idaho Department of Fish and Game to reintroduce burbot into the lower Kootenai/y River and Lake because Kootenai River burbot have become functionally extinct. Additionally, the Kootenai Tribe, agency partners and local community stakeholders cooperated to produce a Conservation Strategy to guide these efforts. In 2003, the Kootenai Tribe initiated investigations of burbot aquaculture methods in collaboration with the University of Idaho – Aquaculture Research Institute (UI-ARI). These efforts have yielded significant advances in aquaculture techniques for a species that has historically received little such attention. This work has demonstrated that large-scale aquaculture of burbot is feasible. However, the production capacity of UI-ARI is limited. Therefore, the Kootenai Tribe is currently in final design and pre-construction planning of a new conservation aquaculture facility (“Twin Rivers Hatchery”) that will support white sturgeon and burbot aquaculture in order to restore those species in the Kootenai/y River and Lake. The Twin Rivers Hatchery will provide multiple water supplies (Kootenai River, Moyie River, and groundwater); a wide-range of water temperature regimes; increased rearing capacity; and increased number of families, allowing for incorporation of more wild adults to ensure proper genetic contributions. During the design of the new facility, UI-ARI research and input from co-managers in terms of current and future Kootenai River burbot recovery and management were considered. Two main documents / exercises were completed to guide engineers and architects. First, a “Biocriteria” summary was developed for the aquaculture of burbot. The Biocriteria lists estimated survival, water source(s), temperature regime, feed, equipment needs, rearing density, flow rates, etc. for each life stage. Second, a “Basis of Design” was completed to outline the recovery and management of the population in order to arrive at production goals to support the recovery effort. The Twin Rivers Hatchery design will be presented, and the rationale behind the design will be discussed.

Salmon and Steelhead Issues

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Salmon life history in an altered landscape: reconstructing juvenile migration using chemical and structural analysis

Pacific salmon populations have suffered declines and local extirpations in the Pacific Northwest over the last century as a result of physical and functional changes to their freshwater environments. Understanding the distribution, abundance and relative performance of juvenile life history types is critical in increasing population sustainability and development of passage for at risk populations of Chinook salmon. Our objectives were to 1) quantify the composition of juvenile freshwater life history strategies in the Upper Willamette spring Chinook salmon population, 2) develop a methodological test of the accuracy of scale analysis in identifying life history strategies, and 3) use a matrix population framework to assess the relative survival of juvenile life histories. Otolith isotope and elemental ratios $^{87}\text{Sr}/^{86}\text{Sr}$ and $\text{Sr}:\text{Ca}$ combined with otolith structural patterns were used to characterize juvenile life histories, estimate juvenile size and age at freshwater emigration, and assess relative growth between natal rearing habitats. We also used scale morphometric patterns, to discern juvenile habitat use and age at freshwater emigration. We found that a significant portion of juvenile Chinook salmon reared in project reservoirs and emigrate from freshwater at large sizes, which may provide a survival advantage to adulthood. Otolith microstructure analysis suggested increased growth in project reservoirs relative to natal rearing streams. We found a high correspondence between scale juvenile life history assignment and otolith chemical life history, which suggests accurate scale life history depiction. Our life history model found variability in survival between juvenile life history strategies. Determining the juvenile rearing habitat, emigration ecology, and relative survival of these populations will enhance the understanding of the interaction between life history variation and anthropogenic disturbance and assist in developing appropriate management strategies.

Salmon and Steelhead Issues

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Salmonid Smolt Management within the Bulkhead Slots at the Priest Rapids Hydroelectric Project, Columbia River

During their outmigration, salmonid smolts passing a hydroelectric dam via the powerhouse, have the possibility of finding themselves in the gatewell bulkhead slots of the turbines. Historically, the Public Utility District No. 2 of Grant County has used a large "dip-net" to remove these smolts on a daily basis and truck them around Wanapum and Priest Rapids dams. Upon evaluation of the design and use of Gatewell Slot Exclusion Screens on each of the bulkhead slots, along with the results of a gatewell smolt retention study, assumptions made about the fate of these "trapped" smolts has changed and operational practises at both Wanapum and Priest Rapids dams are changing in a direction that is better for the smolts and also less labor-intensive for Grant PUD.

Salmon and Steelhead Issues

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Survival and Traits of Reconditioned Kelt Steelhead *Oncorhynchus mykiss* in the Yakima River, Washington

We evaluated the traits and survival to release of reconditioned kelt steelhead *Oncorhynchus mykiss* in the Yakima River (Washington State, USA). From 2001-2011 we captured a total of 9,738 downstream migrating kelts at an irrigation diversion facility, on average about 27% of each annual wild steelhead return. Captured kelts were reared for 4.5-10 months in an artificial environment, treated for diseases and parasites, and fed both krill and pellets. Surviving reconditioned fish were released into the Yakima River coincident with the peak of upstream pre-spawn steelhead migration. Reconditioned steelhead kelts were predominantly (>92%) female. Annual survival to release ranged from 20-62% and averaged 38% over the course of the study with surviving reconditioned kelts showing increases in fork length, weight, and Fulton's K condition factor. Kelts in good condition and those with bright coloration at the time of collection were more likely to survive. Post-release upstream migration timing of reconditioned kelts was spread out over several months and correlated well with run timing of upstream pre-spawn migrants. The empirical results we observed demonstrate the potential of kelt reconditioning to provide recovery benefits for imperiled wild repeat spawning populations in highly developed river systems.

Salmon and Steelhead Issues

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Survival of pre-smolt spring Chinook salmon migrants from the Middle Fork John Day River

Variability in early-life history strategies provides insurance against losses of entire cohorts of a population. Within the John Day River basin, pre-smolt spring Chinook *Oncorhynchus tshawytscha*, defined as migrants emigrating downstream and over-wintering below trapping sites, are a substantial portion of brood year production. However, little is known about the survival of pre-smolt migrants and whether early migration results in reduced travel time through the migratory corridor. We used a subset of parr PIT-tagged during summer 2009-2011 in the Middle Fork John Day River and subsequently detected as migrants at an in-stream PIT-tag array. We used this subset of migrants to assess influences of size at tagging on early migration, median date of detection through the migration corridor, and compare survival of pre-smolt migrants to smolt migrants. Length at tagging was significantly different for individuals adopting a pre-smolt strategy over most years. However, median date of detection was similar throughout the majority of the migratory corridor. Survival was also comparable between life-history strategies, but was dependent on size at tagging.

Salmon and Steelhead Issues

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Anadromy and residency in steelhead and rainbow trout *Oncorhynchus mykiss*: a review of the processes and patterns

Oncorhynchus mykiss display a wide diversity of migratory tactics. Natural populations of *O. mykiss* have declined in abundance and life history diversity over the past century, leading to increased interest in understanding factors influencing their life histories. We sought to overview and synthesize existing knowledge on the patterns of and processes influencing anadromy and residency of natural *O. mykiss* across their range. We suggest that the conditional strategy provides a strong framework for understanding life history tactics. We first discuss influences shaping anadromy and residency at the individual fish level including condition (growth, body size, and lipid content), size and age at maturation (also associated with survival to repeat spawning), and genetics. We found that there was a high level of variability in the relative effects of individual condition on life history tactic due to differences between sexes and populations, and thus we did not find consistent associations, such as faster-growing individuals maturing early and slower growers becoming anadromous. Second, we looked at ecological and environmental factors shaping *O. mykiss* anadromy and residency. We found research indicating that anadromy and residency are correlated with several factors at different life stages including but not limited to water temperature, food supply, density dependence, cost of migration and ocean survival, river geomorphology and the presence of lakes, stream size, and substrate size. Our review revealed three major patterns: ecological conditions that maximize development and survival in freshwater generally appear positively correlated with increases in residency because they eliminate the need for ocean migrations; spatial distribution patterns in anadromy and residency do not consistently reflect differences in cost of migration or marine survival; and the spatial distribution and frequency appear to be related to the presence of lakes and differences in stream and substrate size. Overall, no single factor is responsible for patterns in residency and anadromy in *O. mykiss*, but water temperature and food supply may be two of the most influential variables. Finally, we also identify current knowledge gaps and priorities for future research on *O. mykiss* anadromy and residency.

Salmon and Steelhead Issues

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The extent and strength of density dependent mortality in a juvenile steelhead population

Conservation strategies for salmon often operate at large spatial scales over which demographic processes can be generalized for populations across extensive and connected watersheds. In contrast, it is well known that the local distributions of juvenile salmon in streams can be extremely patchy over space and time. Further, this heterogeneity in distributions can be a driver of local variability in the individual performance and a factor in the strength of intraspecific interactions. Without information for population demographics from across multiple spatial scales, it is difficult to separate out the relative effects that density-dependent and density-independent factors have on population demographics. Over a five-year period (2008 – 2012) we have measured demographic and habitat variables of a population of federally threatened juvenile steelhead, *Oncorhynchus mykiss*, in a major steelhead-rearing tributary of the Lower Clearwater River, Idaho. We have sampled multiple sites (up to 16 reaches) that are distributed throughout a stream network repeatedly throughout the growing season (5 times per year between June and November). During that time we tagged more than 10,000 juvenile steelhead with high recapture rates. We used mark-recapture analyses and information theoretic model selection to quantify spatial and temporal patterns of apparent survival and suggest drivers of these patterns. Specifically, we considered density, elevation, and temperature as well as hierarchical spatial groupings (i.e. site, stream, watershed) and temporal effects as potential drivers of survival. Additionally, we considered individual covariates of body length and condition factor. Model results show that in years where density is generally low that site and watershed factors have the strongest effect on survival. However, in years and at sites with high density of juvenile steelhead, patterns of mortality demonstrated a significant temporal effect, that was correlated with density. At the highest densities individual covariates were especially useful at predicting survival, where larger fish, which must consume more to maintain basal metabolic rates, were less likely to survive. Our approach identifies when density-dependent mortality can be an important regulating process and our results can be used to better understand freshwater rearing conditions for this and other imperiled salmonid populations.

Salmon and Steelhead Issues

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Patterns and processes of density-dependent growth in juvenile steelhead in Lapwai Creek, ID

One of the primary interests in ecology is identifying the patterns and processes of population growth. Populations are limited by factors such as weather that act independently of population size, and regulated by density dependent factors, that is, when the per capita growth rate of the population depends on its own density. In highly fecund organisms such as stream salmonids it is likely that population density has strong influence on population vital rates. Recent work suggests that population density acts primarily on movement and mortality at high densities, typically at the onset of summer, whereas the effects on individual growth are stronger at lower densities following the initial thinning. Although the effects on mortality might seem more critical, density-dependent growth is a fundamental mechanism of population regulation in organisms with flexible and indeterminate growth. Slower growth of individuals may prolong their period of vulnerability to predators and environmental challenges, typically results in smaller mass at maturity, and oftentimes leads to lower fecundity. Here we study the effects of population density on average growth rates in a population of *Oncorhynchus mykiss* throughout 16 discrete sampling reaches over three years in Lapwai Creek, ID. Secondly we identify the thresholds at which detectable density-dependent effects were apparent, and thirdly relate these back to habitat and environmental covariates. Although densities decreased over the growing season we found that average growth rates also slowed, suggesting that competition over food rather than space increased in intensity. At the same time individual level variation increased, which was consistent with a shift towards exploitative competition. This shift was more prevalent in headwater sites with high initial density, which corresponds with our previous research on self-thinning. The density thresholds varied throughout the basin and we discuss the potential causes for the observed patterns.

Salmon and Steelhead Issues

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Histological assessment of selected tissues in maturing and post spawning Snake River steelhead

Although Snake River steelhead trout are iteroparous, few are recorded repeat spawning. Intuitively, kelt survival and repeat spawning are dependent on the recovery of lost somatic energy via the re-initiation of feeding. Little is known about how prolonged fasting affects the organ tissues of maturing steelhead or how these tissues respond in recovering kelts. We used histological analysis to compare the cellular architecture and function of liver, spleen, ovary, and pyloric stomach tissues in lethally sampled pre and post-spawn Snake River steelhead. Dworshak National Fish Hatchery broodstock served as the model for fasting pre-spawn steelhead, whereas mixed stocks of kelts from the Lower Granite Dam juvenile bypass facility served as the model for steelhead during post-spawn recovery. We documented differences in the cell microstructure of liver and spleen tissues that were correlated with fish condition. The integrity of liver hepatocytes and abundance of vacuoles were generally related to higher energetic and nutritional status of kelts. In ovary tissue we observed oocytes in various stages of oogenesis, but did not find vitellogenic oocytes, suggesting that Snake River steelhead would likely require a year of recovery before spawning again (skip spawning). We documented a negative relationship between the quantity of perinucleolar oocytes in steelhead ovaries and fork length. Pre-spawn steelhead exhibited low villi density with shallow invaginations in the pyloric stomach, whereas kelts exhibited high densities of villi and deep invaginations. We found no variations in columnar epithelial cell integrity of the pyloric stomach between pre-spawn or kelt steelhead, thus the gastrointestinal tract does not appear to undergo complete deterioration during prolonged fasts. We also compared pyloric stomach histology between kelts with identifiable food in the gastrointestinal tract to those with no food, which showed that villi invagination was significantly deeper in feeding kelts than non-feeding kelts. We believe that increased villi invagination increases the surface area for the digestion and absorption of food within the pyloric stomach. The results of these assessments provide evidence that post-reproductive recovery in Snake River steelhead begins in freshwater and that these fish have the capacity for iteroparity.

Salmon and Steelhead Issues

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Adult Chinook salmon: we know they came back; does it matter when they left?

There are two dominant juvenile life history types present in Snake River spring/summer Chinook salmon populations, which differ in their use of freshwater rearing habitats. Parr-type juveniles leave natal reaches as sub-yearlings during the summer and fall months. They overwinter in larger tributaries or main stem reaches above Lower Granite Dam and then smoltify and emigrate to the Pacific Ocean in their second spring. Smolt-type juveniles overwinter in the natal reaches and emigrate directly to the ocean in their second spring. Our objective was to assess the relative contribution of both juvenile life history types to adult returns. We estimated the number of juveniles of both types for nine populations over 11 brood years (1997-2007), then used the detections of PIT tagged adults to determine their juvenile life history type, and finally expanded these results to the untagged adults. Parr were the numerically dominant juvenile life history type in all populations and averaged 70.8-98.6% of the estimated juvenile production from these populations. Adult returns were also dominated by individuals from the parr-type life history and average of 63.2-99.7% of the return over the 11 brood years. The freshwater rearing habitats used by salmon populations extend well downstream of spawning reaches, and these areas are important to eventual adult production. Natal streams simply do not have sufficient space to sustain a large fraction of the juvenile production over the winter, although many of these streams contain sizable areas of seemingly suitable but unused spawning habitat. Management to address overwinter survival in main stem areas could either focus on direct habitat improvements, on increasing the growth or other fitness measure of parr prior to entering these areas, or a combination of the two.

Salmon and Steelhead Issues

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Reproductive Contributions from Migratory *Oncorhynchus mykiss* Colonizing a Natal Stream After Barrier Removal

Migratory life histories of trout provide ecological and genetic diversity important to the persistence of species in stochastic environments. We used passive integrated transponder (PIT) tags and parentage analysis to identify the source, life history and reproductive success of individual migratory rainbow/steelhead for two brood years after barriers were removed from a natal stream. Steelhead and fluvial rainbow trout successfully spawned in the newly opened habitat after barrier removal. Most offspring from brood year 2005 matched to anadromous parents whereas most offspring from brood year 2006 matched to a fluvial parent. Hatchery *O. mykiss* produced only two parr offspring that did not return as adults. Offspring that returned as anadromous adults from these brood years were produced by parents that had only a few matching parr indicating that individual reproductive success may not be related to the number of parr produced by a parent. The fluvial life history polymorphism provided genetic compensation boosting the abundance and number of successful spawners particularly during 2006 when stream flow conditions were unusually high.

Salmon and Steelhead Issues

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Colonization of Steelhead (*Oncorhynchus mykiss*) in a Natal Stream After Barrier Removal

A before-after control experimental design was used to follow the colonization process of anadromous *Oncorhynchus mykiss* (steelhead) at six monitoring sites in a natal stream after the modification or removal of numerous stream passage barriers. Additional sites in nearby tributary basins, Libby and Gold creeks, were used as control sites for the identification of pre-treatment effects of instream passage barriers. Passive integrated transponder tags and stationary interrogation stations were used with population genetic sampling to determine the source, extent and success of the barrier removal projects. Sixteen microsatellite loci were used to test changes in population genetic measures (H, FST and % hatchery admixture). Pre-project conditions were evaluated by estimating recent migration rates. Migration rates indicated no migration between sites in Beaver Creek prior to barrier removal. Migration rates in the comparison basins indicated asymmetrical migration among sampling sites. Adult steelhead and fluvial rainbow trout entered Beaver Creek the first spawning season after barrier removal and were passing the upper-most tag reader 12 km upstream from the mouth 3-4 years later. Population genetic measures significantly changed in the lower two monitoring sites in the basin in 1 generation (4-5 years). Migration data from tag readers verified that parr from Beaver Creek after barrier removal successfully returned as adults. Although migratory life histories were re-connected to Beaver Creek, abundances were low during the first four years after barrier removal. The colonization process is still underway in Beaver Creek and we expect more parr production from this basin in future generations.

Techniques in Fisheries

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Using state-space models to evaluate multiple survey methods: a case study for a threatened population of Chinook salmon (*Oncorhynchus tshawytscha*) in Johnson Creek, Idaho

Fisheries management decisions, including ESA listing status, are often predicated on the ability to quantify population abundance. For many populations, however, there are only indirect measurements of abundance; such as, redd counts that are used to describe the abundance of spawning salmon. Three knowledge gaps frequently exist when there are only indirect measurements of abundance: 1) what is the relationship between the measurement (redd counts) and the unobservable/state (spawner abundance), 2) if more than one measurement method is used, which method is more accurate and do all methods describe the same state, and 3) what is the uncertainty in the measurement versus the state? State-space models address these knowledge gaps with a structure that enables us to combine separate descriptions of the state (spawner abundance) and the measurement (redd counts) into a single framework. The Johnson Creek population of spring/summer Chinook salmon is one of 55 populations in the Interior Columbia Basin that was listed as threatened in 1992 under the ESA, and we use state-space models to describe the relationships between three different redd counting methods and recommended minimum viable spawner abundance thresholds for de-listing. Our approach is useful because it not only clarifies the relationship between redd counts and spawner abundance, but also quantifies the observation error associated with different redd count methodologies, and the process error associated with spawner abundance.

Techniques in Fisheries

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This spot is just right: Using channel morphology to refine steelhead redd surveys

Prior to 2008, monitoring of wild steelhead *Oncorhynchus mykiss* in the Upper Grande Ronde River (UGRR) watershed was limited to tributary weir counts and index redd surveys. At the population scale, improved understanding of abundance trends and distribution of adult spawning steelhead will be used in implementation of management and recovery actions. Beginning in 2008, we implemented a generalized random tessellation stratified (GRTS) survey design, a spatially balanced random selection process, to estimate steelhead escapement for this population. Individual sites were classified by channel type (source, transport, and depositional) and sub-categories based on stream bed morphology. We related location and abundance of redds to stream morphology in an attempt to understand choice of habitat for spawning. We have found significant evidence that steelhead prefer pool-riffle and plane-bed stream bed types for redd construction. Of the 289 total redds that were observed from 2008-2012, 38% were in pool-riffle (transport) habitat, significantly greater than other valley classes ($P = 0.038$) and from other channel types ($P = 0.006$). Stratification based on channel morphology may increase our precision and accuracy in our estimates. Continued monitoring of spawning locations will assist in developing a model for predicting the occurrence of spawning throughout a watershed for directing effort depending on habitat type and conditions.

Techniques in Fisheries

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Self-Reporting Bias in Chinook Salmon Sport Fisheries in Idaho: Implications for Roving Creel Surveys

Self-reporting bias in Chinook salmon *Oncorhynchus tshawytscha* sport fisheries in Idaho was quantified by comparing observed and angler-reported data to creel clerks. A total of 164 observed anglers fished for 541 hours and caught 74 Chinook salmon. Fifty-eight fish were harvested and 16 were released. Anglers reported fishing for 604 h, an overestimate of 63 h. Anglers reported catching 66 fish; four less harvested and four less released fish were reported than observed. A Monte Carlo simulation revealed that when angler-reported data were used, total catch was underestimated by 14-15 fish (19-20%) using the ratio-of-means estimator to calculate mean catch rate. Negative bias was reduced to 6 fish (8%) when the means-of-ratio estimator was used. Multiple linear regression models to predict reporting bias in time fished had poor predictive value. However, actual time fished and a categorical covariate indicating whether the angler fished continuously during their fishing trip were two variables that were present in all of the top a priori models evaluated. Underreporting of catch and overreporting of time fished by anglers present challenges when managing Chinook salmon sport fisheries. However, confidence intervals were near target levels, and using more liberal definitions of angling when estimating effort in creel surveys may decrease sensitivity to bias in angler-reported data.

Techniques in Fisheries

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Comparing standard North American freshwater fish data using a simple online tool: fisheriesstandardsampling.org

Recently, the American Fisheries Society developed standard methods to sample freshwater fish populations, publishing them in 2009 in the book *Standard Methods for Sampling North American Freshwater Fishes*. This project involved 284 scientists from 107 different organizations across Canada, Mexico and the United States. Data collected using standard methods gives biologists the ability to compare data across regions or time. Here we discuss recent progress on an on-line web-accessible tool to compare fish growth, condition, length-frequency, and catch per unit effort data collected using AFS standard methods. Development of this tool is a collaborative effort among AFS, the US Geological Survey, the National Park Service, the U.S. Forest Service, the University of Arizona, and the University of Guadalajara, Mexico. The on-line tool (1) provides on-line summaries of 4,092 data sets of condition, length-frequency, CPUE and growth indices of common freshwater fishes, collected using standard gears from 42 states and provinces across North America, (2) allows entry of new data collected using standardized methods, so averages of commonly-used fishery indices can be updated, and (3) allows queries, graphical, and tabular output of the data summaries so they can be easily accessed and integrated into projects across North America. We invite you to visit the website and compare your data on condition, growth and abundance of fish collected in a particular waterbody with regional and rangewide averages and percentiles, thus increasing resource information in a variety of areas.

Techniques in Fisheries

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A comparison of methods for calculating adult salmon abundances from spawner and redd survey data.

Mark and recapture methods of estimating populations can be highly accurate, but are costly and time consuming, limiting their usefulness in state-wide monitoring programs. Most states with anadromous fish populations currently employ some version of spawner/ redd surveys for statewide population monitoring. In these past, these methods have been considered “relative abundance indexes,” but are increasingly being viewed as accurate enough to estimate populations similar to some mark and recapture programs. The North coast of California in particular is using redd survey counts in this manner, where several protocols are currently being examined that estimate the observer detection rates of redds in order to produce more accurate final abundance estimates. This study compares two such protocols that have been employed in Northern California coastal streams. The first uses two independent observers that are visually separated, basically producing a double blind study design, to estimate observation efficiency and a final redd number for each survey event. In the second design, the two observers are in proximity to each other on the stream, similar to traditional survey designs, but essentially conduct separate surveys, with the second observer acting as an error rate/ observer efficiency measurement for the first. I compared both methods over an entire field season on a small North California stream over 16 separate survey events and discovered both methods contain significant problems with over and undercounting error and developed a third survey design that estimates both error types as oppose to just the “detection efficiency or miss rate” measured in current study designs.

Use of Genetics in Fish

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Association mapping of disease resistance traits in rainbow trout using RAD sequencing

As with other aquaculture species, rainbow trout are susceptible to disease when reared at high densities and outbreaks can lead to significant losses. Commercial rainbow trout producers have therefore been pursuing strategies to prevent such losses such as adjusting feed formulations, vaccine development, and selective breeding. In some commercial programs, rainbow trout have been selectively bred for resistance to cold water disease (CWD) and Infectious hematopoietic necrosis virus (IHNV). This is accomplished by testing disease resistance in juvenile fish by either direct injection (CWD) or waterborne exposure (IHNV) with each pathogen and selecting only fish from the most resistant families as broodstock. For this study we sampled juvenile fish from 39 families from two year classes that either survived or died during disease challenge to either CWD or IHNV. Restriction-site associated DNA (RAD) sequencing using an Illumina HiSeq instrument produced 4,661 unique SNP loci after strict filtering. Genotypes from each SNP for individual survivors and mortalities were then used to test for association between disease resistance and genotype at each locus using the program TASSEL. After accounting for kinship and stratification of the samples, tests revealed 12 SNP markers that were highly associated with resistance to CWD and 19 markers associated with resistance to IHNV. These markers are candidates for further investigation and are expected to be useful for marker assisted selection in future broodstock programs.

Use of Genetics in Fish

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Review of environmental DNA (eDNA) methods for detection and enumeration of fish species and populations

Environmental DNA (eDNA) methods used to sample fish species and populations are developing rapidly, but have yet to be applied widely by fisheries agencies for monitoring and management. The goal of this paper is to provide a review of current and emerging eDNA methods and discuss the state of real-world applications for inland fisheries programs. eDNA methods require concentration of all dissolved or cellular DNA found in a water sample, either by centrifugation or filtering. Determination of a target-species' DNA in this sample is accomplished using species-specific molecular markers and the polymerase chain reaction (PCR) or quantitative PCR to amplify the target sequence. These techniques have been used successfully for dozens of fish species and increasing evidence suggests that eDNA methods are more effective at detecting species than traditional methods, such as electrofishing, snorkeling, and trapping. eDNA methods may also provide some information on relative abundance of species. The state of the science on eDNA methods is at a transition point from experimental to implementation as a sensitive, non-invasive, and valuable sampling tool. There are still challenges for agencies before eDNA methods can be integrated into management or monitoring plans, including sampling protocols, molecular marker development and testing, and evaluation of information gained versus limitations. Despite these challenges, eDNA is on the verge of widespread application and implementation and should be considered another tool in the fisheries toolbox.

Use of Genetics in Fish

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Adaptive alleles useful for early detection of hybridization between rainbow and westslope cutthroat trout

We applied genome-wide sequencing to seven populations of westslope cutthroat x rainbow trout hybrid swarms from different environments that previously showed low admixture from rainbow trout. We sequenced 77,141 loci (each ~300-500bp from RAD contigs) in 133 individuals and used these data to genotype 3,180 previously identified species-diagnostic SNP loci (single nucleotide polymorphisms). Our population-level and individual-level estimates of admixture were similar to previous microsatellite-based estimates from the same individuals. However, we observed slightly lower admixture estimates from genome-wide markers, which might result from natural selection against certain genome regions, different genomic locations for microsatellites versus SNPs, and/or sampling error from the small number of microsatellite loci (n=7). We also identified candidate adaptive “super invasive” alleles that had excessively high admixture proportions in hybridized cutthroat trout populations. Such super invasive alleles can spread rapidly into native populations (via natural selection) and thus provide managers with useful markers for early detection of RBT introgression.

Use of Genetics in Fish

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Archival genetic analysis suggests recent immigration has altered a pristine population of Columbia River Chinook salmon

Oregon's John Day River (JDR) subbasin is located amid many hatchery-supplemented salmon and steelhead populations of the Columbia River Basin, yet the JDR is a wilderness area that has experienced no directed supplementation activity. As a result, spring-run Chinook salmon (*Oncorhynchus tshawytscha*) populations in the JDR have remained relatively distinct among stream-type populations throughout the region. Nevertheless, effective long-term monitoring of JDR populations requires having the ability to detect potential genetic change, and to determine causes of such change in order to assist conservation. In our archival approach, we used 13 SAT loci and 96 SNP loci to examine temporal genetic structure among collections from four primary spawning areas, spanning a 28 year period (1978 to 2006). We observed significant temporal heterogeneity among collections and evaluated the likely causes of divergence by testing for the influence of three demographic and evolutionary forces: natural selection, stochasticity (i.e. genetic drift), and immigration (i.e. straying). The influence of selection among our collections was minimal, as evidenced by similar patterns of allelic variation and population differentiation exhibited by both putative neutral and selection-candidate loci. Further, the stability of JDR abundance estimates and gene diversity estimates over time suggest neither low effective population size nor recent bottleneck events can account for observed population differentiation. Conversely, changes in allele frequencies over time were as high as 15%, averaging 3%, and among-watershed differentiation decreased significantly from past to present. Using genetic stock ID methods we observed a sharp temporal decline in population assignment accuracy of JDR fish, with a corresponding increase in genetic similarity to Snake River populations as far as 170 rkm upstream in the Columbia River Basin. Estimated rate of migration into the JDR population has risen despite surveys having identified only a small number of stray fish on spawning grounds, and this exogenous introgression has apparently eroded population structure.

Use of Genetics in Fish

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Patterns of Genetic Variation in Lahontan cutthroat trout: a comparison of SNP and microsatellite loci

Lahontan cutthroat trout (*Oncorhynchus clarkii henshawi*), one of 14 subspecies of cutthroat trout found in the intermountain western United States, is listed as threatened under ESA. Three Geographic Management Units (GMUs) have been identified within the subspecies range. Here we compare patterns of genetic structure observed at 8 microsatellite markers to patterns at 35 single nucleotide polymorphisms (SNPs) among populations sampled from across the three GMUs. We used Bayesian genotype clustering analysis to examine patterns of divergence within and among the three GMUs. Two genotype clusters was the best fit of the data for the SNP dataset. However, we had statistical support for both $k = 2$ and 4 genotype clusters and report results for both analyses here. At $k = 2$ the SNP markers clearly delineated the western GMU from both the eastern and northwestern GMUs. For $k = 4$ most of the major river systems formed distinct genotype clusters with the exception of the Quinn and Humboldt rivers which formed a single genotype cluster. There was little variation in the pattern of genetic structure among replicates for the SNP analyses. Three genotype clusters was the best fit of the data for the microsatellite loci. Although the $k = 3$ analysis did not cleanly delineate the three GMUs, genotype clusters did tend to form for the major rivers. As with the SNP data the Quinn and Humboldt rivers tended to form a single genotype cluster. We had additional statistical support for both $k = 2$ and 5. Interestingly in the $k = 5$ analysis the Quinn River samples did not form a distinct genotype cluster but tended to cluster with the Truckee River samples, which reflects their shared history of inundation by pluvial Lake Lahontan. Unlike the SNP analysis we observed more variation in clustering patterns across replicates for all “ k ” for which we had statistical support at the microsatellite loci. Combining the SNP and microsatellite datasets did not improve our precision. These results suggest that SNP markers may be more appropriate for large spatial scale analyses in this subspecies.

Use of Genetics in Fish

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Polymorphism or hybridization: verifying whether loci are diagnostic in a population

Hybridization between native and introduced species poses a conservation threat to many taxa. With respect to cutthroat trout, much effort has been invested in determining a set of genetic markers at which hybridizing species do not share alleles. However, because not every population can be screened when developing these marker sets, there exists a possibility that markers are not truly diagnostic across the entire species range. If such a population is encountered, treating a polymorphic locus as diagnostic will bias the estimates of the proportion of genes in that population with a given ancestry. While in some cases it is easy to identify if putative introgression at a diagnostic locus is the result of a polymorphism, in other situations it is much more difficult to make this determination. For example, it is hard to identify a locus as polymorphic when one of the alleles is at low frequency in the population, or background hybridization is present. Because estimates of the proportion of genes in a population with a given ancestry will be biased regardless of whether polymorphic loci are easy or difficult to distinguish, we developed a formal test for identifying polymorphic loci. This test is based on the observed pattern of species specific alleles, both within and across loci, in the sample. In this study, we make use of a simulation framework that allows us to model multiple neutral diagnostic loci per chromosome arm in hypothetical cutthroat trout populations. These populations are simulated with differing census and effective population sizes, and tracked across 25 non-overlapping generations. From these simulated populations, we will investigate the power and Type I error rate of this test, as well as possible implications of incorrectly identifying polymorphic loci on estimates of the proportion admixture in a sample. The goal of this study is to provide a formalized method for identifying polymorphic diagnostic loci from hybridization studies.

Use of Genetics in Fish

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Microsatellite Study Clarifies Non-native threat to Lahontan Cutthroat Trout Reintroduction in Fallen Leaf Lake, California.

Introductions of non-native fishes complicate native fish recovery, and documenting successful native reintroductions remains an ongoing challenge. Brown trout (*Salmo trutta*) pose a piscivory threat to native Lahontan Cutthroat trout (LCT; *Oncorhynchus clarkii henshawi*) while rainbow trout (*O. mykiss*) and LCT readily hybridize. Both species are found in Fallen Leaf Lake and the upper Glen Alpine Creek watershed which drains into the lake and therefore, the presence of these species in LCT recovery waters represents a significant threat to LCT recovery. In conjunction with the USFWS Lahontan cutthroat trout reintroduction program in Fallen Leaf Lake, California we investigated the genetic population structure and connectivity of naturalized rainbow and brown trout throughout the Glen Alpine Creek watershed including Fallen Leaf Lake. Rainbow trout (N=279) and brown trout (N= 350) fin clip samples were collected for genetic analyses using electrofishing techniques in the streams and gill-netting in the lakes. Isolated DNA samples were genotyped at 16 (rainbow) and 10 (brown) polymorphic microsatellite loci. We used the Bayesian clustering program STRUCTURE to assess genetic connectivity within the watershed. Using a delta k approach we found statistical support for K=2 and K=3 genetic subpopulations for rainbow and K=3 and K=5 genetic subpopulations of brown trout. Results indicate genetic connectivity among rainbow and brown trout populations between the upper Glen Alpine Creek drainage and Fallen Leaf Lake, and identify a self sustaining subpopulation of rainbow trout persisting in Fallen Leaf Lake. Lower Glen Alpine Creek provides limited spawning habitat for naturalized rainbow trout in Fallen Leaf Lake. In 2012 we investigated the potential for hybridization in the creek by identifying redds and genetically assessing emerging YOY for hybrid status. The presence of limited hybridization resulted in adaptive management by USFWS and the placement of weirs in both lower and upper Glen Alpine Creek in order to prevent rainbow from the upper watershed entering the lake and rainbow trout within Fallen Leaf Lake from entering Glen Alpine Creek to spawn. These results suggest a self-sustaining lacustrine population of Lahontan cutthroat trout in Fallen Leaf Lake is possible, but confounded by the presence of non-native fishes.

Use of Genetics in Fish

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The phylogeography of westslope cutthroat trout based on whole-mitome sequences and nuclear SNP markers

Westslope cutthroat trout are the marquis native species in many river basins of the U.S. Northwest and Canadian Southwest. Despite its societal value and concerns about its conservation status, we know little about the phylogeographic structure of this taxon. This structure could inform management by identifying conservation units and their distribution, reconstructing the routes of colonization of its historical range, and noting the presence of genetically pure but nonindigenous populations. To address these topics, we sequenced the mitome of 96 westslope cutthroat trout from throughout the historical range in four major river basins—the Columbia, Missouri, Saskatchewan, and Fraser—in the U.S. and Canada. We also analyzed a panel of variable single nucleotide polymorphisms from the nuclear genome for fish from a subset of this range. These data indicate pronounced divergence between lineages at the scale of large river basins. In general, Idaho and Oregon basins south of the extent of glaciation during the Last Glacial Maximum reflect a suite of diverse lineages to which fish in the John Day basin are basal. A less variable northern lineage consists of fish from the Washington Cascades and the remainder of the U.S. and Canadian range. However, populations from the Clearwater River basin appear in nearly all clades. Hydrological connections that would explain these patterns are unclear. Stocked populations appear to be recognizable with either mitochondrial or nuclear markers.

Wild Chinook Salmon in a Dynamic Wilderness Landscape

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Paper #3. Disturbance cascade: fire and debris flows in the Salmon River Basin affect headwater linkages to main-stem habitats with consequences for salmonid fishes

The effects of natural processes may propagate through stream networks via changes in fluxes of materials and organisms. Wildfires and subsequent debris flows may increase downstream exports of sediment while simultaneously increasing the quality of organic matter delivered from tributaries to main-stem rivers. Furthermore, these disturbances may increase exports of drifting invertebrates from small tributaries, many of which may themselves be fishless, potentially subsidizing insectivorous fishes in main-stem habitats. We compared exports of sediment, organic matter and invertebrates from 15 tributaries in the South Fork Salmon River, a basin adjacent to the MFSR in central Idaho (5 unburned, 5 that burned in 2007, and 5 that burned and experienced a subsequent debris flow) during the summer of 2011. We also combined underwater surveys and an experimental depletion of invertebrate export from tributaries to determine the extent to which disturbance history of tributaries influenced selection of confluence habitat by salmonid fishes. Burned + debris flow streams exported more sediment, but also organic matter of higher quality, to main-stem habitats than unburned streams. Biomass of invertebrate exports was 3-4X higher from burned + debris flow streams than from unburned streams. Fish selected for confluence habitats in greater proportion than their availability, but preference was strongest for confluences with disturbed tributaries. Comparisons of rates of agonistic behaviors between confluence and non-confluence habitats revealed that fish were more aggressive in confluence habitat, indicating that these habitats may be worth defending. Tributaries affected by fire and debris flow disturbances may represent important sources to mainstems of high-quality organic matter and invertebrate production, and their confluence habitats may be particularly profitable for salmonid fishes. These processes contribute to the naturally dynamic mosaic of ecosystem conditions that are the stage for the ecology of endangered salmonids in this region.

Wild Chinook Salmon in a Dynamic Wilderness Landscape

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Paper #5. Spatiotemporal variation in demography of MFSR Chinook Salmon Inferred from Redd Surveys

Guidance for effective conservation of declining native fish populations may be obtained through study of natural populations and understanding characteristic spatial and temporal dynamics. We applied annual, georeferenced redd surveys to evaluate Chinook salmon populations in the Middle Fork Salmon River (MFSR). From 1995 - 2003, the population grew at a rate of 5.3 recruits per spawner and redd numbers increased from 20 to 2271. As abundances increased, fish expanded into portions of the stream network that had recently been unoccupied. Even at the highest escapements, however, distributions remained clustered, and a limited portion of the network contained the majority of redds. The importance of the highest density spawning areas was greatest when abundances were low, suggesting these areas may serve as refugia during demographic bottlenecks. Analysis of variance indicated that redd numbers were strongly affected by local habitat conditions and broad climatic controls, but also revealed a space-time interaction that suggested some temporal variation among years in spatial patterns. Temporal synchrony among populations suggests that populations have become strongly synchronized in recent decades—potentially increasing the likelihood of simultaneous extirpations and regional loss. This population has been very dynamic; from 2003 to 2006 the population declined nearly tenfold and averaged less than 500 redds until 2009. Since 2010, redd numbers have averaged 1100. Our results emphasize the importance of maintaining habitats with high densities of individuals, but also suggest that broad views are needed to accommodate the dynamics of these populations. Georeferencing and spatially continuous sampling lend analytical flexibility to the MFSR redd survey database, which remains a foundation for exploring new research questions in wild Chinook salmon populations. For example, the length of the monitoring record now makes it possible to look at trends among individual populations relative to newly developed stream temperature climate scenarios to determine whether populations differ in relative sensitivity to climate change.

Wild Chinook Salmon in a Dynamic Wilderness Landscape

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Paper #6. Application of MFSR spawning ground data to develop productivity estimates for threatened salmon populations

The Idaho Department of Fish and Game (IDFG) has been collecting Chinook salmon (*Oncorhynchus tshawytscha*) spawning ground survey data in the Middle Fork Salmon River for over 55 years. Annual redd surveys and information collected from salmon carcasses enable managers to monitor the abundance, productivity, spatial structure, and diversity of wild populations within this Major Population Group in the Snake River Ecologically Significant Unit. Methods and effort have changed over this extensive time series; early data consisted of fixed wing aerial redd surveys and ground-based surveys. In recent decades, IDFG has collaborated with the U.S. Forest Service – Rocky Mountain Research Station (RMRS) to continue to monitor redds via aerial and ground-based surveys and to collect carcass data. By combining the IDFG data with RMRS data, the Interior Columbia Technical Recovery Team developed abundance and productivity estimates to describe the status of each independent population within the Middle Fork Salmon River. IDFG has continued using these methods in recent years. Here we report those results and address their importance to recovery planning.

Wild Chinook Salmon in a Dynamic Wilderness Landscape

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Paper #4. Integrating genetic and demographic information to characterize MFSR salmon population structure and individual dispersal

The Middle Fork Salmon River (MFSR), Idaho, represents one of the few remaining large basins supporting indigenous Chinook salmon (*Oncorhynchus tshawytscha*) within the Snake River Evolutionary Significant Unit. Significant demographic declines at several points in the 1980's and 1990's raised concerns over the MFSR populations and an understanding of local population structuring and dispersal processes was needed to inform conservation strategies. We examined microsatellite variation in individual geo-referenced carcasses recovered from the MFSR and documented low, but significant levels of differentiation among most of the 10 spawning aggregates (streams) sampled. Several analyses supported a geographic basis to population relationships, particularly influenced by geomorphic differences between habitats in the upper and lower sub-basins. M ratios, used to test for genetic bottlenecks, were significantly correlated with several metrics of population size but did not provide evidence of bottlenecks in any population. To clarify the dispersal processes that structure populations within the MFSR, we analyzed patterns of spatial autocorrelation among both redd locations and individual genotypes. Spawning locations in both sub-basins were spatially clumped but the upper sub-basin generally had a larger spatial extent and continuity of redd locations than the lower sub-basin, where the distribution of redds and associated habitat conditions were more patchy. We made several predictions about differential constraints and breeding tactics between the two sexes, and the potential for fine-scale habitat structure to influence the precision of natal homing and localized movements of individual Chinook salmon on their breeding grounds. In accordance with predictions, male genotypes were not auto-correlated at any spatial scale in either sub-basin. Female genotypes showed significant spatial auto-correlation and genetic patterns for females varied in the direction predicted between the two sub-basins, with much stronger autocorrelation in the sub-basin with less continuity in spawning gravels. The species' substantial life history variation and relatively wide-ranging dispersal in males may have buffered MFSR Chinook salmon against detectable genetic impacts from population declines.

Wild Chinook Salmon in a Dynamic Wilderness Landscape

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Paper #2. Climate, fire, and vegetation change provide primary controls on geomorphic response in the MFSR: Evidence from a 14,000 year record

In the Middle Fork Salmon River (MFSR) of central Idaho, over 40% of the watershed has burned in the last 30 years. Fires have burned throughout the high relief watershed, encompassing high elevation sub-alpine and mixed conifer forests and lower elevation rangeland ecosystems. Subsequent erosion from severely burned hillslopes produced many large fire-related debris flows. This study uses ¹⁴C-dating of charcoal fragments from alluvial fan deposits to reconstruct fire and fire-related sedimentation along this ecological gradient of the main-stem river. We investigate the role of climate on spatial and temporal variations in the timing, frequency, and severity of fire and the associated erosional response. We combine recent (1997-2008) fire-related debris flow sediment yields and reconstructed fire-related debris flow frequencies over the last 6 ka to quantify long-term (10^3 yr) sediment yields. Overall, fire-related deposits compose $74 \pm 25\%$ of total alluvial fan thickness in upper, wetter basins versus $41 \pm 33\%$ recorded in lower, drier basins. Early (14-8.5 ka) and late Holocene (4 ka – present) fires primarily produced debris flow deposits, while mid-Holocene (8-5.5 ka) fires primarily produced sheetflood deposits. Recent (1997-2008) debris flow events followed moderate to high severity fires that burned basins composed of easily erodible Idaho Batholith granites and produced sediment yields between $1,450-34,550 \text{ Mgkm}^{-2}\text{yr}^{-1}$. Lower, drier basins produced significantly smaller yields than upper, wetter basins. High fire frequency, severity, and synchronicity resulted in abundant fire-related debris flows that supplied $83-262 \text{ Mgkm}^{-2}\text{yr}^{-1}$ of sediment to the main-stem river. Over the last 6 ka, we estimate fire-related debris flows have contributed $\sim 30-101 \text{ Mgkm}^{-2}\text{yr}^{-1}$ of sediment to the MFSR. Our results demonstrate fire is a primary control of millennial sediment yields in the MFSR. We hypothesize that centennial scale intervals of increased fire frequency and severity occur during long-term intervals of relatively cool and (or) wet climate conditions and associated increased fuel production. Increased fuel loads, coupled with annual to decadal-scale droughts, produce widespread severe fire and debris flows, which contribute significantly to long-term sediment yields and aquatic habitat in the MFSR.

Wild Chinook Salmon in a Dynamic Wilderness Landscape

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Paper #1. Setting the stage: Introduction to the Middle Fork Salmon River (MFSR), its landscape, natural processes, and biological components

To persist in dynamic landscapes, native aquatic species have developed diverse life history strategies that utilize a broad range of habitats across time and space. Consequently, effective conservation and restoration strategies for at-risk species will require information collected at appropriate spatial and temporal scales. Within the Middle Fork Salmon River (MFSR), we are developing long-term data sets across large spatial scales to describe biological and physical processes. The MFSR drains 7,330 km² of a remote area of central Idaho and for most of its length, flows through wilderness that provides critical habitat for six ESA listed species. The topography has high relief and the geology is highly variable and dominated by Challis Volcanics and Idaho Batholith intrusions. Streams flow through wide, U-shaped valleys in the upper portion of the drainage where deposits of Quaternary alluvium and Pleistocene glacial drift fill valleys and provide meandering pool-riffle sequences. Valleys throughout the remainder of the drainage are typically narrow and V-shaped although low gradient and unconfined channels are patchily distributed in most subbasins. The MFSR drainage provides a unique study area for several reasons: 1.) Chinook salmon and steelhead stocks are wild and indigenous, relatively unaltered by hatchery supplementation, 2.) Natural processes such as fires, floods, and debris flows persist and these processes help maintain the dynamic mosaic of stream habitats that exist within the MFSR, and 3.) The abundance of Chinook salmon has been monitored annually at index sites for more than 55 years. These data have been supplemented since 1995 with a comprehensive, spatially continuous census of redds throughout the full network and a landscape-level description of salmon genetic structure. These biological data are being integrated with basin-scale predictions of salmon spawning habitat distributions, estimates of sediment motion and bedload transport, mapping of recent fires and debris flows, basin-scale patterns of spatial autocorrelation in water temperatures, and continuous remote sensing of selected stream channels via airborne laser altimetry. These data are enabling us to advance knowledge of the landscape and local biophysical conditions and of the processes that influence aquatic habitat, and the distribution, diversity, and persistence of salmon.

Wild Chinook Salmon in a Dynamic Wilderness Landscape

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Paper #7. Building a blueprint for salmon recovery

In previous papers we described characteristics of MFSR Chinook salmon that are essential for maintaining robust populations to facilitate recovery: 1.) Genetics: populations remain genetically diverse, both within and among tributaries; 2.) Life histories: stocks exhibit diverse life histories, including a wide elevational range for spawning and multiple freshwater and marine ages; 3.) Access to high-quality habitat with functioning natural processes: stocks have access to some of the highest quality, spatially diverse, abundant, and connected habitat within the Columbia River basin; and 4. High resiliency: stocks have produced among the highest number of recruits per spawner reported. At higher escapement levels, salmon colonize previously unoccupied habitats and express broader life history diversity. The National Marine Fisheries Service has identified “four Hs” (harvest, habitat degradation, hatcheries, and the hydrosystem) as the primary causes of anadromous fish declines. Despite the absence of three “H’s” in the MFSR (quality habitat, few hatchery strays, and low harvest rates), MFSR salmon populations have declined coincident with other Snake River populations. If freshwater habitats exhibited strong controls on population trends, MFSR populations should have declined less in recent decades than populations in degraded habitats. This suggests that habitat restoration in headwater areas is insufficient to recover these populations since out-of-basin factors are the dominant factors controlling abundance. To illustrate, survival of MFSR populations that pass 8 dams is 1/4 to 1/3 that of populations passing 4 dams. As a result, a substantial gap exists between current MFSR salmon population viability and current abundance and productivity. A series of Biological Opinions (BIOPs) were developed to comply with ESA and address recovery gaps. All (1994, 2000, 2004, and 2008/2010) were rejected by Federal Courts as either “scientifically unsound” or because they rely on “unidentified habitat mitigation actions”. Actions which improve survival in the migration corridor are essential to population recovery. Broader recovery actions are needed soon; despite their resiliency, MFSR populations are less diverse and more synchronous than they were in the 1950s and 1960s. Moreover, a warming climate will add additional stresses to these populations and increases the urgency for more effective recovery actions.