Symposia for the Western Division American Fisheries Society Meeting, Boise, ID

(Alphabetical order by session and by author)

Advancements in co-management of anadromous fishes (Hesse)

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The role of the Technical Advisory Committee (TAC) for managing fisheries within the framework of the United States v. Oregon Management Agreement

The United States v. Oregon Management Agreement provides a framework within which the Parties may exercise their sovereign powers in a coordinated and systematic manner in order to protect, rebuild, and enhance Columbia River fish runs while providing harvests for both treaty Indian and non-treaty fisheries. The primary goals of the Parties are to rebuild weak runs to full productivity and fairly share the harvest of upper river runs between treaty Indian and non-treaty fisheries in the ocean and Columbia River Basin. Parties to United States v. Oregon are: the State of Washington, the State of Oregon, the State of Idaho, the United States, the Shoshone Bannock Tribes, the Confederated Tribes of the Warm Springs Reservation of Oregon, the Confederated Tribes of the Umatilla Indian Reservation, the Nez Perce Tribe, and the Confederated Tribes and Bands of the Yakama Nation. When proposing Columbia River fisheries the effect of that fishery on escapement, treaty rights, and the impact on species listed under the Endangered Species Act (ESA) must be considered. The Technical Advisory Committee (TAC) provides technical information such as pre-season run forecasts, in-season run size updates, amount of harvest, and ESA impacts on listed stocks to managers to make these fishery decisions. All members to United States v. Oregon have membership in TAC. TAC works by consensus and does not make any policy recommendations.

Advancements in co-management of anadromous fishes (Hesse)

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Counting the lost legions: steelhead run reconstruction in the Snake River basin

Steelhead trout in the Snake River basin are the focus of a variety of harvest and conservation programs implemented by multiple agencies. A run reconstruction model offers a systematic way to address information needs for management within the large and complex arena presented by Snake River steelhead. Our goal was to summarize data regarding abundance of adult steelhead entering the Snake River, spatial distribution of spawning fish, and known fates/disposition. To achieve this, a group was convened of representatives from the anadromous fishery management agencies within the basin. The immediate objective was to estimate the disposition of the 2010-2011 return. This was the first effort to synthesize data for all populations and hatchery stocks across the basin. We estimated 152,485 adipose-clipped hatchery fish, 23,454 unmarked hatchery fish and 52,026 wild steelhead entered the Snake River. Fishery-related mortality totaled 96,936 marked hatchery fish, 1,385 unmarked hatchery fish and 1,959 wild steelhead. Further, 25,031 marked hatchery fish, 5,856 unmarked hatchery fish and 91 wild fish were removed at weirs. Potential spawners remaining in the habitat totaled 30,518 marked hatchery fish, 16,213 unmarked hatchery fish and 49,976 wild steelhead. Using the run reconstruction model, we attempted to quantify fishery-related impacts on steelhead as they migrate to their natal or release area, and make inferences regarding spatial distribution of spawners and disposition. Comparison with independent data suggested that the model provides realistic estimates for hatchery fish, but methodology for natural fish estimates needs refinement. This information will help evaluate the performance of the Snake River summer steelhead Evolutionarily Significant Unit towards escapement goals and delisting criteria. The inaugural effort focused on compilation of data from multiple collaborators and general assumptions that may limit specific conclusions; however, the resulting analytical framework can be refined for more rigorous evaluations in the future. Our group is an example of effective technical cooperation and data-sharing among disparate management agencies.

Advancements in co-management of anadromous fishes (Hesse)

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The Pacific Marine and Estuarine Fish Habitat Partnership: Advancing Juvenile Fish Habitat in Estuaries and Nearshore Marine Environments

The Pacific Marine and Estuarine Fish Habitat Partnership is one of 18 nationally recognized fish habitat partnerships in the United States. Recognized by the National Fish Habitat Board in January of 2012, the PMEP seeks to advance juvenile fish habitat, connectivity, and water quality and quantity in estuarine and nearshore marine environments. This presentation will describe the goals of the partnership and efforts to date to work with partners in California, Oregon, and Washington to achieve its goals.

Advancements in co-management of anadromous fishes (Hesse)

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Hatch: Moving towards seamless database protocols

Data collection and ecological processes do not occur at similar scales. Monitoring our environment, therefore, requires research approaches that integrate data across spatial and temporal scales relevant to ecology. Despite the enormous amount of data being collected annually, many government agencies are only now beginning to build coordinated data management systems. With efficient data flows and coded analysis tools, researchers and managers will be better prepared to compile data across systems and through time, at ecologically relevant scales. In this project we have designed an online platform for seamless data management (called Hatch). Our aim is to improve data storage protocols and data access to allow efficient data analysis at the site scale and for meta-analyses across the Columbia River Basin (CRB). Hatch currently uses the ISEMP's Aquatic Resources Schema to link data collection events. While data files are input, the data type is automatically recognized. The data file is then validated and stored along with the metadata. Data search tools are now being designed in accordance with data sharing agreements. The database structure is based on scientific models for ecosystem processes, and in the future, models of fish population dynamics. The project will help data flows directed at answering key management questions in the CRB, with an initial pilot project in the Methow River Basin of Washington State. This work is in close coordination with agencies working within the basin. With less fragmented database protocols, managers and scientists will be better prepared to efficiently answer scientific questions at relevant ecological scales.

Advancements in co-management of anadromous fishes (Hesse)

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Setting the Stage for Fisheries Management in a Multi-Jurisdictional World

Effective management involves a framework that encompasses the population in question (fish), its ecosystem (habitat), and society's values and behavior (people). Global scale actions are influencing our local natural resources at an increasing rate. The life cycle of anadromous fishes inherently crosses multiple natural resource management jurisdictions, making effective collaboration between managers paramount. Fisheries managers are demonstrating they are up to the task of refining management processes and collaborative on-the-ground actions. But what does it really take to effectively share power and responsibility between government and local resource users? Co-management attributes that facilitates: effective knowledge generation and transfer, innovative use of scare resources, trust, conflict resolution, and collaborative decision making will be described. This presentation will set the stage for real life examples of aquatic ecosystem co-management in action in the "Advancements in Co-management of Anadromous Fishes" symposium.

Advancements in co-management of anadromous fishes (Hesse)

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Challenges and Successes of Joint Management at Dworshak National Fish Hatchery

In 2004, Congress passed the Snake River Water Rights Act which contained a provision that the Nez Perce Tribe and U.S. Fish and Wildlife Service become joint-managers of Dworshak National Fish Hatchery. Dworshak Hatchery is an important production facility located on the Clearwater River in Idaho within the Nez Perce Indian Reservation. Joint management of the facility was defined by the Act as "equal partners in operation and management" with a goal of achieving a 50:50 Tribal and Service work force within 15 years. A description of how the joint operation and management concept on paper was actually implemented at the hatchery will be provided. We share challenges and successes of melding funding from several agencies and 27 tribal and federal employees with different cultures, missions, uniforms, human resource manuals, training and perspectives into one team to successfully produce millions of salmon and steelhead juveniles.

Advancements in co-management of anadromous fishes (Hesse)

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Nez Perce Tribe/ Forest Service Watershed Restoration Partnership

The Nez Perce Tribe Department of Fisheries Resource Management Watershed Division and the US Forest Service have worked in partnership for over 15 years on watershed restoration projects that work toward the ultimate goal of restoring aquatic ecosystems addressing all limiting factors so that the physical habitats within the watersheds no longer limit recovery native fish species. The partnership incorporates all aspects of restoration from planning and assessments to implementation and monitoring while sharing resources and cost-sharing to accomplish the work. Restoration work includes: riparian and meadow restoration, road decommissioning, fish passage culvert and bridge replacements, stream channel restoration, mine reclamation, and more. The partnership began on the Nez Perce and Clearwater National Forests and has grown to include the Payette, Boise, Umatilla, and Wallowa Whitman Forests.

Advancements in co-management of anadromous fishes (Hesse)

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A Tribal Perspective: The Role of Hatchery Mitigation Programs that Support Nez Perce Treaty Fisheries in the Snake Basin

Indian tribes in the Pacific Northwest (PNW) ceded millions of acres of land in various treaties in the 1800s. In doing so the PNW Tribes reserved rights to harvest fish in their aboriginal territories. Quite simply, the Tribes were looking to maintain their ability to be a fishing-based people, to live off the land and the resources according to each season. The right to harvest fish is only as meaningful as the number of fish available for harvest. There has to be fish in the rivers in order for tribal members to carry on our livelihood, culture and economy. Hatchery production in the geographic areas encompassing the salmon and steelhead has been occurring for over 70 years and, for the most part, was developed as mitigation for development of the Columbia River hydrosystem. The Snake River Basin has experienced losses of culturally important salmon and steelhead runs (including other species) as result of construction of hydroelectric projects. The Lower Snake River Compensation Plan (LSRCP) is congressionally authorized mitigation for an estimated 50% reduction in salmon and steelhead production in this basin due to development of the four lower Snake River dams. The mitigation, at least for the LSRCP, is fish "in place, in kind." Mitigation ascribed to hatcheries is not solely for fish to the creel but programs can be re-focused as a conservation hatchery program. The hatcheries produce fish for the creel as well as to help rebuild the wild runs where and when possible. Finding the means for hatcheries to do double duty provides benefits and is the reason for the focus on developing appropriate supplementation programs in the basin. For Tribes and others in the mid-upper reaches of the Columbia, nearly the only harvest opportunities available in the past 30 years have been on hatchery fish. The Nez Perce Tribe, in coordination with other co-managers, has developed hatchery and harvest strategies for salmon populations of the basin. These are developed to balance the needs of the fish resources and the people who catch and depend upon them. This can be achieved at existing or planned hatchery programs in the Snake Basin through appropriate, well-designed hatchery supplementation actions. Annual monitoring and evaluation (M&E) of the supplementation program should assess the status of the integrated population and the status (abundance and productivity) of the natural component of the population.

Advancements in co-management of anadromous fishes (Hesse)

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Snake Basin Hatchery and Harvest Co-Management:

The 31 extant wild populations of spring and summer Chinook salmon in the Snake River Basin experienced significant declines following construction of dams on the Columbia and Snake rivers and were listed as threatened under the federal Endangered Species Act. To mitigate for lost natural production, state, federal, and tribally operated hatchery programs in the Snake River Basin produce 12 million spring/summer Chinook smolts annually. Tribal, state, and federal interjurisdictional management of fisheries for conservation of natural populations, sharing of harvestable returns and ESA take, trapping of hatchery broodstocks, and distribution of fish trapped in excess of brood needs is extremely complex. In an effort better coordinate hatchery and harvest management, co-managers in the basin have implemented a structured pre-season planning, inseason coordination, and post season review and evaluation process. Weekly inseason coordination teleconferences where run projections, harvest estimates, and hatchery trapping and broodstock collection data are exchanged are the key to successful co-management in the basin. These weekly information and planning sessions have helped significantly to break down traditional communication barriers between harvest managers and hatchery managers within and among tribal, state, and federal co-management agencies.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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From a model to a response design and back again - or was it the other way around?

Well-conceived management questions are the foundation of useful and efficient monitoring programs. Models are a formalization of those questions; formalizing how data from monitoring programs should be consumed. Subsequent implementation of models and monitoring designs generally proceeds by either constructing a model to utilize existing data or modifying/implementing a monitoring program to meet the data needs of a model. Depending on the complexity of the questions and their similarity to prior management concerns, either approach might work, or the process may be iterative. The Integrated Status and Effectiveness Monitoring Program (ISEMP), was initiated by resource managers in the Columbia River Basin to develop methods that link resource management data with resource management decisions. By developing approaches for identifying watershed condition and limiting factors, prescribing appropriate management and restoration actions, and then relating changes from those actions to the freshwater productivity of anadromous fishes, the project's goal is to close the loop between monitoring and management with predictive and descriptive models. In the Salmon River subbasin (Idaho) we adopted a preexisting population production model, evaluated existing data streams, incorporated those that were useful, and implemented novel sampling approaches as necessary. Subsequently, we have modified the response and survey design, and the model itself as we have identified weaknesses in both the conceptual approach of the model and our ability to generate the data required to populate the model. This coevolution has proven critical in addressing the specified management questions as well as increasing program relevancy for cooperators. We conclude that even very well designed monitoring programs are more likely to be successful if they maintain the flexibility to address a broader suite of management questions than those underlying initial program development.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Impacts of salmon spawner density and stream productivity on the ecology of stream-dwelling fishes in southwestern Alaska

Each year, millions of Pacific salmon return to freshwater ecosystems throughout the Northern Pacific Rim generating massive resource fluxes of nutrients and energy. While there is a growing appreciation that stream-dwelling salmonids benefit from the resource subsidy spawning salmon provide, there remains limited empirical data on how these impacts are mediated by the magnitude of the pulse, the in situ productivity of the recipient system, and the ability of consumers to capitalize on the resources. We assessed the growth and foraging response of two species of coexisting resident fishes to extreme inter-annual variation in the density of spawning sockeye salmon (*Oncorhynchus nerka*) in two streams that vary in productivity in southwestern Alaska. Over 10 years and across a greater than 10-fold variation in sockeye salmon density, both rainbow trout (*O. mykiss*) and Arctic grayling (*Thymallus arcticus*) exhibited a similar, but mechanistically different, non-linear saturating growth response to changes in salmon density. This growth response was driven by both an increase in salmon egg consumption and a decrease in dietary overlap among the two species. Additionally, the relative change in growth from low to high salmon densities was different between streams and depended on in situ stream productivity. Therefore, our study provides strong evidence that understanding of both the foraging ecology of consumers and the in situ productivity of recipient ecosystems, which together regulate the ecological consequences of changes in resource subsidies, is required for successful implementation of ecosystem-based management in systems dependent on pulsed resource subsidies.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Marine survival and spatial scaling of density-dependence: consequences for freshwater productivity in salmonids

Density dependence is a fundamental process limiting the size and growth rate of salmon and steelhead populations during the freshwater rearing phases of their life-histories. However, density-independent processes such as marine survival may also influence adult carrying capacity. One explanation for this phenomenon is that more smolts should be required to produce each returning adult during low marine survival. Conventional stock-recruit models have assumed that the relationship between spawner abundance and juvenile productivity remains constant when marine survival is depressed, allowing freshwater dynamics to remain unchanged, however this is not necessarily so. Observed patterns of whole life-cycle and watershed density dependence are likely the integration of density dependence operating at finer temporal and spatial scales. Salmon also exhibit strong fidelity to spawning areas, and as such, their populations are structured at relatively small spatial scales, allowing dynamics of populations to be driven by processes functioning at these scales. Thus, scaling up density-dependent population parameters may be complicated by temporally variable dynamics at biologically relevant spatial scales. For example, as a result of the strong philopatry exhibited by salmon and variable habitat productivity, some habitat patches that support salmon during periods of high marine survival may no longer be occupied during periods of poor survival. Consequently, density dependence may continue to limit the growth and survival of fish within occupied habitats more than expected since juveniles are no longer distributed according to an ideal free distribution at the population scale. This should lead to lower than predicted productivity during periods of low marine survival and slower recovery from these periods. We use spatially explicit population model simulations to explore whether changes to distribution resulting from low marine survival could explain greater reductions in freshwater carrying capacity than would be predicted by observed reductions in spawner abundance at the populations scale. We also evaluate whether persistent changes in marine survival have been associated with altered freshwater productivity and carrying capacity in long term steelhead and salmon spawner-juvenile recruit datasets. Results highlight an underappreciated linkage between productivity of marine and freshwater habitats for salmonids.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Viability of Isolated Populations: What Life History Traits Aid Persistence?

Habitat loss resulting in fragmentation of wildlife populations is a leading cause of population decline across taxa. Yet for cutthroat trout (*Oncorhynchus clarkii spp*.), intentional isolation of populations is being used as a management strategy to protect against interactions with invasive fish species. We used integral projection models (IPMs) to estimate population growth rates in isolated populations of westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) located on the Flathead Indian Reservation in western Montana. IPMs are individual based models that use the size of individuals in a population to determine demographic parameters, such as probability of maturity and fecundity. This modeling technique allows biologists to utilize more information in their dataset beyond a standard matrix model because individuals do not need to be categorized into discrete life stages for population viability analysis. We used IPM results from multiple isolated populations to examine the relationships between population viability, habitat size, and genetic diversity. With few exceptions, our model outputs suggest that the isolated populations in our study are rapidly declining. Population growth rates were positively correlated with both size of available habitat and genetic diversity. Our results highlight the potential importance of local adaptation in isolated populations. Specifically we see evidence for a smaller size of maturity in the isolated systems, improving the probability of persistence in these populations. Climate change threatens to further fragment populations of aquatic organisms, and isolation management continues to gain popularity as a management strategy for protecting native trout species. In this context, our results provide powerful insights for management strategies aimed at long-term persistence of native fish species.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Fundamental Life Stage Specific Abundance, Survival and Productivity Relationships for Grande Ronde River Basin Chinook Salmon Life Cycle Modeling

Threatened spring Chinook salmon populations in Northeast Oregon have complex life histories with survival impediments throughout the entire life cycle. Spawning and early juvenile life stage rearing occurs in high elevation headwater streams in the Blue and Wallowa Mountains up to 1100 km from the ocean. Juveniles rear for about 18 months in freshwater prior to seaward migration and exhibit diverse life history patterns during their freshwater residency. In route to the ocean, smolts encounter eight large hydroelectric dams and associated reservoirs. A vast array of management actions across the full life cycle are underway and many more proposed for the future to improve survival and place populations on a path to recovery. Management actions are being taken to restore and protect tributary habitat, supplement natural production with hatchery fish, improve smolt and adult dam passage survival, improve in-river migration conditions with increased flow and spill, and reduce predation. To evaluate potential management actions and develop an understanding of the benefits of proposed actions to viability, recovery, and population extinction risk detailed empirical full life cycle production and survival models are required. The models we have developed are based on population specific life stage specific life history, abundance, productivity, and survival including smolt migration and ocean survival relationships. In addition, we incorporate the influence of hatchery supplementation and habitat-fish production relationships in the model to characterize the range of expected population performance improvements (abundance, productivity, extinction risk) under various management action scenarios. Freshwater abundance, survival, and density dependent relationships vary considerably between populations within the Grande Ronde River basin. We have observed significant differences in egg-to-parr, parr-to-smolt, smolt migration and smolt-to-adult survival rates between populations. Strong density dependent effects at relatively low spawner abundance levels are evident for the Catherine Creek and Upper Grande Ronde populations. Parr and smolt size appear to be strong drivers in survival and length is strongly correlated with parr density in these populations. Differences in life history diversity, life stage specific survival, and density dependent effects results in different responses of populations to ongoing and proposed management actions.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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A Stochastic Life Cycle Model Using Population Specific Adult and Juvenile Abundance and Survival Data for Grande Ronde River Basin Chinook Salmon

Stochastic life cycle models adapted to specific populations can be valuable tools for evaluating population performance under alternative future scenarios. We have developed life cycle models for four Grande Ronde River basin spring Chinook salmon populations incorporating detailed functional survival and capacity relationships for freshwater stages derived from ongoing monitoring and tagging efforts in each system. Our primary objective is to enhance the capability for modeling the impacts of potential changes in habitat on projected population abundance and risk, either in isolation or in combination with actions aimed at other life stages. The Grande Ronde population models are designed to incorporate alternative assumptions regarding annual patterns in estuarine/ocean survival, juvenile and adult passage through the hydropower system and harvest management strategies. Brood year adult spawner recruit data series were used in combination with the juvenile estimates generate model input parameters for out of basin life stages. Initial model runs incorporate previously derived ocean climate scenarios and estimates of main-stem Snake and Columbia River passage survivals. We derived empirical relationships for three sequential tributary life history stages and incorporated them into the population specific models, including provisions for parameter uncertainty and annual variation. When expressed in terms of a standard amount of habitat, parr production per spawner estimates are relatively consistent across the four populations. Relatively strong density dependent effects are apparent in the summer parr to spring out-migrant phase survival relationships for each population. Initial model runs indicate substantial differences in projected abundance levels and extinction risk across the four populations. We are coupling results from the juvenile data analyses with data that are being generated through a major habitat study focused on Catherine Creek and the Upper Grande River to explore alternative approaches for linking habitat conditions and to juvenile stage survivals and capacities in the models. Other immediate priorities for the Grande Ronde Chinook modeling effort include adding a sub-model capturing the effects of ongoing hatchery supplementation programs on natural production under alternative assumptions of hatchery/natural interaction, and conducting sensitivity analyses with an expanded range of assumptions regarding within basin and out of basin survivals.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Determining where and what to fix for optimum stream restoration benefits

Both the location within a stream network and the type of action taken to improve stream habitat can strongly affect benefits to the overall fish population. We completed habitat surveys and fish population modeling for a full watershed to evaluate how the spatial distribution of habitat characteristics was likely to influence benefits of various restoration actions. The quantitative relationship of habitat features, including flow, temperature, and channel unit morphology, to the capacity for juvenile rearing, upstream passage, and spawning were established from a synthesis of published studies for Chinook, Coho, steelhead and chum salmon. In the watershed's present condition and assuming unimpaired adult passage, our model predicted that 148 Chinook, 261 chum, 240 coho, and 146 steelhead could be produced on average at full spawner seeding. These values were similar to historic run sizes. Results showed that spawning capacity was distributed among reaches differently by species, and that accounting for movement of juveniles dramatically affected estimates of survival to adulthood. Only 45% of adult production resulted from juveniles that reared to smolting within the watershed, so production was substantially dependent on fish that emigrated as fry or parr to rear in the Sandy and Columbia rivers. Without improvements to upstream fish passage, adult equivalent production will be reduced by half in years of low flow in October and November, and in the range of 20-40% most other years. Other key factors limiting fish production were proximity of rearing habitat to spawning habitat, low flows and high temperatures.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Life-cycle models for the diverse and plastic *Oncorhynchus* mykiss: challenges and opportunities

Oncorhynchus mykiss support numerous fisheries in North America, have tremendous social and cultural value, and are an integral part of river and stream ecosystems. However, many populations have declined. The species displays a wide variety of life history strategies, which can be influenced by environmental and anthropogenic factors. Life-cycle models can be used to better understand these strategies of *O. mykiss* and evaluate their population dynamics both spatially and temporally. I will talk about recent efforts to develop life-cycle models for interior Columbia River basin *O. mykiss* populations. I will discuss existing life-cycle models upon which we are building and available data from eight steelhead populations in two ESUs including Rapid River, Big Bear Creek of the Potlatch River, and Catherine Creek (Snake River Steelhead ESU) along with Umatilla River and Satus Creek, Toppenish Creek, Naches River, and upper Yakima River of the Yakima River basin (all Middle Columbia River Steelhead ESU). Overall, we have found that resident *O. mykiss* (rainbow trout) data are not available for most populations, which may limit the power of some models. However, we can successfully evaluate a number of scenarios, including juvenile survival; downriver survival associated with hydropower corridor passage; estuary and early marine survival; later marine survival; and upriver survival. We found that population abundance and extinction probability trends varied a great deal among the populations and were sensitive to the various scenarios. These flexible models demonstrate great potential to increase our understanding of how changes in survival rates at different stages of the life cycle of *O. mykiss* affect population abundance trends and viability.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Advancing the Science of Estimating Pacific Salmon Production Potential

The combined effects of habitat degradation, overfishing, and hatcheries have resulted in "lost baselines" regarding the number, productivity, diversity, and distribution of Pacific salmon spawners that should be filling available habitats. We propose using recent modeling advances and emerging data to integrate intrinsic habitat capacity, salmon life-history, and environmental drivers in enhanced models that improve estimates of the production potential of extant habitat. We also describe concepts for decision tools that can help salmon managers select the best models for estimating the productive potential of extant habitat in light of available data. Outputs from the new habitat-based productive potential models can be used to estimate escapement goals and can subsequently be integrated into other models that will evaluate habitat, hatchery, and harvest management decisions for restoring naturally reproducing populations. While this paper is primarily focused on the Pacific Northwest, the concepts addressed here can be applied throughout the range of Pacific salmon.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Modeling to predict habitat capacity and population dynamics of spring-run Chinook and steelhead: A Case Study for Reintroduction Planning in the Upper Yuba Basin, CA

The North, Middle, and South Yuba rivers historically supported Central Valley spring-run Chinook salmon and Central Valley steelhead, but both species are now absent from these upper basin tributaries and access is blocked by Englebright Dam and other dams. In the Public Draft Recovery Plan for Central Valley salmon and steelhead, NMFS identified the upper Yuba River watershed as a top priority for reintroduction, with moderate to high potential to support spawning populations if upstream and downstream passage solutions can be found. To evaluate the feasibility and help prioritize reintroduction planning efforts, a basin-wide analysis of stream habitat capacity and production potential upstream of Englebright Dam was conducted using RIPPLE, a digital terrain-based salmonid habitat and population model. RIPPLE predicts capacity of salmonid habitat based on basin-scale physical characteristics that co-vary with stream habitat. Geomorphic characteristics, such as channel gradient and drainage area, and physical habitat characteristics were combined with density and suitability criteria for each species and life stage, to predict reach-specific salmon and steelhead capacity. RIPPLE then employs a multi-stage, stock-production model to predict long-term average abundance for each life stage. Parameter uncertainty and sensitivity were evaluated. Current conditions for the three rivers, as well as future scenarios of alternative flow regimes were modeled to explore reintroduction potential. Preliminary results suggest the Upper Yuba basin can support moderate numbers of salmon and steelhead under current conditions, and substantial increases in production would occur in response to increased stream flows. The results of this study are being used as an integral part of the Reintroduction Implementation Plan for Central Valley Spring-Run Chinook salmon and steelhead in the upper Yuba River watershed.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Resource allocation optimization for salmon habitat restoration

We develop a method to spatially and temporally optimize resource allocation efforts aimed at salmon habitat restoration. Using a spatially explicit life cycle model with underlying habitat/survival relationships, we explore the potential for restoration activities to be targeted such that production yields are optimized. We postulate that not all restoration activities will yield immediate results, and that the current spatial distribution of the quantity and quality of resources and fish abundance has a direct bearing on where investments are most likely to produce results. We consider a variety of habitat factors and their affect on survival as well as the effect of straying and dispersal on the survival of adults spawners and juvenile migrants.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Evaluating potential life history tactics in an extirpated steelhead population in Alameda Creek, California

Life history characteristics and diversity of behaviors within and between populations allow species to accommodate variation in environmental conditions over short and long time frames. The importance of this diversity is highlighted by its inclusion in the Viable Salmonid Population (VSP) concept and its application to ESA listed salmonid recovery. The tuning of life history strategies to environmental conditions may be especially important in marginal environments. Alameda Creek in San Francisco Bay is near the southern range of steelhead distribution and has a Mediterranean environment characterized by hot summers and flashy winter flow conditions. Steelhead have been extirpated from the creek due to a variety of conditions but mitigation associated with San Francisco Public Utilities Commission's (SFPUC) Calaveras Dam replacement project will re-introduce steelhead to the watershed. How might the life history tactics of the re-introduced steelhead respond to habitat restoration efforts? We have used a salmonid-habitat model, Ecosystem Diagnosis & Treatment (EDT), to address this question and evaluate a range of plausible steelhead life history tactics against flow management regimes. EDT is particularly well-suited to this analysis because it evaluates habitat along temporally and spatially diverse habitat pathways arrayed along steelhead life history patterns. EDT evaluates habitat along these pathways for steelhead life stages and then integrates performance across life stages to estimate potential capacity and productivity of steelhead using the pathway. Constraints on performance are set by exposure to conditions along each pathway that is set by varying life history tactics (speed, spatial movement, residence time). EDT evaluates thousands of these pathways varying conditions in time and space while sampling within a proscribed range of life history characteristics. The result is a distribution of potential performance reflecting environmental variation and within-tactic life history variation. We have used the model to evaluate the performance of hypothetical steelhead life history tactics in Alameda Creek in response to flow-related management actions. The model has indicated that the environment in Alameda Creek will sharply select for optimal life history tactics but that variation within tactics may arise that will allow steelhead to respond to the variation in the conditions within Alameda Creek.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Modeling complex populations in their freshwater habitat: An example using Wenatchee spring Chinook salmon

Current life cycle modeling efforts in the Wenatchee River Basin seek to build on several recent life cycle models (Leslie matrix and Shiraz models). The primary distinction between past and current efforts is the ability to capitalize on the multitude of habitat and fish already and to be collected, and to account for Wenatchee River spring Chinook salmon juvenile life history diversity. The Wenatchee River Basin spring Chinook salmon population consists of five major spawning aggregations in distinct areas that comprise a diverse range of habitat conditions. The proportion of spawners that are of hatchery origin (pHOS), that are derived from an ongoing integrated conservation hatchery program, also varies among the five major spawning areas (mean pHOS range 0.28 – 0.77), and strongly influences spawner abundance. Presumably in response to certain habitat conditions and spawner abundance levels, juvenile salmon exhibit different juvenile life history strategies. The proportion of juveniles that either emigrate out of their tributaries and rear in the mainstem Wenatchee River or that rear entirely in their natal tributaries varies among the major spawning areas. Our effort is focused on extending the matrix model to incorporate the five major spawning and rearing areas in both natal spawning tributaries and summer/winter rearing areas in the mainstem Wenatchee River, and to incorporate area-specific survival in response to habitat restoration. We developed several preliminary scenarios and parameter perturbations to explore the dynamical response of Wenatchee spring Chinook salmon as a representation of the potential of the model's current capabilities.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Using an explanatory model to explore freshwater food webs and salmon carrying capacity

The Aquatic Trophic Productivity Model (ATP Model) described here takes an energetic approach to modeling fish food webs by linking fish production explicitly to the transfers of organic matter between different components of a stream food web. First we describe the model structure. Then we present simulations that show the effect of marine derived nutrients on salmon production in the context of a full life-cycle model. The framework of the ATP model is fashioned after the pioneering lotic ecosystem model of McIntire et al. (1978), whereby food web dynamics are explicitly linked to the environmental conditions of the stream and adjacent riparian habitats. Similar to McIntire et al. we examine stream production as changes in the biomass of periphyton, detrital, secondary and tertiary trophic stocks, and the elaboration of the coupled processes that affect those changes in production. We chose the commercial systems dynamics software Stella® because its stock and flow diagrams provide visual representations of the system dynamics and because free run-time versions of the software are available. Field experiments will be conducted to parameterize, calibrate and test (validate) each model component. The model will then be modified as needed to reflect empirical findings. We will use the ATP model to quantify how habitat restoration projects change fish production by affecting the underlying mechanisms represented in the model.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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Individual variation in behavioral strategies leading to successful recruitment in sockeye salmon

Prevailing approaches to life-cycle modeling of salmonids assume that most important variation occurs between life stages as the body size and behavior of individuals change through ontogeny. However, substantial ecological variation may occur within life stages in salmonids, but data to characterize this variation remain rare. Here, we used otolith microchemistry to quantify the variation in migration patterns and habitat use observed among the recruits to a sockeye salmon stock inhabiting a geomorphically complex watershed. The Chignik watershed on the Alaska Peninsula consists of two lakes, each supporting a distinct stock of sockeye salmon; Black Lake in the upper watershed and Chignik Lake in the lower watershed. Recent natural geomorphic changes have reduced the volume of Black Lake, causing concern for the productivity of valuable stock of sockeye salmon that relies on the lake for rearing habitat. As summer progresses, Black Lake sockeye juveniles migrate downstream to Chignik Lake where they must compete with juveniles of the Chignik Lake stock before smolting in the spring. Increased competition with the Chignik Lake stock and reduced growth potential in colder, less productive Chignik Lake may reduce the survival of earlier migrants. Otolith microchemistry revealed a broad diversity of habitat-use strategies exhibited by successfully recruiting Black Lake sockeye. The percentage of juvenile growth accumulated in Black Lake had a mean of 48.6% (sd = 25.3%). Interestingly, three Black Lake sockeye demonstrated the life-history strategy of rearing for a short period in the headwater lake, swimming through the lower lake to a marine lagoon, returning upstream to the lower lake to overwinter, and outmigrating as smolts the following spring. These results suggest that diverse habitat availability may provide sockeye salmon populations with a buffer against unpredictable environmental conditions in primary rearing areas. Additionally, these results have implications for modeling and management of salmon populations, as intact habitat mosaics may buffer density-dependent dynamics of juvenile life-stages. If salmonid populations are to be sustained or restored, maintenance of diverse rearing habitats and diversity of behavioral strategies that exploit these habitats, may play a significant role in buffering salmonid populations to variable and new environmental conditions.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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The density dilemma: limitations on juvenile production in threatened salmon populations

Density dependent processes have repeatedly been shown to have a central role in salmonid population dynamics, but are often assumed to be negligible for populations at low abundances relative to historical records. Density dependence has been observed in overall spring/summer Snake River Chinook salmon *Oncorhynchus tshawytscha* production, but it is not clear how patterns observed at the aggregate level relate to individual populations within the basin. We used a Bayesian hierarchical modeling approach to explore the degree of density dependence in juvenile production for nine Idaho populations. Our results indicate that density dependence is ubiquitous, though its strength varies between populations. We also investigated the processes driving the population level pattern and found density dependent growth and mortality present for both common life-history strategies, but no evidence of density dependent movement. Overwinter mortality, spatial clustering of redds, and limited resource availability were identified as potentially important limiting factors contributing to density dependence. The ubiquity of density dependence for these threatened populations is alarming as stability at present low abundance levels suggests recovery may be difficult without major changes. We conclude that density dependence at the population level is common and must be considered in demographic analysis and management.

Advancing techniques for modeling salmonid life cycles and population production: considerations and case studies (Copeland and Knudsen)

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A modeling approach for simultaneous estimation of persistence of multiple populations for freshwater conservation planning

Single-species conservation planning often involves ranking habitat patches with the goal of distinguishing locations that can support a healthy population from locations where long-term population viability is uncertain or unlikely. Because estimates of population dynamics and persistence probability require large datasets, however, most prioritization schemes rely on indirect indicators such as habitat suitability or ad-hoc scoring systems that can be applied over large areas. We describe an alternative approach that marries intensive population modeling with broad-scale habitat modeling. The key is to analyze abundance data from many locations at once, using spatial and temporal covariates to explain variability in population parameters through space and time. The fitted model can then be used to estimate population size and viability, with realistic error rates, across landscapes and under future climate conditions. The methods are based on a simple density-dependent Ricker model of population dynamics, but use a Bayesian statistical approach to incorporate multiple data sources, including limited and fragmentary records. We demonstrate this novel approach using data for cutthroat trout (*Oncorhynchus clarkii*) in isolated streams in the Western United States. We also discuss potential extensions to incorporate genetic data, interconnected populations, and species interactions.

Aquatic Habitat Monitoring: What are we measuring, what trends are emerging, and how is the data being communicated? (Reber)

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Developing an improved understanding of sediment delivery from forest roads and effects on instream habitat in Northwest Montana

The majority of native salmonids across the Pacific Northwest rely on headwater streams for part or all of their life cycles. Many of these headwater streams, however, occur in watersheds with varying densities of forest roads, which have been found to considerably alter hydrology, sediment delivery, and geomorphic processes. Today, agency managers have insufficient funding to maintain this 400,000 mile road system and have been directed to begin strategically reducing road densities, despite a lack of public support in many regions. However, there is a pressing need to make informed decisions in prioritizing road restoration actions, particularly given limited resources and the desire to reduce factors limiting native fishes. Here, we applied an empirical methodology known as GRAIP (Geomorphic Roads Analysis and Inventory Package) to estimate sediment delivery from forest roads across a variety of watersheds in the Southwest Crown of the Continent in northwest Montana. Additionally, we capitalized on this opportunity to match estimates of sediment delivery with commonly-collected stream habitat metrics and macroinvertebrate samples to refine: 1) our understanding of the linkages between road densities and sediment delivery; and 2) link measures of sediment delivery with instream sediment estimates and macroinvertebrate data. Preliminary results from GRAIP surveys of over 250 miles of road indicate that although road densities are locally high in this area, the hydrologic connectivity between roads and streams may be moderate to low. Two percent of the road drainage locations delivered 90% of the road derived sediment to the channels. At a sub-watershed scale, four percent of the observed road length is hydrologically connected to the channel network and was modeled to deliver 5% of the total mass of fine sediment eroded from the road surfaces and ditches. Correlations among instream sediment metrics varied considerably, indicating information from sediment data is not consistent across metrics. Overall, we found relatively low levels of fine sediment across most sites supporting the linkages between sediment delivery from GRAIP and instream estimates. Our results provide critical insights into restoration monitoring activities as well as the effectiveness of detecting trends in stream habitat.

Aquatic Habitat Monitoring: What are we measuring, what trends are emerging, and how is the data being communicated? (Reber)

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Level of effort and prediction success, techniques for two dimensional hydrodynamic habitat modeling

Many in-stream rehabilitation efforts are conducted on the Pacific coast of the North America but few of these include a quantitative evaluation of their effectiveness, particularly in large riverine systems. In 1964, the Trinity River in northern California was dammed and had most of the inflow diverted to the Central and San Joaquin Valleys as part of the Central Valley Project, resulting in severe declines in the anadromous fish populations due to habitat reductions and degradation. Due to efforts of the Hoopa Valley Tribe and partners, a large scale restoration effort commenced in December 2000 to restore the fisheries resources of the river through flow augmentation, channel rehabilitation, gravel augmentation, and watershed improvement. A primary objective of this effort is to increase and improve salmonid rearing habitat, identified as the principle factor limiting fish production. To evaluate the effectiveness of restoration actions in creating and improving salmonid rearing habitat, we developed two methodologies. The first methodology involves the creation of a planar representation of what habitat is present at the flow it was mapped based on the target species and lifestage. In validation studies we found this mapping technique is repeatable and good predictor of target habitat. The second methodology we employed involved the development of two-dimensional hydraulic models which allow predictions across multiple flows and species lifestages. We evaluated the accuracy of two-dimensional models with differing levels of effort put into inputs and calibration and compared the habitat predictions to those that were mapped at the same location the same year.

Aquatic Habitat Monitoring: What are we measuring, what trends are emerging, and how is the data being communicated? (Reber)

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Reconnecting Tributaries in the Lemhi River Sub-basin-Do Fish Respond?

The effects of isolated tributary habitat on the distribution and abundance of salmonids in the Lemhi River sub-basin are well documented. Of the 31 tributaries to the Lemhi River, only two were considered functionally connected. Currently, Chinook salmon production is limited to the upper Lemhi River and in Hayden Creek even though several other tributaries contain high intrinsic spawning potential for Chinook salmon. Migratory forms of freshwater resident trout have declined dramatically in the Lemhi River and the lack of tributary habitat availability is a suspected cause. Habitat restoration actions are being implemented to reconnect critical tributary habitat to provide biological benefits to ESA listed Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*Oncorhynchus mykiss*), and bull trout (*Salvelinus confluentus*). In 2007, an effectiveness monitoring and evaluation program was implemented to assess changes in habitat condition and associated response fish response to restorative actions.Although monitoring efforts focused on the entire sub-basin, a substantial effort was placed on evaluating population response measures such as changes in fish distribution, abundance, productivity, and survival in reconnected tributaries. Fish monitoring activities include operation of PIT Tag arrays and rotary screw traps, roving fish surveys, annual redd count surveys, and radio telemetry. Preliminary results suggest fish are responding and utilizing newly reconnected tributary habitat. Of particular interest are juvenile Chinook salmon and steelhead that are pioneering into multiple tributaries. Collaboration between resource managers, non-profit organizations, and various stakeholders has resulted in implementation of restoration projects to address limiting factors. Results from our monitoring efforts will be used to evaluate the effectiveness of restoration projects and to guide future actions using an adaptive management strategy.

Aquatic Habitat Monitoring: What are we measuring, what trends are emerging, and how is the data being communicated? (Reber)

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Innovative Visualization of Hydrologic and Fisheries Data

Planning and implementing fishery-related projects such as habitat restoration often depend on integrated management, realistic modeling, and key environmental time-series data. Having a better understanding of the temporal characteristics of data will increase the chance of a successful project. To achieve project goals, new data visualization tools are necessary to meet the information needs of researchers, managers, funding partners and the general public. An innovative visualization tool is presented in this paper where time-series data are plotted as "time maps" similar to a GIS. This offers an innovative approach to simultaneously examine multiple time-scales of aquatic systems. The technique permits visualization of natural short- and long-term variation as well as artificial fluctuations. For example, when examining salmon migration data over the length of a river, both spatial and temporal variability and the influence of power regulation can be detected using time maps. Specifically this presentation demonstrates and explains how large quantities of time-series data can be quickly and effectively examined visually for patterns, suspect data, anomalies, and outliers. Fisheries-related examples are included for discussion.

Aquatic Habitat Monitoring: What are we measuring, what trends are emerging, and how is the data being communicated? (Reber)

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Using habitat suitability criteria as a tool to understand distribution dilemmas for Apache Trout, a rare southwestern salmonid impacted by non-native crayfish

Over the past century, fishes endemic to the southwestern United States have declined in abundance and range, resulting in listing the majority of these species (70%) under the U.S. Endangered Species Act (ESA). Apache Trout (*Oncorhynchus giliae apache*), a salmonid endemic to the White Mountains of east-central Arizona, is listed as threatened under the ESA. Major reasons for the decline and listed status of Apache Trout include overfishing, drought, habitat degradation and negative species interactions. Many of these threats have been managed for. According to the most recent Apache Trout Recovery Plan, there are 28 pure populations of Apache Trout are needed as one of the major criteria to downlist the species. Virile crayfish (*Orconectes virilis*) is a recently introduced invasive species thought to affect Apache Trout recovery. To date, no removal method has been found to be effective or efficient for suppressing crayfish populations. However, altering certain habitat parameters to disfavor crayfish, while maintaining Apache trout habitat parameters, may be effective. Therefore, we developed habitat suitability criteria for Apache trout and virile crayfish to assess overlap in criteria and determine if habitat could be manipulated to favor Apache trout but suppress virile crayfish. We sampled the West Fork Black River by snorkel survey to identify where Apache trout were located (occupied vs. unoccupied) and measured environmental parameters (water velocity, depth, substrate, instream cover, overhead cover and temperature) at occupied and unoccupied locations. We used a $1m^2$ quadrat sampler to sample crayfish at random locations. We performed a habitat suitability analysis to develop habitat suitability criteria for both species. Apache trout nonrandomly select for all habitat parameters tested ($p<0.01$); whereas crayfish only nonrandomly select for substrate and temperature ($p<.0001$). Virile crayfish and Apache trout occupy habitats with similar depths, water velocity and substrate; however Apache trout occupy habitats with colder water and more in stream and overhead cover. We hope to use this assessment of habitat suitability criteria as a tool to better understand virile crayfish and Apache trout interactions and manage Apache trout recovery streams.

Aquatic Habitat Monitoring: What are we measuring, what trends are emerging, and how is the data being communicated? (Reber)

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Understanding Stream Habitat; Misperceptions, Dreams, and Nirvana

Stream habitat has been evaluated for over 75 years. These studies have primarily focused on how fish are related to stream habitat and how stream habitat is affected by human management activities. In stream habitat evaluations 100's of aspects of stream habitat have been assessed. At first many of these attributes were visually estimated whereas now many of the protocols are more repeatable among observers. The objectives of these studies have cycled through time; from improving fishing opportunities, to evaluating attributes that are a surrogate of productivity, to channel form, to understanding channel complexity, depending upon what is in vogue at the time. Many of these studies have a limited number of replicates and generally find that what they measured was either important to fish or altered by human activities. I will use stream data collected throughout the Interior Columbia River Basin as well as the published literature to explore the limits and insights to be gained from large scale stream habitat monitoring programs.

Aquatic Habitat Monitoring: What are we measuring, what trends are emerging, and how is the data being communicated? (Reber)

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A Method for Assessing Status of Stream Habitat Conditions Accounting For Natural Variability on Federal Lands within the Interior Columbia River Basin

Evaluating physical stream habitat status is critical for land managers to prioritize management actions. It is also important that land management agencies have the ability to set appropriate goals for habitat conditions based of expected values under natural conditions. In 1995, the Forest Service and Bureau of Land Management published an environmental assessment directing protection and restoration of habitat for native fish species on federal lands in the Columbia River Basin. This assessment established riparian management objectives (RMOs) as consistent standards for evaluating status of existing fish habitat within the Interior Columbia River Basin. Research shows that using a universal threshold approach, such as RMOs, to assess status in not meaningful given the natural variability in streams geomorphic context. As a result, PACFISH/INFISH Biological Opinion Effectiveness Monitoring (PIBO-EM) program has developed a stream habitat index to compare reference to managed stream reaches. The stream habitat index ranks habitat conditions at a reach based on what would be predicted at a reference reaches with the same geomorphic and environmental characteristics. A stream is considered degraded if the actual habitat condition differs greatly from the predicted habitat condition. Using the habitat index land manages can evaluate the status of managed stream reaches compared to reference reaches and account for natural variability in stream attributes.

Aquatic Habitat Monitoring: What are we measuring, what trends are emerging, and how is the data being communicated? (Reber)

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A Classification System for Large U.S. Reservoirs and its Application to the West

In order to prioritize conservation efforts, the Reservoir Fish Habitat Partnership needs information regarding the condition of reservoir fish habitats, and reservoir classification provides a framework within which to assess fish habitat condition. Using a combination of ecologically-based spatial partitioning and cluster analysis, we developed a classification system for large U.S. reservoirs. First, we conducted a survey of fisheries biologists to evaluate habitat of reservoirs ≥100 ha in the U.S. Questions covered numerous habitat attributes – including availability, water quality, water regime, and degradation processes – as well as selected aspects of the fish community and recreational fishery. A total of 1,302 useable responses were received. Second, we examined several extant systems of spatial partitioning reflecting ecological differences among regions (i.e., Omernik's Level II and III ecoregions, EPA Wadeable Streams Assessment [WSAs], Landscape Conservation Cooperatives, and HUC2 regions). Using habitat variables from the survey, we conducted cluster analysis within each region of each partitioning system. Our goal was to balance recognition of inherent ecological differences and recognition of natural groups within the data. Our final classification system utilized WSAs and yielded 24 unique reservoir classes that showed various types and levels of habitat impairment. Reservoir class characteristics for the western U.S. are presented.

Aquatic Habitat Monitoring: What are we measuring, what trends are emerging, and how is the data being communicated? (Reber)

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Using Diatom Samples to Interpret Stream Impairment in Montana Streams

The State of Montana has been using benthic diatoms to assess water quality in wadeable streams since the 1970s. In the early 1990s, guidelines were established to assess biological integrity and impairment of aquatic life. A review of these protocols in 2005 found that the metrics underlying the assessment performed poorly in discriminating between non-impaired streams and those streams impaired for sediment, nutrients, and metals. Generally, the metrics were presumptive in that they relied on universal ecological attributes of diatom species and and structural characteristics of benthic diatom associations. Because they were presumptive, taxa lists used in the metrics were often too inclusive and this diminished their discriminating ability. In response to this, Montana Department of Environmental Quality funded development of empirically-derived metrics that employ "Increaser Taxa"--taxa that, as a group, exist in detectable amounts in all streams and demonstrate meaningful, measurable, repeatable, and significant response to sediment, nutrient, and metal impairment. These metrics are readily derived from standard diatom samples now collected as part of the State's standard water quality assessment protocol. They are used to interpret the probability of impairment and are used along with other observations in a weight-of-evidence approach to determining stream impairment. In this presentation, we provide an overview of the development and validation of these metrics, improvements they provide over "traditional" interpretation of periphyton samples, and application of the metrics in water quality assessment. This effort directly addresses the symposium theme by demonstrating how it was possible to develop methods for samples collected under well-established data collection methods that interpret sample results in a manner that was meaningful and reliable to water quality practitioners.

Aquatic vegetation management (Hand)

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Effects of the aquatic herbicide Endothall (Cascade®) on survival of salmon and steelhead smolts during seawater transition

Pacific Northwest salmon and steelhead utilize both fresh and saltwater habitats during their life-cycle, and their ability to quickly and effectively transition to seawater is a critical determinant of survival. We evaluated latent effects of endothall exposure on juvenile salmon and steelhead trout survival during seawater transition. Endothall is a widely used aquatic herbicide that exhibits low acute toxicity to salmonids (LC50 of 32-230 ppm a.e.); however, effects on osmoregulatory performance of seagoing juveniles (smolts) following exposure remained uncertain. Previous research implied latent toxicity may occur, but small sample sizes, inappropriate life-stages, static exposure systems, and insufficient seawater challenge durations generated contradicting results between studies. Here, coho (*Oncorhynchus kisutch*), Chinook (*O. tshawytscha*), and steelhead (*O. mykiss*) were subjected to a ten-day seawater challenge following acute exposure to endothall dipotassium salt (Cascade®) in a flow-through system. Acute exposure ranged from 0 to 12 ppm acid equivalent (a.e.) endothall for 96 hours. The seawater challenge yielded mean survival rates of 82% (n=225), 84% (n=133), 90% (n=73) and 59% (n=147) for 0, 3-5, 6-8, and 9-12 ppm a.e. exposure groups, respectively. Steelhead exhibited a statistically lower survival rate for all treatments relative to coho and Chinook. Surviving fish of all species did not experience significant changes in osmoregulatory function compared with control fish, as revealed by plasma sodium analysis. Lowest observable effect concentrations were 9 ppm a.e. for steelhead and 12 ppm a.e. for coho and Chinook, indicating a lower effect threshold compared with results reported from previous acute toxicity studies, but a higher threshold compared with results from previous seawater challenge experiments. Our findings emphasize the importance of considering the unique life-cycle of anadromous salmonids and carefully designing appropriate assays when defining the toxicity of aquatic herbicides applied in the presence of salmon and steelhead.

Aquatic vegetation management (Hand)

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Tools to selectively control Invasive aquatic weeds to improve water quality and fish habitat

Invasive aquatic weeds such as Eurasian Milfoil, Parrotsfeather and Brazilian Elodea are an increasing threat to waters in the Western United States. These invaders replace native aquatic plants and the organisms that have evolved to live with them forming dense monocultures in infested lakes and river/reservoir systems. In addition to the impacts these noxious weeds have on beneficial uses for humans, they often cause dramatic changes with respect to water quality and habitat parameters critical to fish. Littoral areas of these systems experience lower dissolved oxygen levels, elevated water temperatures, changes in pH, accelerated deposition of organic matter and reduced cover from predators. There has been a considerable amount of management work performed in the Pacific Northwest to map and selectively target these noxious aquatic weeds with the goal of restoring native aquatic plant communities and reducing impacts on water quality that affect fish. This paper will present an overview of these concerns and case studies of control programs that have resulted in improved water quality for fish.

Aquatic vegetation management (Hand)

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Thomas Moorhouse (Clean Lakes, Inc.)

Integrating Submerged Aquatic Vegetation Mapping into Aquatic Vegetation Control Programs

In support of Evaluating Operational Tools and Strategies for Large Scale Submerged Aquatic Vegetation (SAV) Management, SAV data was collected pre and post treatment on various projects in Idaho, Montana and Florida to document the extent of SAV pre and post treatment. SAV mapping of coverage, height and bio-volume in the treatment plots was conducted to support the documentation of pre and post treatment SAV presence, as well as to support efficacy evaluations. The data generated will be presented.

Aquatic vegetation management (Hand)

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Thomas McNabb (Clean Lakes, Inc.)

A Review of a Mechanical Control Project for Emergent Aquatic Vegetation Control in Coastal Southern California.

Bulrush (*Scirpus californicus*) and cattail (*Typha domingensis*) can develop into nuisance populations in southern California causing impacts to water flow and conveyance, increasing mosquito breeding habitat, and causing the loss of open water area. Clean Lakes, Inc. implemented a mechanical and manual control project on the 29 acre shallow brackish water pond at the Andree Clark Bird Refuge (City of Santa Barbara) utilizing a Tiger Cut (cookie cutter), harvester, trailer conveyor and other supporting equipment. The presence of the federally endangered Tidewater Goby (*Eucyclogobius newberryi*) and the state species of special concern Southwestern Pond Turtle (*Emysmarmorata pallida*), as well as other wildlife species had to be considered during the project. A review of the permits, regulations, and operations will be discussed.

Aquatic vegetation management (Hand)

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Aquatic Plant Issues in Idaho

Idaho began an aggressive Eurasian watermilfoil (EWM) treatment program in 2006 in response to rapidly expanding populations that were impacting recreation, boater access and aquatic habitat. Treatments have utilized a number of innovative strategies and significant reductions of EWM have been documented. Native species diversity and frequency increases rapidly following the removal of milfoil resulting in improved habitat. Other invasive aquatic plant treatment programs in Idaho include hydrilla, water hyacinth and flowering rush. Presentation will discuss habitat impacts, treatment methods and prevention activities.

Aquatic vegetation management (Hand)

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Aquatic Herbicide Effects on Pacific Northwest Amphibians

Conflict between native amphibians and aquatic weed management in the Pacific Northwest is rarely recognized because most native stillwater-breeding amphibian species move into upland habitats during the summer, when application of herbicides to control weeds in aquatic habitats typically occurs. However, for some species and life stages present in wetland habitats through the summer, aquatic weed management may pose a risk. Acute toxicity of herbicides used to control aquatic weeds tends to be low, but the direct effects of herbicide tank mixes (active ingredient, surfactant, and dye) on Pacific Northwest amphibians has remained unexamined. To address this gap, we exposed juvenile Oregon Spotted Frogs (*Rana pretiosa*) to mixtures of the herbicide imazapyr (Polaris AQ, 28.7% active ingredient), Agri-Dex surfactant, and Hi-Light dye; and Northern Red Legged Frog (*Rana aurora*) metamorphs to mixtures of the herbicide triclopyr (Renovate® 3, 44.4% active ingredient), Competitor surfactant, and Hi-Light dye for 96 h using 24-h static renewals in a 96-hour static-renewal test. Concentrations of the imazapyr and triclopyr tank mixes were those associated with labeled rates used to control Reed Canarygrass (*Phalaris arundinacea*) and Purple Loosestrife (*Lythrum salicaria*), respectively. A clean-water control was included in both trials. Following exposure, frogs were reared for 2 months in clean water to identify potential latent effects on growth. Endpoints evaluated included behavior, growth, and liver condition index. We recorded no treatment-related mortalities. We also found no significant differences for any endpoint between the herbicide-exposed and clean-water control frogs.

Challenges of invasive mollusks: threats, management tools and options (Moffitt)

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Christine Moffitt (US Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho)

Use of elevated pH as a disinfection tool against two invasive mollusks of concern

Increased global commerce and transportation has increased the risk of transporting live organisms from one region to another. Many organisms easily transported include mollusks that are able to survive for some time in adverse conditions, and out of water. We are working to evaluate inexpensive and safe disinfection tools such as hydrated lime (calcium hydroxide:Ca(OH)2) or sodium hydroxide (NaOH) that can be used to raise treatment waters to a elevated pH (11- 12). We conducted a series of laboratory based, static exposure tests with two invasive mollusk species that are known to be most resistant to many disinfection procedures: quagga mussels (*Dreissena bugensis*) and Asian clams (*Corbicula fluminea*). We found that temperature of test systems as well as the test chemical affected the time to mortality. In general solutions of equal pH with NaOH had a longer time to mortality than did hydrated lime. We found Asian clams exposed to NaOH at 20°C were all dead after 192 h. Mortality in adult quagga mussels was more rapid, and 100% mortality at 15°C was recorded after 72 hr of exposure, and 20°C mortality occurred after 26 h. Quagga mussel veligers were killed rapidly (within 0.5 h) in exposures to NaOH at temperatures from 15°C to 20°C. In our experiments with Ca(OH)2, mortality of adult quagga mussels was more rapid, and within 7 hours, all test organisms were dead. Tests with veligers at 15°C and 20°C show 100% mortality at 6 and 8 min respectively. We are replicating our tests to determine the range of safety and options for scaled up experiments. These disinfection tools hold promise for use on large and small vessels, or as a rapid response tool for eradicating small established populations.

Challenges of invasive mollusks: threats, management tools and options (Moffitt)

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Prevention and Management of Invasive Mollusks in Montana

The Montana Fish, Wildlife and Parks Aquatic Invasive Species (AIS) Program works to implement the AIS Management Plan through coordination and collaboration, prevention of new AIS introductions, early detection and monitoring, control and eradication, and outreach and education. Each component of the program serves to minimize the harmful impacts of AIS through the prevention and management of AIS into, within and from Montana. Montana's AIS early detection and monitoring system has been in place since 2004. Early detection is used to find small or source AIS populations, while monitoring is used to study population trends. Over 120 waters were surveyed in 2012, and Dreissenid mussels and Asian clams are not currently detected in any Montana waters. There are known populations of New Zealand mudsnails in Montana. The best management tool available for Montana is to prevent the introduction of new invasive species such as zebra or quagga mussels, and to minimize the spread known invasive species such as New Zealand mudsnails. FWP employs early detection, outreach and education to ensure that boaters are aware of the risk, and mandatory boat inspections to increase awareness and prevent the spread of AIS. Results of monitoring and boat inspections will be presented.

Challenges of invasive mollusks: threats, management tools and options (Moffitt)

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Applied Management to Control *Dreissena* Mussels in Utah

Four water bodies (Lake Powell, Red Fleet Reservoir, Electric Lake and Sand Hollow Reservoir) within Utah have been affected by either quagga (*Dreissena rostriformis bugensis*) or zebra (*D. polymorpha*) mussels since their invasion into the western United States in early 2007. The Utah Division of Wildlife Resources has been appointed as Utah's lead agency for an array of partners dealing with invasive mussels. Utah's invasions are classified as inconclusive, detected or infested; unaffected water bodies are classified as not-detected. The management tactic for preventing and controlling quagga and zebra mussel invasions into Utah's water bodies is simple: Prevent sufficient numbers for any life form of invasive mussels from becoming established as self-sustaining populations. Inadvertent inoculations of *Dreissena* mussels likely occur on occasion, but aquatic organisms oft times require multiple introductions in order to successfully establish; if not, they simply fail due to insufficient population mass. So, management efforts involve early detection monitoring coupled with a robust outreach program, backed up by law enforcement, when needed, to enlist boaters' support to prevent repeated inoculations. This either prevents invasive mussels from arriving or caused early arriving *Dreissena* populations to fail. Management success has been apparent as follows:

(1) Most of Utah's 250 water bodies that can be boated remain as not detected.

(2) Lake Powell was downgraded from an inconclusive discovery of quagga mussel veligers in 2007 to not-detected in 2010.

(3 & 4) Red Fleet Reservoir and Electric Lake were each downgraded from a detection of quagga and zebra mussel veligers, respectively, in 2008 to inconclusive in 2011.

Ongoing management challenges are as follows:

(5) Sand Hollow Reservoir, remains classified as infested since the 2010 discovery of a single adult quagga mussel that was removed. Although environmental DNA continues to be measured, no other evidence of quagga mussels has been found.

(6) Unfortunately, a new situation for Lake Powell has developed in 2012, when quagga mussel veligers were discovered. This is non-related to the 2007 episode, and continues to be assessed. It is possible that the veligers may fail under the ongoing, described management scheme.

Challenges of invasive mollusks: threats, management tools and options (Moffitt)

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Invasive mollusks: what are the risks and what can we do?

Native freshwater mollusks are important components of stream and lake ecosystems. They are increasingly being recognized for their role in nutrient cycles and food webs. Many river restorations now incorporate re-introducing native mollusks and conduct post restoration monitoring programs. Three alien mollusk species have been introduced into freshwater ecosystems of western North America: the Asian clam, New Zealand mudsnail, and the quagga mussel. The consequences of these introductions include economic costs and infrastructure damage and ecosystem and food web shifts. It is thought that Asian clams were first deliberately introduced to several areas on the west coast, first in the Columbia River system more than 70 years ago. The negative consequences of their infestations have been documented to include alteration of the structural and functional relationships in the benthos. Populations of Asian clams are established across the continent. In Lake Tahoe an extensive two state management program is underway to suffocate established beds. New Zealand mudsnails were likely first introduced into Idaho's Snake River system in the early 1980s, and have now been spread throughout much of western North America because of their ability to survive desiccation, and successful clonal reproduction. The recent introduction of quagga mussels into waters and reservoirs of southwestern states has garnered widespread public attention to the risks of invasive mollusks, as these byssal mussels have rapidly populated hard surfaces of water intakes, boats, and benthos. How do we better understand the certainty or uncertainty of their introduction? What tools are available to prevent introduction and what are the likely long term consequences these species in the environments. Following this review, we provide in more detail case studies on invasive mollusk and the management challenges for both public and private entities.

Challenges of invasive mollusks: threats, management tools and options (Moffitt)

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Status of the Lake Huron ecosystem after the invasion of multiple exotic species

The native offshore fish community in Lake Huron was disrupted by introductions of sea lamprey, alewife and rainbow smelt and was dominated by invasive species by the 1950s. More recently, introductions of dreissenid mussels, predatory zooplankters, and round gobies have further affected this community. The offshore waters of Lake Huron have recently shown signs of increasing oligotrophy, including reductions in phosphorus levels, changes in the concentration and seasonality of chlorophyll, and shifts in zooplankton abundance and community structure. The estimated lakewide biomass of offshore prey fishes in Lake Huron reached unprecedented low levels, and the offshore demersal fish community had collapsed by 2006. Invasive alewife populations crashed in 2003 and estimated biomass of this species has remained very low, while native bloater abundance is beginning to rebound. Thiamine levels in lake trout eggs have increased in recent years, and natural reproduction and recruitment of lake trout is occurring lakewide. Changes in offshore fish habitat use suggest that large-scale changes may be occurring in the offshore benthic environment. It is currently difficult to assess prey fish biomass estimates in the context of primary production and predator demand, as these are currently highly variable, poorly understood, and dependent on ongoing food web changes. Data on nearshore fish species are sparse, but many species appear to be stable and some are increasing in abundance. The recent increased occurrence of Cladophora events and botulism outbreaks may also be related to recent foodweb changes. It has been suggested that Lake Huron may be undergoing a regime shift, and the consequences for future ecosystem services from the lake are uncertain.

Challenges of invasive mollusks: threats, management tools and options (Moffitt)

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Economic Risk Associated with the Establishment of

The zebra mussel *Dreissena polymorpha* and quagga mussel *Dreissena rostriformis bugensis*, two species of invasive bivalve mollusks, pose an economic risk to the Columbia River Basin (the Basin), but there is a large range in the forecasts of potential economic costs. This presentation, based on a 2010 report prepared by the Council's Independent Economic Analysis Board (IEAB), will identify the potential economic implications of a widespread Dreissenid mussel infestation in the Basin. The potential effects of such a mussel infestation on facilities, resources, ecosystems and species that are closely related to the Council's Fish and Wildlife Program (FWP) and the Federal Columbia River Power System (FCRPS) will be highlighted. The 2010 IEAB report reviews the current state of knowledge about the risk of mussel introduction, establishment, growth and densities, and estimates some potential costs of infestation, avoidance and control. I will conclude with some recommendations for research and policies to improve the assessment of the risks and costs of a mussel infestation in the future. In January 2013, the Council tasked the IEAB to update its 2010 economic risk assessment for the Columbia River Basin. That updated IEAB assessment is presently ongoing.

Challenges of invasive mollusks: threats, management tools and options (Moffitt)

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Protecting the Environment while Controlling Zebra and Quagga Mussels—Methods and Case Studies

Invasive zebra and quagga mussel (*Dreissena* species) populations have been prevalent in the Great Lakes and Midwest regions for nearly two decades. In recent years, these prolific filter feeders have spread into the Western United States, causing economical and/or ecological damage to waterways, reservoirs, and infrastructure. It has been shown that in ecosystems where invasive mussels are present, the abundance of native organisms decreases dramatically while the growth of unwanted weeds and algae increase. This ecological imbalance can negatively impact fisheries, recreational life, and facility operations (e.g., power production). Current chemical and mechanical mussel control methods often provide high efficacy, but they come with economic and ecologic implications. Zequanox®, an environmentally compatible molluscicide developed by Marrone Bio Innovations, Inc., can be used to control zebra and quagga mussels without harming humans, infrastructure, non-target species, or the environment. The active ingredient in Zequanox is killed cells from a ubiquitous soil microbe—*Pseudomonas fluorescens*, and the toxicology studies demonstrate that the product is highly selective toward *Dreissena* mussels. At concentrations that produce mussel mortality of 76–100%, no product-induced mortality was recorded among any non-targets, including algae, fish, mollusks, or crustaceans. Zequanox was registered by the US EPA in March 2012 for use in industrial closed or semi-closed systems (e.g., cooling water systems) and can now be used as an alternative to chlorine and quaternary ammonium compounds to control invasive mussels at industrial and energy-producing facilities, reservoirs, fish hatcheries, and in irrigation systems. A review of case studies of Zequanox treatments conducted at facilities in the U.S., Canada, and Europe, including open water trials show promising results. Recent research regarding methods for reducing mussel settlement and controlling veligers will also be presented.

Challenges of invasive mollusks: threats, management tools and options (Moffitt)

Panel Discussion, Moderator: Leah Elwel

Panel Members: Pat Stone(Tahoe), Amy Ferriter (ID), Allison Begley (MT), Larry Dalton(UT), Bob Kibler (USFWS); Rich Boatner (OR)

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Hydroturbine passage related barotrauma research in the Columbia River Basin: How far have we come?

Within the past decades, most of the research related to hydroturbine passage has centered on seaward migrating juvenile salmonids. Throughout the years the techniques and technologies used to study barotrauma have evolved as have our understanding of the causal pathways. Tools that are used to measure pressure changes fish are exposed to when passing turbines, such as the Sensor Fish, have also improved considerably. Research has also begun to be done on other fish types such as lamprey and sturgeon. This past research has led to a rethinking of the fundamental way that turbine survival studies are conducted and evaluated and how past research should be viewed. Having a comprehensive understanding of the effects of barotrauma in fish is increasingly important as the need to expand energy output of current hydropower facilities exists. This presentation will provide an overview of past, present and future research on hydroturbine passage and will detail stumbling blocks experienced upon the way and common misconceptions about turbine survival research.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Matthew Keefer (University of Idaho)

A review of adult salmon and steelhead straying in the Columbia River basin

We recently completed a comprehensive review of straying by adult salmon and steelhead (*Oncorhynchus spp*), with an emphasis on Columbia River populations and the role of the smolt transport program. We found that adult straying rates vary among species, among populations within species, and among life history types. The weight of evidence also suggests that hatchery fish stray more than conspecific wild fish, and that straying rates by adults that were transported as juveniles are higher than for those that migrated in-river. Strays can have positive, negative, or neutral effects on recipient populations, depending on the source and relative abundance of the strays versus the recipient population(s). In general, however, strays associated with human activities like hatcheries, outplanting, and smolt transport programs are likely to have negative genetic, fitness, and other population-level impacts on recipient populations. These patterns potentially hinder salmon and steelhead recovery efforts in the Columbia-Snake basin and elsewhere.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Passage distributions and Federal Columbia River Power System survival for steelhead kelts tagged above and at Lower Granite Dam

Steelhead (*Oncorhynchus mykiss*) populations have declined throughout their range in the last century and many populations, including those of the Snake River Basin are listed under the Endangered Species Act. The reasons for their decline are many, but include habitat loss and degradation, overharvest, and the construction of dams. Unlike Pacific salmon, which all die after they spawn, post-spawning steelhead (known as "kelts") can migrate back to the ocean to feed and replenish their energy stores, then return to freshwater and spawn in subsequent years (known as iteroparity). However, it is estimated that <2% of Snake River steelhead are able to make a second spawning run. Kelts may be vulnerable to delays in their migration caused by mainstem dams and reservoirs in the Snake and Columbia rivers, and may also suffer high mortality while passing the dams. The primary goal of this research was to estimate route-specific survival of steelhead kelts through up to seven Federal Columbia River Power System (FCRPS) dams using the Juvenile Salmon Acoustic Telemetry System (JSATS). In addition, system wide and reach specific survival were estimated. Passage metrics such as forebay residence, tailrace egress, and project passage timings were also calculated at each FCRPS dam. In 2012, JSATS transmitters were surgically implanted into 324 steelhead kelts captured at Lower Granite Dam (LGR) and several tributaries in the Snake River basin. Overall, 37.0% (120 of 324) of the tagged kelts successfully migrated from LGR (rkm 695, as measured from the mouth of the Columbia River) to rkm 113 (downstream of Bonneville Dam). The majority of kelts passed the dams via spillway routes (i.e., spillway weirs, traditional spill) where survival estimates were generally higher compared to all other routes of passage (e.g., juvenile bypass systems, turbines, sluiceways). The results of this study contribute to understanding the impact of hydropower on steelhead kelt migration in the FCRPS. Specifically, this study is the first to document route-specific survival since the installation of spillway weirs at many of the dams in the FCRPS. The data may be used to adaptively manage configuration and operation of FCRPS dams to maximize kelt survival.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Salmonid Smolt Mortality: At the Dam or in the Reservoir?

The Public Utility District No. 2 of Grant County, WA owns and operates Wanapum and Priest Rapids dams on the Columbia River. Being a FERC licensed hydroelectric project, we are required to meet specified performance (survival) standards for salmonid smolts passing through the Priest Rapids Project. Within our new FERC license, topics of new turbines, powerhouse operations, building of fish bypasses is discussed for the sole purpose of increasing smolt survival past the dam and the utility meeting its "smolt survival" requirement. The "concrete" (dam) is not the only component of a hydroelectric project nor the only source of salmonid smolt mortality. To meet your Project's salmonid smolt performance standards, you must take a complete look at your Project and possible sources of smolt mortality. You can spend millions of dollars to pass smolts safely past the concrete but still not meet your requirements.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Mark Timko (Blue Leaf Enviromental)

Using Acoustic Tagged Fish in the Design Process of a Fish Bypass at Wanapum and Priest Rapids Dams

The Public Utility District No. 2 of Grant County, WA owns and operates two hydroelectric dams on the Columbia River - Wanapum and Priest Rapids Dams. During the outmigration of salmonid smolts (April – August), large volumes (39% - 61%) of the river were spilled via tainter-gate at Wanapum and Priest Rapids to provide non-turbine passage for salmonid smolts. Through the use of acoustic-tagged smolts, the behavior of these out-migrating smolts was analyzed and used in the design process for surface-spill fish bypasses. It is through these fish bypasses, that the volume of river that is being spilled in decreased, increased smolt survival seen and an increased potential for power generation. In the world of hydroelectric power generation, this combination is seen as a “win-win” for all parties involved.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Cumulative Survival of Juvenile Salmonids Passing Through the Lower Columbia River Hydrosystem

Pacific salmon populations have been in decline for decades. Juvenile and adult salmon runs on the Columbia and Snake Rivers have been impacted by a wide variety of environmental and anthropogenic factors, including hydropower development. This study examines the cumulative survival estimates of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) passing through three lower Columbia River hydropower projects. In the spring of 2011, the Juvenile Salmon Acoustic Telemetry System (JSATS) was used to track 15,458 individual salmon on their outward migration. Acoustic telemetry offers several advantages over traditional passive telemetry by increasing the horizontal detection area, allowing for multi-dimensional tracking at dam faces, in-river monitoring and specific route of passage survival estimates. Acoustic transmitters and passive integrated transponders were surgically implanted into yearling Chinook salmon (n=7,692) and yearling steelhead (n=7,766) at the John Day Smolt Monitoring Facility. The fish were tracked through the lower Columbia River hydropower system to Rkm 86 using in-river autonomous hydrophone arrays and dam-mounted hydrophones. Based on initial findings, the cumulative survival of juvenile Chinook salmon passing through the three lower Columbia River hydroprojects was 81.7% (SE + 0.01) with a median travel time of 5.24 days (SE + 0.061) whereas the cumulative survival of juvenile steelhead was 82.1% (SE + 0.012) with a median travel time of 4.67 days (SE + 0.065). These findings suggest that cumulative survival measures do not deviate substantially from reach-by-reach survival estimates. Accounting for the confounding environmental and anthropogenic factors involved with the survival of Columbia River salmon remains a major obstacle in addressing the decline of anadromous fishes in this system. Continued investigation into the cumulative effects of hydrosystem passage will help inform future management options for endangered and threatened species on the Columbia River.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Avian Predation on the Columbia Plateau: A Synthesis of Research Results

Caspian terns, double-crested cormorants, American white pelicans, California gulls, and ring-billed gulls are native piscivorous colonial waterbirds that nest in the Columbia Plateau region. As part of a comprehensive study, we evaluated the impact of these predators on juvenile salmonids from the Columbia and Snake rivers during 2007-2012. Numbers of Caspian terns in the region averaged 900 breeding pairs at six separate colonies. Numbers of double-crested cormorants averaged 1,360 breeding pairs at four colonies and numbers of American white pelicans averaged 1,729 adults at one colony. Gulls were the most numerous colonial waterbird with > 65,000 adults counted at 20 different breeding colonies. Colony sizes fluctuated and new bird colonies emerged and disappeared during the study, indicating populations in the region were shifting and dynamic. We used bioenergetics modeling to estimate prey consumption by Caspian terns nesting at colonies on Crescent and Goose islands, and double-crested cormorants nesting on Foundation Island, colonies identified as posing a potential substantial risk to smolt survival. Consumption varied by colony and year, with ca. 1.2 million smolts consumed annually by all three colonies combined. We used recoveries of salmonid PIT tags, adjusted for detection efficiency and off-colony deposition (where available), to estimate population-specific predation rates. Results varied by year and colony, with annual predation rates ranging from < 1% to > 20% of available fish, per population. In general, steelhead populations were more susceptible to bird predation than salmon populations, and predation rates were higher at tern and cormorant colonies compared to gull and pelican colonies. Results also demonstrated that avian predation rates on smolts

were condition- and size-dependent, varied temporally, and were influenced by river conditions. Tern and cormorant colonies on the Columbia Plateau were an order of magnitude smaller than their Columbia River estuary counterparts. On a per capita basis, however, Plateau colonies were more reliant on salmonids as a food source. This greater reliance, coupled with lower diversity and numbers of salmonid populations available compared to the estuary, is responsible for the higher than anticipated impact of some Plateau bird colonies on specific salmonid populations.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Relationship between smolt condition and survival to adulthood in steelhead from the Columbia and Snake rivers: Do individual fish characteristics recorded at the time of out-migration matter?

Understanding how the external condition of salmonid smolts is associated with survival to adulthood can be valuable for both population monitoring programs and research. To evaluate if individual fish characteristics observed during the smolt life stage were associated with the probability of returning as an adult, steelhead smolts from two distinct population segments (DPS; Snake and Upper Columbia rivers) were captured, examined for external conditions (body injuries, descaling, signs of disease, fin damage, and ectoparasites), length, and rear-type (hatchery, wild), marked with PIT tags, and released to continue out-migration. In total, 25,959 Snake River smolts from Lower Monumental and Ice Harbor dams and 21,736 Upper Columbia River smolts from Rock Island Dam were sampled during 2007-2010. Of these, 443 (1.7%) Snake River and 386 (1.8%) Upper Columbia River smolts returned as adults (i.e., detected at Bonneville Dam fishways) during 2008-2012. We compared models that included variables for year, run timing, external conditions, rearing type, fork length, and combinations thereof. Each steelhead DPS was modeled independently to determine if similar models were supported across populations. Individual fish characteristics recorded during the smolt life stage were important factors in predicting the probability of a steelhead smolt surviving to adulthood. The data provided strong support for models that included individual smolt characteristics of length, rearing, and external condition, in addition to year and run-timing. Results indicated that the probability a smolt surviving to adulthood was positively related to smolt length and generally higher for wild smolts. Survival was lower for smolts with body injuries, fin damage, and external signs of disease. Models that included variables for descaling and ectoparasite infestation, however, generally had less support than those that incorporated measures of tissue damage and disease. These trends were consistent across both steelhead populations; implying that fish characteristics, including smolt external condition directly affects survival to adulthood. More study is needed to determine the proximate cause(s) of smolt damage and degradation, if external and internal measures of fish condition change during out-migration, and if the trends observed in steelhead persist in other anadromous species in the Columbia River basin.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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History of hydrosystem fish operations in the Columbia Basin

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Design of a Columbia River main stem spill management experiment to evaluate improvements in life-cycle and life-stage specific survival rates for Snake River Chinook and steelhead

The hypothesis that juvenile out-migration conditions in the Federal Columbia River Power System can influence salmon survival during out-migration, as well as in subsequent marine life stages, is supported by multiple lines of evidence. Analyses by the Comparative Survival Study scientists have found that influential migration variables include the amount of spill at dams, number of powerhouse passages, water velocity, and proportions of smolts transported. Maximizing controlled spill at dams is a promising, potential management action, which would help smolts avoid powerhouse passage through bypass systems and turbines, and speed the smolt migration. Maximum controlled spill was defined as the volume of spill that could be provided at Snake River and Lower Columbia River dams without exceeding total dissolved gas standards, based on U.S. Army Corps of Engineers models. We developed prospective management models to predict the changes in juvenile survival rate and smolt-to-adult return rate (SARs) associated with a hypothetical management action of maximum controlled spill. Expected effects were estimated within the context of variable, inter-annual run-off volumes and ocean conditions (e.g., Pacific Decadal Oscillation, upwelling, sea surface temperatures). The analysis examined the distribution of predicted survival improvements from a recent baseline over these variable river and ocean conditions relative to Northwest Power and Conservation Council SAR objectives and population resiliency.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Achieving juvenile and adult passage survival standards at the Rocky Reach Project: Success based on a unique juvenile bypass system and effective adult fishways

Public Utility District No. 1 of Chelan County (Chelan PUD) completed construction of the $112 M Rocky Reach Juvenile Fish Bypass System (JFBS) in March, 2003. The JFBS is a key component of the Project's 50-year Anadromous Habitat Conservation Plan. The bypass system is composed of a surface collector system in the forebay of Rocky Reach Dam which utilizes submerged pumps to create attraction flow into collector channels. Inside collector channels, the initial 6,000 cfs attraction flow is reduced to 360 cfs through balanced dewatering screens where fish and water enter a 1,402 m conduit pipe. The bypass pipe then transports fish across the downstream face of Rocky Reach Dam, down the opposite river bank, and discharges water and fish to the center thalweg flow in the tailrace. HCP survival testing for yearling Chinook, steelhead, sockeye, and subyearling Chinook began at Rocky Reach in April 2003, and was completed in 2011 following 17 triple-release acoustic tag survival studies. Mean bypass efficiency was 68.8 percent for juvenile steelhead (four studies), 46.0 percent for yearling Chinook (five studies), 44.4 percent for juvenile sockeye (seven studies), and 37.4 percent for subyearling Chinook (one study). Mean bypass survival for all species combined was 98.6 percent over 17 studies. Adult salmon and steelhead passage survival was estimated using conversion rates based on full-duplex PIT tag detections through the Rocky Reach Project (dam and reservoir) beginning in 2009. Three-year mean adult passage survival estimates at Rocky Reach were 99.90 percent for upper Columbia River (UCR) spring-run Chinook, 98.93 percent for UCR steelhead, and 98.92 percent for Okanogan basin-origin sockeye.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Long-term Compliance with Passage Survival Standards at a Mainstem Columbia River Dam

Public Utility District No. 1 of Douglas County, Washington, (Douglas PUD) owns and operates the Wells Hydroelectric Project on the Columbia River. Douglas PUD receives ESA coverage for Wells Dam operation via the Wells Habitat Conservation Plan (HCP), the first HCP for anadromous salmonids in the United States. The concept of "no net impact" (NNI) forms the basis of the Wells HCP. NNI consists of achieving passage survival standards, and compensating for unavoidable Wells Project-related mortalities through hatchery production (for juvenile passage losses) and tributary enhancement (for adult passage losses). With its basis in NNI, the Wells HCP provides substantial incentive for Douglas PUD to maximize survival through the Wells Project, for in doing so they also minimize obligations for hatchery and habitat compensation. The "hydrocombine" configuration of Wells Dam facilitates achievement of passage standards for juvenile migrants, with powerhouse flows providing attraction flow to the bypass system. Studies indicate 92.0% bypass efficiency for yearling spring migrants and 96.2% for summer-migrating subyearling Chinook. Consequently, Juvenile Project Survival rates exceed the 93% HCP standard for yearling spring migrants, averaging 96.3% over four years of studies, and Calculated Juvenile Dam Passage Survival for subyearling Chinook exceeds the 95% standard. Douglas PUD's NNI hatchery compensation rates are low (8,000 steelhead, 62,423 spring Chinook, and 54,575 summer Chinook) because so few juveniles are impacted by hydropower operations. Douglas PUD provides NNI mitigation for sockeye by funding a computer model (and input data) that Canadian fish and water managers use to avoid water-management decisions that historically resulted in density-independent mortality of Okanagan Sockeye. This program is credited with the recent phenomenal resurgence of Okanagan sockeye. Adult passage survival meets or exceeds the 98% HCP standard, and Douglas PUD compensates for adult losses by contributing approximately $250,000 annually to fund habitat enhancement in salmonid spawning tributaries above Wells Dam. Douglas PUD has maintained the achievement of survival standards at Wells Dam since 2005. The Wells HCP serves all signatory parties by providing ESA take coverage for hydropower operations and predictable mitigation commensurate with the minimal impact of those operations on anadromous salmonids.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Identifying fishway passage bottlenecks at large dams: a Pacific lamprey case study

Fishways designed for salmonids often restrict passage by non-salmonids and effective tools are needed both to identify passage problems for non-salmonid species and to inform remediation planning. In this meta-analysis of a 10-year dataset, we used migration histories from 2,170 radio-tagged adult Pacific lamprey (*Entosphenus tridentatus*) to identify and prioritize passage bottlenecks at Bonneville Dam. Bonneville Dam is a large, multi-fishway hydroelectric project on the Columbia River that has features similar to many salmonid-style fishways in the Pacific Northwest. Overall, 49% of tagged lamprey that entered Bonneville fishways failed to pass the dam, a much lower rate of success than has been recorded for adult salmon and steelhead (*Oncorhynchus spp*). Models accounting for repeated attempts by individual Pacific lamprey indicated successful passage strongly depended on attempted passage route. Time of fishway entry, water temperature, and lamprey body size were also influential. Most failed passage attempts terminated in lower fishway segments and occurred during relatively cool, high-discharge conditions. Multinomial models showed extensive seasonal shifts in bottleneck locations associated with fluctuating environmental conditions and the distribution of attraction flow. Bottleneck ranking metrics identified several priority sites where structural or operational modifications could increase lamprey passage. We compared the relative benefit of improving passage at individual priority sites to overall upstream passage using a series of models to inform selection of future passage improvements. Our integration of spatially-intensive monitoring with quantitative analytical techniques was critical to understanding the complex relationships between fishway features, environmental variation and Pacific lamprey migration behavior. The broader research framework and analytical tools we used can be applied to a wide range of fish passage assessments.

Columbia & Snake Rivers Mainstem Passage: Past, Present, and Prospects (Kiefer)

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Assessing freshwater and marine influences on life-cycle and life-stage specific survival rates of Snake River Chinook and steelhead

Pacific salmon from the Snake River basin experience a wide range of environmental conditions during their freshwater, estuarine, and marine residence, which in turn influence their survival rates at each life stage. There are also multiple lines of evidence that juvenile out-migration conditions can influence survival during estuarine and marine residence, a concept known as the hydrosystem-related delayed mortality hypothesis. Improved understanding of the relative influence of marine and freshwater factors on survival of at-risk anadromous fish populations is critical to success of conservation and recovery efforts. However, separating the influence of marine and freshwater factors is challenging. We explored influence of both river conditions during seaward migration and ocean conditions on life-cycle survival rates of Snake and Columbia River stream-type Chinook salmon over a period spanning development of the Federal Columbia River Power System (FCRPS). We also examined FCRPS migration and marine factors affecting smolt-to-adult and marine survival rates of Snake River Chinook salmon and steelhead. Through this and previous studies, it is evident that delayed hydrosystem mortality increases with the number of powerhouse passages and decreases with the speed of out-migration. Maximizing controlled spill at dams is a promising, potential management action, which would help smolts avoid powerhouse passage through bypass systems and turbines, and speed the smolt migration. A promising conservation approach would be to explore management experiments that evaluate these relationships by increasing managed spill levels at the dams during the spring migration period over a period of years.

Establishing Common Ground in Reproductive Success Studies (Hesse and Narum)

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Reproductive success of hatchery and naturally spawned Chinook salmon colonizing newly accessible habitat

Following removal or circumvention of migration barriers, permitting hatchery salmon to spawn can provide an immediate demographic boost but may also reduce the long term fitness of the colonizing population. Construction of a fish passage facility at Landsburg Diversion Dam on the Cedar River, WA, USA, provided a unique opportunity to explore this trade-off. We thoroughly sampled adult Chinook salmon (*Oncorhynchus tshawytscha*) at the onset of colonization (2003 – 2009), constructed a pedigree from genotypes at 10 microsatellite loci, and calculated reproductive success (RS) as the total number of returning adult offspring. Despite the absence of a hatchery on the Cedar River, hatchery salmon were a large proportion of the initial colonizing population (range = 17 – 68 %). Hatchery males were consistently but not significantly less productive than naturally spawned males (range in relative RS: 0.70 – 0.90), but the pattern for females varied between years. The sex ratio was heavily biased towards males, so inclusion of the hatchery males increased the risk of a genetic fitness cost with little demographic benefit. Due in part to straying by hatchery fish in the past and present, the naturally spawned and hatchery Chinook salmon in our study had similar ancestry (Fst ≤ 0.0037), suggesting that the RS patterns we observed were caused by a single generation of artificial propagation. Measurements of natural selection indicated that larger salmon had higher RS than smaller fish. Fish that arrived early to the spawning grounds tended to be more productive than later fish, although in some years, RS was maximized at intermediate dates. Our results underscore the importance of natural and sexual selection in promoting adaptation during reintroductions.

Establishing Common Ground in Reproductive Success Studies (Hesse and Narum)

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Diminished reproductive success of steelhead from a hatchery supplementation program (Little Sheep Creek, Imnaha Basin, Oregon)

Hatchery supplementation programs are designed to enhance natural production and maintain the fitness of the target population; however, it can be difficult to evaluate the success of these programs. Key to the success of hatchery supplementation programs is a relatively high reproductive success of hatchery fish. This study investigated the relative reproductive success (RRS) of steelhead *Oncorhynchus mykiss* by creating pedigrees based on microsatellite loci for hatchery and natural spawning steelhead. We genotyped adult steelhead spawners as well as adult resident rainbow trout from multiple locations upstream of a weir. We then determined the parentage of progeny collected at various life history stages, including parr, migrants, and returning adults. Analysis of progeny sampled at both the juvenile and adult life stages suggested that the RRS of hatchery-origin fish was 30–60% that of their natural-origin counterparts. Using generalized linear models we determined that the greatest effects on RRS were origin (natural versus hatchery), length, return date, and the number of same-sex competitors. Natural parents were less negatively affected by same-sex competitors. Differential survival of juveniles and the behavior of offspring and/or spawning adults may all contribute to diminished fitness in hatchery-reared salmon, although it could not be determined to what extent these effects were of a persistent, heritable nature as distinct from an environmental effect associated with hatchery rearing and release strategies.

Establishing Common Ground in Reproductive Success Studies (Hesse and Narum)

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Factors influencing the relative reproductive success of hatchery and natural spring Chinook salmon in the Wenatchee River

We review results from a large (>30,000 fish) study of reproductive success of spring-run Chinook salmon in the Wenatchee River. Prior work has shown that: a) the average reproductive success of hatchery fish is ~50% that of wild fish in the same streams; b) differences between hatchery and natural fish in male age and size, and male and female spawning location contribute to the lower reproductive success of hatchery fish; and c) the frequency of early male maturity of hatchery-spawned fish tends to run in families, leading to a negative correlation between parental reproductive 'success' in the hatchery and offspring success in the wild. Here, we review these results, focusing on alternative metrics of reproductive success, including both individual and spawning-pair based approaches and evaluating whether differences in success are primarily due to failure/success in spawning or variance in offspring number following successful spawning.

Establishing Common Ground in Reproductive Success Studies (Hesse and Narum)

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Reproductive success of reintroduced spring-run Chinook salmon in the Hood River, Oregon

Pacific salmonids have been extirpated from large portions of their historical range due to anthropogenic disturbances, including construction of hydropower dams without adequate fish passage. As habitat and passage conditions become restored to certain areas, reintroduction of native species is a viable option to reestablish populations to river systems. However, when entire populations have been extirpated from historically occupied areas, no indigenous stock remains to initiate a re-introduction program, necessitating use of an out-of-basin stock. We examine how a reintroduced stock in the Hood River, Oregon, may be adapting to its new environment, as reflected by differences in reproductive success between hatchery and natural origin individuals. Spring-run (stream-type) Chinook salmon were deemed extirpated from the Hood River basin following seven consecutive years (1965-1971) of essentially zero escapement to the fish ladder at Powerdale Dam. A reintroduction program was initiated in 1986 with annual releases of juveniles from Carson NFH, then beginning in 1993 with releases from the adjacent Deschutes River stock. To create a localized Hood River stock, an increasing proportion of in-basin adult returns have been incorporated into the hatchery broodstock. Here we report results, involving genotyping of ~8,000 individuals across 19 years (1992-2010) using 15 microsatellite loci, followed by parentage analysis for hatchery and natural origin individuals spawning above Powerdale Dam (brood years 1992-2005). Our results showed that fish returning to the Hood River during this period were mixtures of the reintroduced interior stream-type genetic lineage as well as an unexpected proportion of stray fish from the Lower Columbia lineage. The interior stream-type and Lower Columbia lineages are evolutionarily distinct in the Columbia River Basin, and their sympatry in the Hood River affords a rare opportunity to study their reproductive success, in addition to fitness comparisons between the hatchery and natural origin fish derived from the Carson and Deschutes supplementation stocks.

Establishing Common Ground in Reproductive Success Studies (Hesse and Narum)

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Can interbreeding of wild and artificially propagated animals be prevented by using broodstock selected for a divergent life history?

Two strategies have been proposed to avoid negative genetic effects of artificially propagated individuals on wild populations: (i) integration of wild and captive populations to minimize domestication selection and (ii) segregation of released individuals from the wild population to minimize interbreeding. We used genetic assignment tests to test the efficacy of the strategy of segregation by divergent life history in a steelhead trout, *Oncorhynchus mykiss*, system, where hatchery fish were selected to spawn months earlier than the indigenous wild population. The proportion of wild ancestry smolts and adults declined by 10–20% over the three generations since the hatchery program began. Up to 80% of the naturally produced steelhead in any given year were hatchery/wild hybrids. Proportions of hatchery and hybrid smolts were correlated with environment conditions and hatchery fish abundance. Genetic assignment tests were used over parentage assignment due to the small fraction of parents that were sampled. However, assignment test methods were possible only because a genetically divergent non-local hatchery broodstock was used in the hatchery program. The biggest hurdle for relative reproductive success studies to overcome is obtaining samples from a large enough fraction of parents and offspring for adequate parentage assignment and statistical power.

Establishing Common Ground in Reproductive Success Studies (Hesse and Narum)

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Detecting introgressive hybridization between segregated hatchery and wild populations

Genetic-based studies designed to differentiate the relative reproductive success of naturally spawning hatchery- and wild-origin populations rely on our ability to genetically differentiate individuals from these two "populations," and to identify with statistical confidence admixed (introgressed) individuals. Unless the pedigrees (i.e., parental lineages) of individual fish are known, assigning fish as pure hatchery or wild, or as a hybrid is normally based on a statistical analysis, using software such as STRUCTURE or NEWHYBRIDS. The intent of this study was to determine the extent to which a segregated hatchery population (Marblemount Hatchery, Skagit River, Washington winter steelhead) has hybridized with wild steelhead populations(s) within the Skagit River Basin. All native winter steelhead populations in Puget Sound (including fish spawned at Marblemount Hatchery) share a relatively recent common ancestor. Since a hybrid individual will show genetic similarities to both parent populations, to adequately document hybridization between two closely related populations, one would need to differentiate similarity due to common ancestry from similarity due to introgressive hybridization. Based on empirically-derived molecular diversity and differentiation values among winter steelhead populations within the Skagit Basin, I simulated two populations ("hatchery" and "wild") and their F1 hybrids to determine the power of various datasets (including the SPAN microsatellite baseline dataset) to differentiate F1 hybrids from pure hatchery or wild individuals. Using the program STRUCTURE, the simulated data with 15 loci (as in SPAN microsatellites) lacked sufficient power to reliably quantify Marblemount Hatchery introgression into the wild Skagit River winter steelhead populations, or to reliably identify pure unmarked hatchery or hatchery-ancestry fish. Furthermore, the error rates dramatically increased as the proportion of hybrid fish in the population decreased. However, simulated datasets with more loci (e.g., 100 or 500), as you may have with a typical SNP dataset, significantly decreased the assignment error rates to the point where there would be no error assigning F1 hybrid individuals, despite the genetic similarity due to common ancestry between the hatchery and wild populations.

Hydraulics and Habitat (McFall and Hallock)

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Restoration of the Lower Cle Elum River Valley, Washington: a successful example of using targeted wood placement to restore habitat and mitigate the impacts of regulated flows and channel incision downstream of dams

The downstream impacts of large dams have on altering natural flow regimes and cutting off sediment and wood supply are well known and have severe adverse impacts to in-stream and floodplain habitat. One of the most significant outcomes of altered flow regimes can be disconnecting a river from its floodplain and secondary perennial and ephemeral channels. Reductions to flow and sediment can also limit critical habitat forming processes such as bank erosion and wood recruitment. The ecological consequences of a given flow released in a simplified channel versus a morphologically complex channel can be dramatically different in terms of habitat suitability. Mitigating for these impacts are challenging and typically involve attempting to naturalize flow regimes as much as possible, particularly with regards to sediment transport and channel altering flows. We present an example of using physical modifications in the Cle Elum River in central Washington State to mitigate the downstream impacts of a large dam. The first phase of restoration built in 2009 re-connected flow to a disconnected floodplain channel to more than double total perennial channel length, enhance hyporheic exchange, and result in a several fold increase in complex cover, pools and spawning and rearing habitat for salmon. Because no flow modifications at the dam were possible, the project offers an excellent illustration of what can be done with strategic wood placements and minor changes to channel geometry. Phase 2 of the project will restore over 5 km of perennial side channel. Our approach is broadly applicable to incised alluvial channels with at least some portion of their floodplain intact.

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Predicting the undesirables: Novel use of hydraulic models to predict presence of the invertebrate host of the invertebrate host of the salmonid parasite ceratomyxa

Many emerging infectious diseases are caused by parasites that have complex life cycles involving multiple obligate hosts, one or more of which is often poorly understood. In the Klamath River, CA, salmonid population declines attributed to ceratomyxosis have led to demand for appropriate management solutions. The causative agent, *Ceratomyxa shasta* (myxozoan parasite), has a complex life cycle involving the freshwater polychaete, Manayunkia speciosa. Alteration of the natural flow regime is hypothesized to have increased habitat available to the polychaete host leading to amplification of *C. shasta*, thus actions that target the obligate polychaete host are considered feasible solutions for managing *C. shasta*. The aims of this study were to predict the distribution and density of polychaete hosts in three sections of the Klamath River 'infectious zone,' a section of river characterized by elevated densities of *C. shasta*. Two-dimensional hydraulic models (2DHM) were developed for each of three river sections using topographic survey data, water surface elevation profiles, stage-discharge relationships, and spatial maps of substrate. These models allow us to predict depth, velocity, and shear stress over a range of discharges. We used the 2DHM to describe hydraulic variation and stratify polychaete sampling locations across gradients of depth and velocity within substrate classes. Benthic samples were collected in July 2012 and used to build predictive models of polychaete distribution. Our results show that in summer, the distribution of polychaetes is associated with substrate, as well as depths and velocities predicted from the 2DHM during peak discharge from the previous spring and winter. Development of models to predict polychaete density is in progress. We plan to validate models with polychaete data collected during other water years but our preliminary results suggest that manipulating the hydrograph could influence distribution of polychaete hosts, which in turn may influence prevalence of *C. shasta* and disease in salmonids.

Hydraulics and Habitat (McFall and Hallock)

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Newsome Creek Stream Habitat and Floodplain Restoration

The Newsome Creek Watershed has always been a sacred place to the Nez Perce Tribe. From time immemorial Tribal members have regarded Newsome Creek as an integral part of their culture. Salmon and steelhead were abundant in this tributary stream of the South Fork Clearwater River. During the late 1930's-1950's dredge mining in Newsome Creek was at its peak. While the mining had a positive effect on the areas' economics it left devastating negative effects on the stream channel and floodplain. On a 3-mile long stretch of upper Newsome Creek lie over 2,500 tailings piles associated with the historic dredge mining. Large woody debris, that fish use for cover and habitat, has been removed from the stream channel and what was once a complex productive stream system has been reduced to a shallow, straightened, & simplistic stream, that does not provide the habitat characteristics that salmon and steelhead desire. During the summers of 2011 & 2012, the Nez Perce Tribe in cooperation with Bonneville Power Administration and the Nez Perce National Forest, began restoring the stream channel and floodplain from the devastating effects of the dredge mining. Dredge piles were removed from the streamside floodplain and large woody debris and boulders placed back into the stream channel to increase habitat complexity. New side channels and meander bends were also constructed to provide more rearing habitat for juvenile steelhead trout and Chinook Salmon as well as other resident fish species.

Hydraulics and Habitat (McFall and Hallock)

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The Influence of Salmon Spawning on Grain Architecture, Critical Bed Shear Stress, and Bed Load Transport in Streams with Implications for Fisheries Restoration and Management

Salmonid spawning occurs in many high to mid-order streams in North America and Europe, but the detailed mechanics of this disturbance on stream bed mobility is not well studied. We calculated and measured spawning effects on incipient bed mobility and sediment transport in a laboratory flume and found that the tailspill portion of simulated spawning nests ("redds") are less stable than unspawned beds. This result agrees with field research by others, but counters prior calculations of tailspill stability that used grain architecture relationships derived from unspawned beds. Redds have coarser and better sorted surfaces, which reduce grain exposure and protrusion compared to unspawned beds, but load cell measurements of the total resistance to movement of grains on redds were lower despite deeper grain pockets and larger pivot angles. This is because the redd-building process flushed fine sediment that had previously cemented bed material, resulting in a looser bed structure and more mobile grains. These observations are supported by force balance calculations of critical shear stress on redds being lower on average than on unspawned beds. Computational results are supported by visual observations and measurements of bed load transport from redds and unspawned beds in the flume, where redds mobilized sooner and exhibited a higher sediment transport rate than unspawned beds. Redds were observed to erode by translating, then dispersing and evacuating downstream, before grains on the unspawned bed mobilized. Further increase in discharge mobilized greater proportions of the unspawned bed but did not scour the deeper portion of redds where spawners deposit their eggs. Our results suggest both an evolutionary trade-off and advantage to large spawning populations. Namely, the structurally loose tailspill likely increases intragravel flow to eggs at the expense of tailspill instability, which may sufficiently elevate sediment yields in streams with high spawner densities to increase the resilience of fish habitats to sedimentation by landscape disturbance.

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Yankee fork PS3 side channel habitat improvement project

Land uses in the Yankee Fork watershed during the past 150 years have negatively affected physical and ecological processes and subsequently native fish populations. The channel in a 6-mile reach of the lower subwatershed is impacted by dredge piles and disconnected from some tributaries. Regardless, this tributary to the Salmon River in central Idaho continues to support spring/summer Chinook salmon (*Onchorynchus tshawytscha*), steelhead (*O. mykiss*), westslope cutthroat (*O. clarkii lewisi*), and bull trout (Salvelinus confluentus) and provides late-summer flow and cold water temperature, two factors frequently absent in anadromous fish restoration projects. Strategic habitat improvement actions in the Yankee Fork watershed are needed to address limiting factors including riparian condition, large woody material (LWM), floodplain condition, bed form, channel complexity, and sediment quantity. Building upon CH2M HILL's 2008 Yankee Fork Floodplain Restoration Project: Alternatives Analysis and Evaluation and the Bureau of Reclamation's 2012 Yankee Fork Tributary Assessment, CH2M HILL worked in collaboration with the Bureau of Reclamation, Idaho Governor's Office of Species Conservation, Shoshone-Bannock Tribes, United States Forest Service, Trout Unlimited, and J.R. Simplot Company to design, permit, and construct the PS3 Side Channel project in fall 2012. By converting a series of remnant dredge ponds to a perennial side channel, the project increases habitat available to juvenile salmonids and helps re-establish physical and ecological processes. The PS3 Side Channel project was designed and permitted in ten months and constructed in two months. The 0.7-mile-long perennial side channel will convey up to 10-percent of the mainstem flow, provide velocities and depths desirable to juvenile salmonids, and transport fine sediment annually during high flows. Eight LWM structures were constructed in the side channel, and more than 200 pieces of wood were placed on the floodplain to provide habitat complexity and floodplain roughness. Re-grading of 25,000 cubic yards of tailings created 4.5 acres of floodplain. Groundwater channels and wetlands were constructed to provide additional high-flow refugia. Approximately 16,400 live cuttings were planted in fall 2012, and 3,600 container plants will be planted in spring 2013. The project partners anticipate the project will provide immediate and sustainable habitat for ESA-listed juvenile salmonids.

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A cost-effective, low impact method for large wood replenishment in streams

The Granite Creek Large Wood Replenishment project used unique, cost-effective and low impact methods to reintroduce large woody structure into seven miles of stream federally-designated as bull trout critical habitat on the Idaho Panhandle National Forest. In the summer of 2012, a two person team, including a highly skilled sawyer/rigger, using a combination of hand tools and directional felling techniques, installed 380 logs/log complexes in seven weeks along the North and South Forks of Granite Creek, a tributary to Priest Lake, Idaho. Construction cost was $215/log, which is about a quarter of the cost of traditional log placement methods using heavy equipment. No heavy equipment entered the stream or riparian zone. All trees were felled from the adjacent riparian area and a grip hoist and/or chain-saw winch was used to move logs into position. For a few structures, large equipment was used to assist with winching from nearby roads. Structures were passively anchored, using ballast trees and/or bracing against existing trees/boulders, limiting movement where necessary to protect downstream infrastructure such as roads and bridges. Smaller diameter or shorter length woody material was installed upstream of wood complexes to initiate future natural "racking" of additional debris. The approach to project design was also unique and cost-effective. An interagency team of fish biologist, hydrologist, environmental engineer, and forester identified structure locations, trees to be used, and structure design in the field. Structures were located and designed with the intent to maximize stream hydraulics to create scour, pools, cover and support gravel retention. Designs provided to the sawyer were intentionally conceptual in nature to allow for contractor flexibility. The project engineer and/or hydrologist were on site for the first several days of construction to help the contractor interpret the intent of design drawings and to "calibrate" the contractor to side-boards (i.e., where was the flexibility in design). An engineer was also on-site during construction of complex structures. Costs were minimized by this approach to design and administration. Because this project did not rely on heavy equipment, environmental impact was extremely low and cost associated with environmental analysis and permitting were negligible.

Hydraulics and Habitat (McFall and Hallock)

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How to use streambank soil bioengineering techniques to restore aquatic habitat

Understanding and identifying riparian planting zones was a key to the successful establishment and long term survival of most woody species. Ensuring that the woody plant material were always in the lowest water table of the year was the best way to ensure establishment. Small plants took 10-15 years to grow big enough to improve habitat values. Larger plants took 5-9 years. Development of detailed project objectives decreased unfounded expectations. Lessons learned about a variety of bioengineering treatments like where to install them, how to install them, what to expect, and time lines for "success" are discussed. Unrooted cuttings are cheaper and easier to plant in large numbers than rooted stock, but sacrifice adaptation to very wet locations. Rooted cuttings are more expensive and will give high establishment success rates. Planting techniques with rooted cuttings are limited and much more exacting. Clump plantings were the best treatment over all. When harvested and planted correctly, they established quickly and provided both root binding capacity and above ground biomass for bank protection. Clumps also provide stream function much faster than almost any other treatment. Brush Mattresses were difficult to establish correctly and required significant plant material to build. They are equal to 8 in rock riprap bank protection after sprouting. Fascines are the most difficult to establish in dry parts of the country. They are often installed either too low or too high which means they tend to drought out or drown out. Brush revetments are one of the easiest and cheapest treatments that can provide velocity reduction, sedimentation, and protection for establishing vegetation. Native collected wetland sod is a superb treatment in the toe zone that covers bare ground with an extensive root system. This root system provides significant streambank protection. There are many different bioengineering treatments that can be used to reestablish vegetation and improve aquatic habitat. Knowing how to use them correctly will increase the ability of the plants to rapidly grow and spread which translates into successful aquatic habitat restoration.

Hydraulics and Habitat (McFall and Hallock)

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Paul DeVries (R2 Resource Consultants, Inc)

Partnering with beaver to restore natural hydrologic processes

Sheep Creek is a fish-bearing tributary of Hangman Creek in which the entire watershed has undergone a wide variety of anthropogenic impacts resulting in a loss of more than 80% of the fish distribution. Changes to the habitat have been severe resulting in high stream temperatures, low discharge, high stream temperatures, lack of connectivity to floodplains, and lack of diverse habitat. Previous attempts to enhance riparian habitat has met little success, and large scale channel reconstruction was not financially feasible. We studied the feasibility of using beaver and prioritized reaches for restoration using passive and active methods. Hardwood clippings were left on stream banks to provide food and building supplies for beaver. Secondly we constructed flow-choking and beaver attracting wood structures emulating local hydraulic effects of beaver dams and wood jams. Combined with strategic re-vegetation and engagement of relict channels, the design should give the system a 'kick-start' and allow natural processes to take over in the long run.

Hydraulics and Habitat (McFall and Hallock)

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Hydraulic Complexity and Linkages with Uncertainty, Variability, Habitat, and Climate Change

This presentation, intended to introduce the Symposium, will be focused on a brief discussion on hydraulic complexity creating habitat complexity. The proposed topic will provide audience members a basic understanding of the important linkages between engineering and fisheries science to include a discussion of scale, uncertainty, and population distribution. Numerous confounding factors and habitat response variability will be presented including how stabilization can prevent evolution. The presentation will conclude with a brief discussion of predicted climate change impacts on hydraulic variables and the resulting impact on habitat variables.

Hydraulics and Habitat (McFall and Hallock)

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Riparian roads reduce instream woody debris in the Columbia River Basin

Instream woody debris is one of the most important components of salmonid habitat, which provides numerous habitat functions. Despite the success of recent management efforts to reduce streamside logging, woody debris recovery may be limited by the presence of near-stream roads. In this research, we investigate the impact of near-stream roads on different size classes of woody debris in the interior Columbia River Basin. We use distance to roads as our primary measure of road effects. We develop models to evaluate the average reduction in woody debris as a result of being near a road (< 30 m or 30.01 m – 60 m). We compare this to the comparable change in environmental factors (precipitation, bankfull width, gradient, forest cover, and % reach grazed) which would have the same reduction in woody debris. In order to extrapolate our findings to the entire study area, we use a GIS approach to determine distance to roads for randomly selected sites throughout the interior Columbia River Basin. Large changes in our environmental predictors had a similar effect as being near a road, which were comparable to entirely different climatic conditions and watershed positions. Based on our GIS analysis, approximately 29% of sites in the study area within 60 m of a road. Due to the strong relationship between woody debris and salmonid habitat, these reductions in woody debris may represent a near-permanent loss of habitat conditions in the interior Columbia River Basin.

Hydraulics and Habitat (McFall and Hallock)

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Chunling Tang (U.S. EPA)

Climate change and Chinook salmon habitat in high-mountain headwater streams in the Pacific Northwest

Climate change projections suggest a generally warming climate has the potential to alter the timing, volume and temperature of spring runoff and the annual hydrograph for streams in the Pacific Northwest. Several anadromous salmonid fish species, that inhabit these streams during the spawning and rearing stages of their lives, are highly adapted to and dependent upon the thermal and hydraulic cycles that are common to these streams. Several of these species are already considered to be threatened and concerns exist that climate change could put their survival in jeopardy. The effects of changes to the hydrologic regime, upon fish habitat, can be investigated using long-river reach aquatic habitat modeling. Traditional approaches to long-river habitat modeling are typically based upon a 1D hydraulic model where flow velocities are averaged between and across measured cross sections. The resolution of these models is limited to the scale of the distances between cross sections. Biologic models are coupled with the 1D hydraulics to create a habitat model where areas of suitable habitat are usually described in terms of weighted usable area (WUA). Researchers have long known that to accurately describe habitat at the spatial scales that fish inhabit, 2D or 3D models are necessary. Most 2D and 3D habitat models have, to date, been limited to reach lengths that are on the order of 100 meters or less. The Experimental Advanced Airborne Research LiDAR (EAARL) was used to measure submerged and floodplain topography for a continuous, 7-kiliometer section of Bear Valley Creek, in Central Idaho. The survey was used as boundary condition for a 2-dimensional hydraulic model whose hydrologic boundary conditions were informed by predicted climate change condition. Spatially explicit WUA were computed for Chinook spawning and rearing life stages using the modeled output datasets of velocity and depth combined with modeler-delineated substrate conditions. Evaluating habitat suitability at various flow rates enabled us to determine effects of the projected range of hydrographs due to climate change on Chinook salmon spawning and rearing habitat. The model suggests that spawning habitat may be reduced during the Chinook spawning season in this region.

Hydraulics and Habitat (McFall and Hallock)

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Sedimentation, scour and turbulence: potential pitfalls with vegetation as a restoration measure

Vegetation is often used as a river restoration measure to increase bank stability and provide shade. However, vegetation effects on turbulence and sediment transport are not well understood and the addition of vegetation to a floodplain or channel bar could have undesired consequences on flow conditions, sediment deposition and aquatic habitat. To better understand these processes we conducted flume experiments in which we varied the mean flow velocity, shear stress, or vegetation density between runs. We used 2D particle imaging velocimetry (PIV) to measure flow velocities and high-speed video to determine sediment fluxes. In our experiments, vegetation caused distinct local scour and deposition zones that could impact future recruitment and survival of other plants. These patterns were created by highly spatially variable near-bed flow turbulence and sediment transport rates around stems. At the scale of a vegetation patch, greater stem densities either increased or decreased sediment fluxes, depending on whether the mean flow velocity or shear stress was held constant with vegetation addition. Therefore the amount of sediment deposition in vegetation patches will depend on how vegetation alters patch-averaged flow properties. For example, vegetation planted on the upstream end of channel bar is likely to increase sediment fluxes and could cause subsequent scour of the bar. Changes in sediment erosion and deposition, and flow turbulence by vegetation could have significant impacts on the stability of a restored reach and local aquatic habitat. Caution may be warranted in using vegetation as a restoration measure without properly assessing its potential impact on flow and sedimentation.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Response of Fish Communities to Peaking Flows at the Toledo Bend Hydroelectric Project

The 81MW Toledo Bend Hydroelectric Project is located on the Sabine River where it forms the boundary between the states of Louisiana and Texas. The Project was developed jointly by the two states as a water supply facility and is also a multi-purpose resource, providing renewable hydroelectric power generation and a variety of recreation uses. The FERC license for the hydropower portion of the project expires on September 30, 2013, which triggered a series of environmental studies and assessments over the last 5 years, including extensive studies of the project's operating effects on downstream fish communities and aquatic habitat. A primary concern was the effect of hydropower peaking operations on the Sabine River fish community, which can result in rapidly changing downstream releases from the powerhouse with flows increasing from 150 cfs up to 14,000 cfs at certain times of the year. In order to evaluate the effects of hydropower peaking, fish community sampling was performed under critical summer peaking generation conditions in 2009 and 2010 at 10 locations spanning 82 miles of river below the Project. The goal of the sampling was to assess whether the river fish community exhibited a change in quality that correlated with the hydraulic attenuation gradient of hydropower peaking flows with increasing distance downstream. A site specific IBI metric was developed to assist in the evaluation of fish community health. What was discovered upon completion of sampling was a remarkably robust fish community. Over 37,000 individual fish representing 23 families and 75 species were captured. IBI metrics did not reveal a consistent upstream to downstream pattern in fish community quality and the overall diversity of physical habitat appeared to drive fish community composition as much or more than the hydraulic effects of hydropower peaking flows. This presentation will take a closer look at fish community data and the relationship to physical habitat and hydropower peaking operations below the Toledo Bend Project. Enhancement measures developed in collaboration between the River Authorities' and the resource agencies to further improve downstream fish and aquatic resources will also be reviewed.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Documentation of Spawning and Estimation of Reproductive Success for Bull Trout Transported Above Mainstem Clark Fork River Dams

Upstream migrations of adfluvial bull trout *Salvelinus confluentus* populations in the lower Clark Fork River have been impacted by mainstem dams since as early as 1913. In an effort to reconnect these migratory populations an upstream transport program was initiated in 2001. Beginning in 2004, genetic testing of fin tissue samples was used to determine the most likely tributary of origin of adult bull trout captured below Cabinet Gorge Dam and this assignment to tributary was used to make transport decisions. From 2001 through 2012, a total of 396 adult bull trout captured downstream of Cabinet Gorge Dam, Idaho, have been transported upstream to release locations in Montana. Many of these fish have been observed entering tributaries during the spawning season, but to verify spawning and estimate the reproductive success of transported fish; a parentage study was initiated in 2008. Fin tissue samples were taken from juvenile bull trout captured in two tributaries to the lower Clark Fork River in 2008, 2009 and 2010, along with any adult bull trout captured in the study area including all transported fish. By comparing the genotypes of these fish using microsatellite markers we were able to assign a proportion of these juvenile bull trout to either one or both parents. Out of a total of 1,362 juvenile bull trout sampled, 26.9 percent were assigned to at least one transport parent; therefore, transported adults are successfully reproducing following upstream transport. Additional information on reproductive success and mating pairs was also derived during this analysis including the observation that upstream transported bull trout produced a significantly lower ($P = 0.003$) number of offspring than transported fish.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Feather and Yuba River Chinook Salmon Interactions: Revisiting What We Thought We Knew About Yuba River Chinook Salmon

Using acoustic telemetry we are the studying migration behavior FRFH steelhead and Chinook salmon smolts. Primarily we are investigating the effect of different release strategies (location, time of day, and method) on survival through the Feather River. Preliminary results for steelhead indicate that relative survival through the Feather River is greater for fish released at the downstream release site and in the evening, while survival for Chinook salmon released at two different sites were not substantially different. Data regarding migration behavior and survival through the Sacramento-San Joaquin Delta (SSJD) to the Pacific Ocean will also be discussed. Results from this study will improve the performance of the FRFH steelhead program and provide insight about through SSJD survival for migrating *O. mykiss*.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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The Future of Hydropower in a Dynamic US Energy Market

The use of flowing water as a source of power dates back thousands of years and electrical generation from the modern hydro turbine has been a mainstay of the US electrical generation portfolio since the early 1900s. Today hydropower provides approximately 8 percent of US utility-scale electrical generation. The role of hydropower in future US electrical generation will be determined by policy and regulation, economics factors, and the strength and direction of technological innovation. Major policy and regulatory drivers include potential development of a Federal energy policy, state and Federal renewable portfolio standards, and air quality and climate change initiatives. Economic drivers include costs of alternative fuels and generation technologies, tax incentives provided to hydropower and other renewable and non-renewable power sources, and the future level of investment in transmission and distribution improvements. Technological innovation within all generations types, including efficiency improvements in generation and power usage, smart grid growth, and distributed generation each represent potential disruptive forces for hydropower. These major potential drivers of hydropower's role in future US electrical generation are discussed along with emphasis on how these drivers will affect existing and development of new hydropower in western states.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Instream flow studies and the FERC Licensing Process

The Federal Energy Regulatory Commission's (FERC) Integrated Licensing Process (ILP) mandates that environmental studies conducted in support of a new or renewed hydroelectric project license focus on the ability of project configurations and operations to provide balance between economic and environmental resource benefits and adverse resource effects. Instream flow studies are often the cornerstone from which the evaluation of potential effects on aquatic resources is conducted, and potential protection, mitigation and enhancement measures are developed. When developed as part of a comprehensive aquatic habitat evaluation, instream flow study design can inform many studies requested by reviewing resource agencies and provide an important vehicle for incremental analyses linking numerous aquatic resources, morphological processes and riparian functions. In addition to a review of the most commonly used instream flow methodologies employed in the FERC licensing process, important linkages, information pathways and process efficiencies for evaluating other resource areas will be presented.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Operating your Powerhouse for Smolts

Turbine passage for outmigrating smolts has always been an area of concern regarding a hydroelectric project meeting Project performance standards for smolt survival. In looking at this issue, the Public Utility District No. 2 of Grant Couny, owner and operator of both Wanapum and Priest Rapids dams on the Columbia River, conducted fish studies to determine the best way to operate its turbines for smolt survival, to operate its powerhouse for smolt survival and also evaluated turbine designs for the installation of turbines that were more "fish friendly". Through the use of acoustic-tag and ballon-tag fish studies, and also CFD modeling for turbine blade design, Grant PUD has increased its salmonid smolt turbine passage survival rate to greater than 96%.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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A river, and many fish, run through it: the removal of Condit Dam and other large-scale dam removals in the PNW

After fish passage had been blocked for nearly a century, salmon and steelhead have returned to the upper White Salmon basin following the removal of Condit Dam. Scientists, managers and regulators have been monitoring the return of salmon and steelhead and the characteristics of the river since the breaching of the dam in October 2011, as the river responds to the removal of the 38 m structure and flushing of sediments behind it. The release of approximately 1.8 million cubic meters of sediment that had accumulated behind the dam has replenished gravel bars and buried bedrock in the lower river. The addition of sand and gravel to the lower river has provided improved spawning and habitat conditions in the 5.3 km stretch of river downstream of the former dam site, previously starved and scoured of smaller substrate. Fish have positively responded to the conditions in the river, reestablishing their presence throughout the former project area and upstream habitat. Fish passage in this evolving environment has been successful in the mainstem river, while access to important tributary habitat has only had a few obstacles. Wood and sediment continue to adjust and provide researchers with insight on dam removal scenarios, maintenance, and monitoring. Lessons can be learned from dam removal projects and can be used to inform the science of river restoration.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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The Lower Yuba River Accord, a paradigm for negotiated settlement and implementation of a flow regime and fisheries monitoring & evaluation program

In March of 2008, California state officials approved the "Lower Yuba River Accord" (Accord), an innovative settlement agreement designed to resolve one of the longest-running environmental disputes in California. Five years later, the award-winning Accord is surpassing expectations by providing significant benefits to California's economy and environment. This science-based initiative has improved fisheries habitat while ensuring the ability of the Yuba County Water Agency (YCWA) to sustainably operate the Yuba River Development Project (licensed by the Federal Energy Regulatory Commission – FERC) for renewable energy generation, water supplies, and flood protection to benefit the people of Yuba County. This is the story about of a collaborative strategy that led to a sustainable solution, and how it is providing valuable and even unanticipated benefits. The lower Yuba is one of California's signature salmon streams. It supports steelhead, fall-run and spring-run Chinook salmon. Spring-run Chinook salmon and steelhead are listed as "threatened" under the Endangered Species Act, while fall-run Chinook salmon are a federal "species of concern." The Lower Yuba River flow requirements were originally set in the 1966 license for the Yuba River Development Project. However, in a contested proceeding stretching over a dozen years before California's State Water Resources Control Board (SWRCB) new higher flow requirements were established – which promptly shifted the 'discussion' to federal court, with protests and litigation brought from all sides of the issue. After nearly 15 years of controversy and frustration with the regulatory process, YCWA initiated a collaborative process that would strive to resolve the controversy. The approach called for three key elements: (1) increased reservoir releases to maximize fisheries habitat availability (developed collaboratively with state and federal agencies and conservation groups); (2) comprehensively-managed surface and groundwater resources to avoid water-supply impacts from these higher reservoir releases; and (3) a plan for downstream agencies to pay for the water-supply benefits from these higher reservoir releases. Building a foundation of trust among the parties to encourage innovation in problem-solving was essential to our strategy.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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A Twenty-Year History of the Upper Cowlitz River Basin Anadromous Fish Reintroduction Program and its Challenges

Abstract

The Cowlitz River, located in western Washington State, historically produced abundant runs of salmon and steelhead. In the 1960s two large hydro-electric dams were constructed, one of which blocked upstream and downstream migrations. In the early 1990s, plans were developed to reintroduce anadromous fish above the dams into 240 river miles of their historic habitat. This unique opportunity began following the completion of the Cowlitz Falls Dam in 1994 and the subsequent construction of the adjoining Cowlitz Falls Fish Facility (CFFF) two years later. The reintroduction program is based on "trap and haul" where adult spring and fall Chinook, coho and late winter steelhead are captured at a downstream barrier dam and trapping facility then trucked upstream approximately 40 miles and released to spawn naturally above the three Cowlitz River dams. Juvenile downstream migrants and steelhead kelts are collected at the upstream CFFF and transported downstream around the three dams to continue their migration to saltwater. This attempt to reestablish three ESA listed anadromous fish species into the critical upper Cowlitz River habitat has met with mixed results. Although more than two million smolts have been transported downstream for release since the program began, the proportion of the run successfully captured is insufficient to attain self sustaining populations. This presentation will discuss several of the Reasonable and Prudent Measures outlined in the Biological Opinions that dictate the recovery and monitoring efforts for the two Cowlitz River utilities and will focus on three of the primary challenges facing the reintroduction program.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Thompson Falls Fish Ladder, novel solution for moving Bull Trout over a Montana Dam.

In 2001, as required under Section 7 ESA consultation with the USFWS for threatened bull trout, PPL Montana conducted flow induced fish behavior studies and concluded that Bull Trout, when attracted, would move up a 39 foot Denil fish ladder. PPL Montana then assembled a Fisheries Technical Advisory Committee (TAC) to consult on the studies, design and operation of an inland full height fish ladder on the Clark Fork River at Thompson Falls Dam, Montana. As a result of the complexity of this dam site, it was essential to determine the best location for a ladder. Salmonids were radio tagged and movements monitored at various flow and spill configurations for two years. These fish movement data determined an optimal site to build the fish ladder. The TAC determined that a full height volitional ladder would be constructed, but that initially each fish must be individually sorted before being passed over the dam. Construction of the ladder began in the fall of 2009 and was completed one year later. Operation of the full height bull trout ladder (first of its kind in the U.S.) began in the spring of 2011. As determined by cold weather, the ladder operates between March and October. Operations in 2011 and 2012 respectively captured 1,805 and 2,668 fish. Suckers (428 and 1,403) and Northern Pike Minnow (1000 and 926) dominated fish passage in both years. Salmonids were 13 and 11 percent (241 and 304) of each year's total. Only 4 Bull Trout have ascended the ladder, a reflection of the few number of Bull Trout presently downstream of Thompson Falls Dam.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Fish in Space –Chinook Salmon Spatial/Temporal Distributions in the Lower Yuba River, CA

As part of a 17-party science-based flow initiative, the lower Yuba River Accord has provided over $6 million for fisheries monitoring, studies and enhancement since 2006. A River Management Team (RMT) comprised of Federal & State fisheries representatives, Yuba County Water Agency and several non-governmental organizations has guided the monitoring and evaluation of fisheries resources on the lower Yuba River. As part of this consensus-based approach, the RMT has been employing emerging technologies to provide new windows into understanding habitat use and temporal distributions within this limnetic system for several key species. The RMT has been actively gathering high accuracy geospatial data for species like Chinook salmon in the lower Yuba River. Results from these studies are providing an eye-opening understanding of the multitude of diverse spatial and temporal habitats occupied by several life stages of Chinook salmon in the lower Yuba River. Adult Chinook salmon exhibiting phenotypic run timing synonymous with spring-run periodicities were captured by hook and line, fitted with an acoustic transmitter and monitored using a combination of acoustic "gates" and vessel-based mobile tracking for a total of 18 months over a three-year span. The resulting data demonstrated a widespread occupation of the lower Yuba River that provided a contrasting jolt to the existing conventional wisdom regarding spring-run Chinook salmon life history strategies employed in the lower Yuba River. Concurrently, near-census redd surveys were conducted during a two-year period using high-accuracy GPS. Over 6,000 Chinook salmon redds were identified and geospatially analyzed using cutting-edge LIDAR mapping and 2D flow modeling. Fascinating new results emerged, including distinct morphological delineations for all spawning locations and new methods for identifying the potential for redd superimposition impacts using ArcGIS. More recently, a juvenile habitat use survey has provided a glimpse into this exciting life history stage on the lower Yuba River. The RMT began a juvenile habitat use survey in January 2012 with the purpose and goal of identifying the spatial and temporal distribution, diversity, and habitat utilization by the lower Yuba river juvenile fish community. When these data are combined with geospatial data from the adult fish, a more complete picture of temporal and spatial distributions for Chinook salmon has emerged.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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A Design for Portable Floating Fish Collector Using Off-the-shelf Parts

The U.S. Army Corps of Engineers (USACE) identified a need for a small-scale, portable floating fish collection (PFFC) device to gather additional information on juvenile fish movement in Willamette Valley Project (WVP) reservoirs. This device was intended to provide a cost-effective means of safely obtaining juvenile fish in WVP reservoirs for use in research, monitoring and evaluation efforts as well as to gather information on the behavior of both tagged and run of river fish near a small floating surface collector. USACE planned to deploy the PFFC at several reservoirs and sought a design that can be broken down into components sized to allow legal transport over the state highway system. Yet the PFFC had to be capable for use in the Cougar Reservoir, a flood control facility with a large storage capacity and a 200 ft variation in water surface elevation. The attraction flow can be varied from 20 to 140 cfs with hydraulic components that allow tuning of the flow for optimum hydraulic performance. Features that provide separation and protection of various sized fish include a grader with adjustable bar spacing, shelter areas and the means to sort fish by way of a crowder and hopper system. Power for operating systems is provided via a submerged cable tied into station power. The cable also contains wiring that can be used to convey instrumentation and operational readings back to land based computer equipment. Once positioned the winch/anchor system can be used to vary the orientation of the PFFC. With this system it is also possible to move the PFFC within reservoirs by lifting the anchors and using an auxiliary craft to push the PFFC to a new location.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Fish Population Compositions in Nine Sierra Nevada Reservoirs

Since 2009, HDR has conducted reservoir population studies as part of FERC relicensing activities for four different clients. Nine reservoirs were sampled including Nevada Irrigation District's Jackson Meadows Reservoir, Bowman Lake, and Rollins Reservoir; Pacific Gas and Electric's Lake Spaulding, Fordyce Lake; Yuba County Water Agency's New Bullards Bar Reservoir; US Army Corps of Engineers' Englebright Reservoir; and Merced Irrigation District's Lakes McClure and McSwain. While all of these reservoirs were built with the original purpose being some combination of flood control, water supply and hydropower production, they also provide habitat for native and introduced species, as well as unique opportunities for recreational fisherman. These reservoirs span over half of the range of the Sierra Nevada from north to south and represent a complete distribution of the elevations found within the Sierra. These reservoirs also represent a broad range of trophic and thermal regimes, which are likely the two most significant factors influencing the fish population compositions of these reservoirs. Fish were primarily sampled using gill nets and boat electrofishing. A summary of catch, species composition, relative abundance, fish condition, and habitat composition will be presented.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Lower Deschutes River Gravel Study: monitoring downstream effects of the Pelton Round Butte Hydroelectric Project on geomorphology and salmonid spawning habitat in Oregon's Deschutes River

The Lower Deschutes River Gravel Study (LRGS) is being implemented by Portland General Electric Company and the Confederated Tribes of the Warm Springs Reservation of Oregon, with technical assistance from Stillwater Sciences. The overarching objective of the LRGS is to assess the impacts of the Pelton Round Butte Hydroelectric Project on downstream channel morphology and gravel availability for spawning salmon and trout in the Deschutes River. The LRGS consists of two components, providing for (1) geomorphic evaluation and (2) biological monitoring, between the Pelton Reregulating Dam, at river kilometer (rkm) 161.2, and Trout Creek, at rkm 140.5. Study sites are grouped for comparison in reaches upstream and downstream of Shitike Creek, the first tributary source of gravel recruitment downstream of the Project. Geomorphic evaluation studies include monitoring of individually tagged tracer rocks, cross section profiles, bedload transport measurement and scour chains. Experimental gravel augmentation deposits were constructed at three sites, and are monitored following threshold river flows. Biological monitoring includes detailed mapping of redband and steelhead trout redds, suitable spawning gravel, and suitable depth and velocity at sites upstream and downstream of Shitike Creek, and at the experimental gravel augmentation sites. Fall Chinook spawning is enumerated by annual helicopter redd counts. After 2014, a panel of experts will review the study results, and recommend one of three options: programmatic gravel augmentation, further studies, or no further action. Preliminary results substantiate previous studies indicating the Deschutes River has very low sediment transport capacity due to its groundwater- dominated flow regime, and spawning activity of large salmonids is a primary factor in localized gravel redistribution.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Innovative Fish Passage: A Cost-Effective Solution for High-Head Hydro

Providing downstream fish passage at high-head hydroelectric facilities can be prohibitively expensive, especially at smaller projects, due to the engineering challenges associated with maintaining safe passage conditions over a large change in elevation. Traditional solutions involve large structures such as fish ladders, locks, or bypass flumes. Floating surface collectors combined with hauling operations can cause migration delays and be prohibitively expensive due to high operating and maintenance costs. An innovative, cost-effective system for downstream fish passage at high-head hydropower facilities has been developed, and is ready for prototype-scale testing. The system uses engineered decompression raceways to safely pass fish through conventional screening technology by regulating pressures and controlling bypass flows. The development of the decompression raceway allows proven screening methods to be used at high-head hydropower facilities because it solves the problem of controlled decompression at the bypass and discharge locations. Results from Computational Fluid Dynamic (CFD) model tests verify the hydraulic performance of the decompression raceways and their ability to meet fish passage criteria. Hyperbaric pressure tests on salmonids verify low injury and mortality rates during controlled decompression. This approach expands the applicability of existing screening methods to allow volitional downstream fish movement at high-head facilities with minimal delay and a small physical footprint.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Ramping Rate Evaluation and Rainbow Trout Fry Stranding Study, Spokane River, Washington

Avista completed a ramping rate evaluation and rainbow trout fry stranding study to assess the potential for a 4-inch per hour hydroelectric down-ramping rate to strand rainbow (redband) trout (*Oncorhynchus mykiss gairdneri*) in the Spokane River, Washington. Four habitat study sites were established in areas of known and expected rainbow trout spawning and where rainbow fry were most likely to occupy. The habitat sites were surveyed and modeled to develop stage versus discharge relationships from 20,000 cubic feet per second (cfs) to 3,000 cfs; the range of flows that the Post Falls Hydroelectric Development (HED) can control. Down-ramping events performed in 2011 and 2012 resulted in less change in water level downstream of the HED and attenuated over several minutes at the habitat study sites. Observations during these trials found numerous rainbow trout fry in the near shore areas successfully moved to adjacent river reaches during the actual down-ramping events. The 4-inch per hour down ramping rate required by the Federal Energy Regulatory Commission (FERC) license for the Spokane River Hydroelectric Project was found to be protective of rainbow trout fry in the Spokane River.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Freshwater ecology of a glacially dominated stream under consideration hydropower production

The State of Alaska has set a goal of 50 percent renewable power generation by 2025, and the development of new hydropower facilities will be an important component in meeting this goal. The ecological effects of hydropower development are diverse and principally driven by changes in stream flow. To meet rigorous State and Federal permitting requirements, a landscape perspective must be taken to identify locations and set operational parameters that sustain healthy aquatic resources. Battle Creek is a glacial system located at the head of Kachemak Bay, Alaska that has the potential to supplement the Bradley Lake Hydroelectric Facility. This 23-square-mile watershed transitions from glaciated coastal mountains to tidewater in a 9-mile stream course, following deep bedrock dominated gorges, passing over waterfalls before transiting on to fish-friendlier habitats in its lowest 1.8 miles. During 2010 and 2011, investigators sampled and monitored the biotic and abiotic in this system to better understand how dramatic flow fluctuations affect the availability of stream habitat for aquatic organisms. Biotic monitoring and sampling efforts included: resident and rearing fish distribution, adult salmon distribution and timing, and sampling of macroinvertebrate communities. Abiotic factors include stream flow, water quality, temperature, stream bed characteristics, and cross sectional geometry. By understanding these elements and modeling their key inter-relationships, investigators hope to predict how aquatic communities will respond to the diversion of a portion of Battle Creek's waters.

Interactions of fish and hydropower operations in the west – an update on recent studies and trends in resource management in the FERC relicensing process (Hutchinson)

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Restoration of Floodplain Lakes in the Lower Columbia River Estuary

Restoration of floodplain, wetland, and off-channel rearing habitat in the Lower Columbia River Estuary (LCRE) has been a priority for recovery of multiple salmonid ESUs in the Columbia Basin. Reasonable and prudent alternative (RPA) 37 in the 2008 Biological Opinion of the Federal Columbia River Power System (FCRPS) identifies restoration of LCRE habitat in order to increase overall survival for both ocean and stream-type juvenile salmon. Floodplain lakes have been identified as potentially productive LCRE rearing habitat that could also contribute to overall LCRE food web productivity. Recent restoration planning for LCRE floodplain lake projects in Post Office Lake, WA and Sturgeon Lake, OR have identified a number of key considerations that present challenges to successful restoration concepts and design. River regulation, levee construction, off-channel water management and associated changes to flood frequency, duration, and water surface elevations have altered the historically predominant mechanisms of hydrologic connectivity and fish access to these lakes. Design concepts that include surface water connections between riverine and lake habitat attempt to emulate this historical connectivity. Contemporary river hydrology, with lower overall water surface elevations during the spring freshet, requires restoration approaches that provide fish access at multiple water surface elevations. Tidal prism is also an important hydrologic factor in habitat-forming processes that benefit juvenile salmonids, such as formation of emergent marsh zones. Although these lakes likely provide high quality rearing habitat during most of the year, surface water temperatures rise rapidly in the early summer, making fish egress to the main channel an important design consideration. Finally, many LCRE floodplain lakes have been managed for deep-water waterfowl habitat with the use of water control structures. Since waterfowl populations in the LCRE are important and valuable resources, salmonid rearing restoration concepts must consider waterfowl habitat loss during restoration planning.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Implications of historic conditions, as determined through paleolimnological analysis, on fishery management decisions in Pend Oreille Lake, ID

Sediment cores were collected from 4 locations in Pend Oreille in 2010 and 2011. The cores were processed to determine date of deposition, carbon and nitrogen content, diatom community structure and cladoceran taxa and size. This information was then used to determine conditions within the lake as early as 1850. By examining sediment from various depths we were able to reconstruct past conditions within the system and determine the likely impact these conditions would have on the fishery. There were several noticeable changes in the diatom and cladoceran communities indicative of substantial disruption to the food web. We were also able to determine that there was an increasing trend in nutrient loading, and primary productivity within the system. The trends indicated an ongoing impact on the lake due to human induced changes in the watershed. Additionally, the conditions within the lake over the last 150 years were used to determine if changes observed within the fish community could have been a result of changes in the productivity of the system or due to changes in the lower trophic levels of the aquatic community. This information was used to inform managers of how projected future conditions may affect the fishery.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Attempted manipulation of gerrard rainbow trout using unlimited and incentivized angler harvest in Lake Pend Oreille, Idaho

The nonnative lake trout *Salvelinus namaycush* population in Lake Pend Oreille, Idaho increased exponentially from 1999-2006. The increased abundance of lake trout, combined with already established populations of Gerrard-strain rainbow trout *Oncorhynchus mykiss* and bull trout *Salvelinus confluentus*, led to an unsustainable level of predation on kokanee *Oncorhynchus nerka*. In response, an aggressive predator removal program was developed to target long-term suppression of the lake trout population and temporarily reduce rainbow trout abundance. Unlike lake trout, rainbow trout inhabit pelagic habitats and were not vulnerable to commercial netting equipment. Therefore, incentivized angler harvest was the only tool to reduce the rainbow trout population. Despite a long-standing social mindset of catch-and-release fishing, anglers harvested 51,443 rainbow trout during 2006-12. Although the rainbow trout population initially decreased (46% from 2006-08), it later increased to 128% of the 2006 abundance in 2012. Even with unlimited incentivized harvest and unlimited rod rules in place, exploitation rates remained low (15-30%), and the population was not reduced after seven years of program implementation. Ageing data in 2011 showed that rainbow trout growth rates decreased during the years of record-low kokanee abundance (2006-2008), but growth in recent years appeared more similar to historically when rainbow trout more commonly reached trophy size. By 2012, kokanee abundance sufficiently rebounded to a level where rainbow trout predation was no longer a threat. As a result, incentivized harvest was ended starting in 2013, and restrictive harvest rules were re-instituted based on both biological and social considerations.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Complex trophic interactions following nonnative species introductions to Flathead Lake, Montana

Multi-trophic level impacts from the introduction of nonnative fishes and an opossum shrimp were documented in a spatially extensive system that played out over more than a century. Over 19 different nonnative fish species were introduced to Flathead Lake by fisheries managers beginning as early as 1890 and ending in the mid-1960s, although reintroduction of nonnative kokanee salmon continued into the late 1990s. From 1968 to 1976, the opossum shrimp, *Mysis diluviana*, was introduced into lakes upstream of Flathead Lake and is now a strong interactor in the present food web. Nonnative lake trout had been introduced 80 years prior but remained at low densities until nonnative Mysis became established. The bottom-dwelling mysids provided a deep water food source for lake trout where little was available previously. Lake trout, a voracious piscivore, now dominates the lake fishery. Formerly abundant kokanee salmon were extirpated and native bull trout and cutthroat are imperiled. *Mysis* predation shifted the size structure, species composition and abundance of zooplankton and phytoplankton. However, one of the most important and unexpected findings was that the rate of primary productivity increased suddenly by 21%, exactly consistent with the peak in Mysis abundance, and has not decreased since. Abundance of *Mysis* continues to fluctuate (e.g., lake-wide mean from annual census of 40 sites has ranged from 19 to 90 individuals per m2 since Mysis became established) while zooplankton abundance appears to have stabilized at pre-*Mysis* densities. The persistent change in food web structure is decidedly problematic for fisheries managers given Endangered Species Act threatened status for bull trout. A fully integrative ecosystem model of Flathead Lake is needed to understand the emergent properties of these complex interactions.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Seasonal Distribution of Invasive Lake Trout (*Salvelinus namaycush*) in Yellowstone Lake

In an attempt to restore balance to the foodweb of Yellowstone Lake, the National Park Service has been actively suppressing lake trout *Salvelinus namaycush* since 1995. Gillnetting has been the primary technique for capture, but although large numbers of these predaceous invaders have been removed, the number of lake trout captured continues to increase. In order to increase the efficiency of the suppression program, acoustic telemetry is being used to identify movement patterns of invasive lake trout in the lake. Beginning in August of 2011, acoustic receivers were deployed at 40 sites in Yellowstone Lake to monitor the movements and seasonal distribution of lake trout >500 mm TL, and 141 lake trout were implanted with transmitters and released in Yellowstone Lake. In the summer of 2012, an additional 100 temperature/depth sensing transmitters were implanted in lake trout. Yellowstone Lake was divided into four regions based on the deployment of receivers. Lake trout were most commonly located between the western and southern regions of Yellowstone Lake. No more than 36 individuals (8.6% of the total detections) were detected in the northern region. During the winter (November 1 – April 30), movement among regions was limited, but in the spring/summer (May 1 – July 31) and again during the fall spawning season (August 1 – October 31), lake trout moved throughout the lake. In the fall, 73% of fish spending a high proportion of time in a single region were located in the West Thumb where spawning has been documented. Lake trout exhibited a broad depth distribution during spring/summer and fall, ranging from the surface to > 80 m. Interestingly, mean depths of these larger lake trout were generally shallower in the spring/summer period than during the fall spawning period; however, during spawning, lake trout in the West Thumb were detected at the shallowest depths observed during the study. These findings provide new insights concerning lake trout movement patterns that may be useful for future planning of suppression efforts in Yellowstone Lake and are potentially applicable to other lakes in the western United States where lake trout have affect foodweb dynamics.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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The influence of food web dynamics on the growth and production of Lahontan cutthroat trout, in Pyramid Lake, NV.

Quantifying interactions between species is integral for understanding the structure of aquatic food webs and can aid in understanding how species will respond to environmental variability. Lahontan cutthroat trout*, Oncorhynchus clarkii henshawi* (LCT), currently occupy 0.4% of their native lacustrine habitat and are listed as threatened under the ESA. In Pyramid Lake, Nevada, this species provides an important subsistence fishery for the Pyramid Lake Paiute Tribe, is a popular sport fish, and is the apex predator in the aquatic food web. Since extirpation of naturally-reproducing individuals in 1942, LCT in Pyramid Lake have been maintained through stocking programs; however, these hatchery LCT fail to reach pre-extirpation sizes. The primary focus of this study was to investigate food web interactions that may limit LCT growth and production. Tui chub (*Gila bicolor*), thought to be the main forage item of LCT, and exotic Sacramento perch (*Archoplites interuptus*) have also been present since the 1890's. We hypothesized that: 1) LCT are food and perhaps gape limited, and 2) LCT may compete with Sacramento perch for tui chub as a food resource. Fish sampling took place via gill and trap netting three times per year at eight index sampling locations during 2011 and 2012. Depth, location, isotope, and demographic data were collected for all fish. Additionally, hydroacoustic and trawling data were collected in October of 2012 for estimates of fish biomass. While catch data suggests only moderate overlap in distribution, diet and isotope data indicate considerable overlap in the trophic niches of LCT and Sacramento perch. These results indicate they potentially compete for prey, specifically tui chubs; however, bioenergetic simulations indicate that annually, Sacramento perch only consume 5% of what LCT consume lake-wide, perhaps due to gape limitation. In addition, on an annual basis, LCT consume only 80% of the tui chub available lake-wide, suggesting that LCT are not food limited. While this study suggests that LCT stocking rates may be increased, it also highlights the importance of understanding the dynamic interactions of multiple energetic constraints on a community member.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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A *Lota lota* consumption: trophic effects and potential impacts of a novel and voracious predator in Flaming Gorge Reservoir, WY-UT

Widespread biological invasions threaten the success of fisheries management plans and ecosystem health as a whole. Tributaries of Flaming Gorge Reservoir, WY-UT, contain populations of imperiled, native fishes and Flaming Gorge Reservoir is home to highly valuable, trophy sport fisheries. Illegally introduced populations of burbot (*Lota lota*) have spread throughout the Green River drainage, including Flaming Gorge Reservoir, and these novel invaders pose a threat to native and sport fishes. We examined the ongoing effects of burbot on the food web in Flaming Gorge Reservoir. We assessed relative abundance of burbot, and diets of burbot and trophy lake trout (Salvelinus namaycush). Burbot catch varied spatially with the greatest catch rates occurring in the Inflow region and lowest catch rates in the Canyon region. Our dietary analyses indicated that crayfish dominated burbot diets (60% occurrence), but diet breadth was wide and we observed considerable consumption of fish (25% occurrence) by burbot. When exhibiting piscivory, burbot most commonly consumed forage fishes (e.g., sucker and chub), but we also observed sport fish consumption (e.g., rainbow trout, smallmouth bass) and cannibalism by burbot. We most often observed piscivory in larger burbot, but burbot as small as 310 mm consumed fish prey. Trophy lake trout most often consumed other salmonid sport fishes and our analyses showed extremely low rates of burbot consumption by lake trout. Compared to findings of a previous study from the early stages of burbot invasion, our catch differed spatially and was significantly greater (as much as 10 fold) at many sites. Both studies indicated that crayfish were the most consumed prey of burbot by count. However, the greater occurrence of burbot cannibalism in our study suggests possible density-dependent effects. Bioenergetic analyses indicate that consumptive pressure on the prey base of Flaming Gorge Reservoir has increased dramatically since the introduction of burbot and this increase likely has adverse effects on sport fish in the reservoir. Many critical questions remain, such as the availability and consumption of larval and juvenile burbot by sport fishes and the specific predator-prey interactions between imperiled native fishes and burbot in tributaries to Flaming Gorge Reservoir.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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The Arctic char *Salvelinus alpinus* of Dillon Reservoir, Colorado: an evaluation of their present status and future management possibilities

Throughout the West fisheries managers are challenged by trying to provide attractive and valuable fisheries in montane water bodies which are often oligotrophic and limited in fish production capacity. As a strategy to improve desirability, some waters are managed as boutique fisheries where unique species are introduced which are capable of attracting anglers from a wide radius who desire the opportunity to catch a novel species. Dillon Reservoir, in Summit County Colorado provides an example of a fishery with potential as a destination for Arctic char (*Salvelinus alpinus*). Due to high elevation, cladoceran suppression by *Mysis* shrimp (*Mysis diluviana*), nutrient abatement in the watershed, and high densities of competing white suckers (*Catostomus commersoni*), Dillon Reservoir's introduced salmonids grow slowly. Arctic char have recently been reintroduced to provide an opportunity to catch a species which is unavailable in the contiguous United States outside of Maine. We are currently studying this population of Arctic char with the objectives of 1) describing the current status of the Arctic char fishery and their role in the food web of Dillon Reservoir and 2) providing management scenarios aimed at maximizing Dillon Reservoir's potential as an Arctic char destination. We collected Arctic char in 2012 with a mix of gill netting targeted by hydroacoustic sampling and angling. Using diet data and stable isotope modeling analysis, the char's diet has consisted mainly of Mysis shrimp, Pisidiidae fingernail clams, and kokanee eggs. Analysis of otolith strontium isotope signatures combined with aging has also revealed natural reproduction in the population. Future work will employ population and bioenergetics modeling to provide stocking and harvest scenarios designed to maximize the Arctic char fishery at Dillon Reservoir

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Management strategies for multi-use recreational fisheries: coexistence of lake trout and kokanee in western waters

Kokanee (*Oncorhynchus nerka*) are a popular sport fish for both managers and anglers, and have been introduced to many cold water fisheries. Piscivorous lake trout (*Salvelinus namaycush*) have also been introduced to many of these same waters. To sustain rapid growth rates, lake trout require a high quality, abundant prey base and kokanee are often a substantial part of their diet. However, runaway consumption often destroys both fisheries: lake trout decimate the kokanee population, then lake trout growth and condition decline precipitously. Our work on Blue Mesa Reservoir, Colorado, has focused on finding a sustainable balance for the two fisheries, with the primary management goal being a sustainable kokanee population. The secondary goal was to provide a trophy lake trout fishery. We developed an age-structured kokanee population model that incorporated estimates of natural mortality, harvest, and predation from lake trout with a fixed stocking quota of 3.1×106 kokanee fry. We then determined the level of consumptive demand on the kokanee population using bioenergetics models which were comprised of estimated lake trout abundance, measured lake trout growth, and measured energy density values of predator and prey species. After estimating current exploitation on lake trout (u = 0.2307 for age-4 through age-9) by mechanical removal and angler harvest, exploitation was incrementally increased to determine a level permitting a stable kokanee population (u = 0.3807). Our data suggests that removal of young lake trout age classes must be intensified to facilitate possible coexistence of kokanee and trophy lake trout in Blue Mesa Reservoir.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Zooplankton size structure as an indicator of productive stocking sites

Contributing factors to fish fry survival after stocking events are not fully understood. Complex ecological interactions between releasable fry and available forage are rarely investigated prior to stocking. Analyzing possible fish stocking locations prior to large scale fry additions can promote higher survival and recruitment of released fish by optimizing the availability of prey items at fry introduction. Lake Pend Oreille in northern Idaho, USA has recently experienced a resurgence of kokanee salmon (*Oncorhynchus nerka*) stocks after multiple decades of poor recruitment and survival. To further improve stocked kokanee survival within LPO we have adapted a zooplankton quality index (ZQI) from a rainbow trout specific metric into a multiple species index with special concern for the forage available to kokanee fry. We have also applied this index to multiple field observations on Lake Pend Oreille in both a temporal and spatial context. Significant differences between zooplankton size class structure in both space and time were observed and mapped using GIS software over a 7 month period to establish suitable habitat for kokanee fry stocking events. Preliminary investigations suggest that with the newly adapted ZQI, noticeable differences in zooplankton composition can be easily assessed with moderate sampling time and effort. These results suggest that during certain times of the year select areas of Lake Pend Oreille are more likely to hold a higher abundance and size class of zooplankton. These slight variations in zooplankton size structure can increase the success of future kokanee stocking efforts on Lake Pend Oreille. Estimating the composition, availability and size structure of zooplankton available to fish in certain locations throughout the year are essential for maximizing the return on a stocking investment.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Spawning Characteristics of Invasive Lake Trout *Salvelinus namaycush* in Yellowstone Lake

The lake trout *Salvelinus namaycush* suppression program in Yellowstone Lake has primarily relied on removal with gill nets and trap nets. Acoustic telemetry has the potential to improve suppression efforts of non-native species and enhance understandings of predator-prey interactions. New strategies to maximize the effectiveness of the suppression program include the destruction of lake trout embryos on spawning grounds. Embryo destruction requires knowledge of lake trout movement patterns and the location of spawning areas. We initiated an acoustic telemetry study in 2011 to collect critical movement and distribution information concerning lake trout. By 2012, 220 acoustic transmitters had been implanted in adult (weight > 500 g) lake trout, and 52 acoustic receivers were deployed around Yellowstone Lake. A primary objective of the study was to gain understanding concerning the timing of and movements associated with spawning. In this presentation data collected from receivers near Carrington Island, a known spawning area for lake trout in this western lake, were analyzed to learn about the timing of spawning activities around the island. We examined lake trout movements at a single receiver through time (by season, month, and week) and evaluated differences in patterns among years. In 2012, a fine-scale assessment with 11 additional acoustic receivers placed in a grid around Carrington Island provided specific spawning locations and movement patterns in the area. A subset of acoustic transmitters equipped with depth and temperature sensors were deployed to yield additional data on lake trout spawning behavior and response to environmental variables. Lake trout were consistently detected near the surface at Carrington Island. Shallow depths (< 3 meters) were only consistently observed at six other sites around the lake. Average temperatures at the suspected spawning sites were higher than those of other sites around the lake. Temperature data from the receivers suggest a potential spawning window from early September to early October. The analysis provides information that can be used to identify other potential spawning areas throughout the lake.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Seasonal Movement Dynamics by Burbot in Flaming Gorge Reservoir, UT-WY: An Invasive Fish Going the Distance.

Biological invasions alter food web dynamics and threaten ecosystem processes. To effectively mitigate impacts on sport fisheries and native fishes, it is critical to understand and account for the population dynamics of invasive species. Flaming Gorge Reservoir supports trophy sport fisheries in Utah and Wyoming and provides habitat for imperiled, native fishes. However, the recent illegal introduction of burbot (*Lota lota*) to the Green River threatens to impact fish assemblages throughout the drainage, and particularly in Flaming Gorge Reservoir where the population has rapidly expanded. We used acoustic telemetry to measure seasonal movements of burbot associated with winter spawning and identify sources of recruitment within Flaming Gorge Reservoir. We tagged 31 large burbot (>600 mm) at 7 sites throughout the reservoir during November 2012, and relocated 17 fish during January-February 2013. All relocated burbot tagged in the northern portion of the reservoir were found more than 4 miles from their original capture location, while 50% of the relocated burbot tagged in the southern portion of the reservoir remained close to where they were originally tagged. Most burbot moved up-reservoir, and fish that were relocated in the Inflow region began returning to the lower reservoir during February. The greatest distance moved by an individual was 64.4 km, but movements of 24.1 km were common. Furthermore, burbot are able to move rapidly throughout the reservoir, as demonstrated by 2 individuals that moved, on average, over 6.4 km in 24 hours. This rapid movement ability thus facilitates their likely expansion to any available habitat. Preliminary evaluation of movement data indicates that the Blacks Fork and Green rivers, and Linwood Bay, serve as important spawning locations for burbot in Flaming Gorge Reservoir. The presence of both resident and adfluvial life-history expressions in burbot in Flaming Gorge Reservoir will require that management of this invasive predator address multiple sources of recruitment to successfully mitigate impacts to valuable sport fisheries and raises important questions about the potential for large burbot moving out of the reservoir to impact native fishes in the Green River drainage.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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The effects of hypolimnetic oxygenation on the diets of Brook trout (Salvelinus fontinalis) and Rainbow trout (*Oncorhynchus mykiss*) in Twin Lakes, Washington

A temperature/dissolved oxygen "habitat squeeze" is a common problem impacting cold-water fisheries in deep, eutrophic lake systems. A habitat squeeze may increase competition, reduce access to food sources, increase physiological stress, reduce fecundity, and generally negatively impact fish. Hypolimnetic oxygenation (HO) is an increasingly popular management tool that may be applied to address the temp/DO squeeze. HO has been shown to increase available habitat, and our previous studies have demonstrated that fish respond rapidly to utilize that habitat. However, long-term fishery benefits and even basic ecological impacts of HO have not truly been documented in a comprehensive manner. Our study assesses the effects of HO on diet of rainbow trout and brook trout in Twin Lakes, Washington. Trout diets from treated North Twin Lake and untreated South Twin Lake are compared with gut content analysis as percent biomass and relative gut weight, a measure of stomach fullness. Additionally, we compared 2012 trout diet with trout diet from both lakes in 2005 prior to installation of the HO system. While preliminary results do not indicate a clear difference in trout diet between lakes and years, we anticipate observing a difference between treated North Twin and untreated South Twin in August and September when summer stratification is most developed and anoxia is well established in the hypolimnion of South Twin.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Large-scale lake trout removal in Lake Pend Oreille, ID to benefit a kokanee fishery

The nonnative lake trout Salvelinus namaycush population in Lake Pend Oreille, Idaho increased exponentially from 1999-2006. The increased abundance of lake trout, combined with already established populations of rainbow trout *Oncorhynchus mykiss* and bull trout Salvelinus confluentus, led to an unsustainable level of predation on kokanee *Oncorhynchus nerka*. Lake trout establishment also posed a substantial risk to the native bull trout population. In response, an aggressive predator removal program was developed to target long-term suppression of the lake trout population and temporarily reduce rainbow trout abundance. This program was implemented in 2006, using both incentivized angling and contract netting (gill nets and deepwater trap nets). Since 2006, anglers have harvested 72,969 lake trout, while netting has removed 78,220 lake trout. Mark-recapture abundance estimates declined 65% from 2006-2008. Additionally, standardized trap net catch rates, which provide an index to adult abundance, declined 81% from 2006-2012. Juvenile lake trout (250-400 mm) were first targeted in 2008 and catch rates declined by 76% from 2008-2012. Kokanee biomass reached a record low in 2007, but has steadily increased and is now at the highest level since 1996. Major reductions in lake trout abundance have occurred and allowed a nearly collapsed kokanee population to rebound. Progress made towards reducing predation allowed management changes to be made in 2013, including re-opening a limited kokanee fishery (6 fish daily limit) that was closed in 2000.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Havoc at the base of the Lake Pend Oreille Food Web: the role of introduced mysids

Mysid shrimp were widely introduced in lakes of the pacific northwest in the mid 1960's as supplemental fish food to stimulate fisheries. As in many lakes that received mysids, significant changes resulted in the food web of Lake Pend Oreille (LPO). The diel vertical migration (DVM) by mysids in deep lakes represents a mechanism by which materials and nutrients are transferred from surficial to deep waters after which it becomes unavailable to fuel productivity in surface waters including food for planktivores. To understand the role of mysids in LPO, we designed experiments to quantify nutrients released by mysids during ascend, night time surface feeding, and descend in the water column. We also examined gut contents and calculated lake-wide impacts via predation. Nutrients excreted were similar during all stages of DVM, indicating mysids were not a net sink of nutrients via excretion. However, large lake-wide effects were estimated via predation. Mysids delayed the onset of high zooplankton densities in spring after stratification and resulted in their rapid disappearance in autumn after destratification. This limited the nutrients available in surface waters via excretion by zooplankton. Thus in LPO, mysids represent a bottleneck to epilimnetic productivity because of their raptorial predatory habits and diel vertical migrations. Restoration of ecosystems is difficult because no methods to eliminate mysids are known. Currently mysid densities in LPO have declined precipitously and it will be interesting to observe any cascading effects in the foodweb

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Exploring the potential for biological control of an explosive prey base by a suite of three predatory fishes in a high elevation, western reservoir

In western reservoirs, the rapid spread of introduced species into an already artificial species assemblage can alter trophic interactions in ways that can be difficult to predict, creating challenges for fisheries management. In Scofield Reservoir, Utah, the unintentional introduction of Utah chub and subsequent potential for a population explosion has prompted managers to shift the stocking program from exclusively rainbow trout, to include tiger trout and Bear Lake cutthroat trout as potential biological controls, as well as to enhance angling opportunities. However, unintended consequences of these introductions are likely, and could include reduced catch-per-unit-effort (CPUE) and condition in preferred sport fishes. We initiated a multi-faceted study consisting of field observations, theoretical comparisons of gape limitation, and bioenergetic simulations, to investigate interspecific interactions between the top predators and infer predator demand versus prey supply. Our results suggest that a substantial portion of chub outgrow the gape limit of trout predators; 16% of chub (those greater than 250 mm in length) are not susceptible to predation. Furthermore, stable isotope and diet analyses demonstrate considerable trophic niche overlap suggesting the potential for competition among these trout species is high. Large cutthroat and tiger trout occupy a top piscivorous trophic niche with both species consuming large amounts of prey fish throughout all age classes. In addition, the trophic niche space of rainbow trout overlaps considerably with Utah chub, with both species relying heavily on invertebrate consumption. Relative weight and Fulton's condition factor for all three species are all below average (100 and 1, respectively). Moreover, there is a significant decline of rainbow trout catch (CPUE) in recent years, which could potentially be due to competition for shared food resources and or the preferred littoral feeding space. Collectively, this research will aid managers in designing and implementing the best stocking strategy to optimize sport fish growth and survival, control chub, and, in turn, enhance and maintain angler satisfaction.

Lake and reservoir fisheries management: food web-based approaches (Dux)

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Are Wallowa Lake kokanee showing signs of resilience following large size and low abundance?

Kokanee exhibit density-dependent growth, therefore increased length at maturity may signal a declining population. Population crashes are often preceded by the recreational catch of unusually large fish, and influenced by interspecific competition with non-native species. Wallowa Lake hosts a self-sustaining kokanee population, non-native mysis shrimp and lake trout. Recently in 2009-10 a streak of four state-record kokanee were caught in eleven months, culminating with a new world record kokanee (9.6 lbs.). Concurrent surveys of the river-spawning aggregate indicated spawner lengths also reached historical highs. While positive for angler opportunity and local tourism, managers were concerned the record-size kokanee were indicative of a sudden population decline. Since 2008, kokanee abundance and size structure was monitored with hydroacoustic surveys and spawner surveys. Mysis shrimp densities were monitored annually with vertical tows. Lake trout information was obtained via gill netting in 2008 and 2011. Kokanee abundance was expected to decline during the study period. However, hydroacoustic surveys indicated a 10-fold increase in abundance since 2008 with a population comprised of mostly young fish. Mysis shrimp densities peaked during 2009-2010, and are currently at historically-observed lows. Lake trout appear to remain at low densities, but population characteristics remain largely unknown. The exact causal mechanism for the record-size kokanee remains undocumented, but may be related to a suite of stochastic environmental factors that resulted in low abundance and increased availability of mysis shrimp as a prey source. While recent abundance of young kokanee is a positive sign, the Wallowa Lake food web is in flux. Better understanding the lake's ecology and its introduced species will be imperative to formulating successful management strategies that optimize this unique resource.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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Lake Cascade Yellow Perch Fishery Restoration

Lake Cascade is an 11,300 surface ha USBOR reservoir located in west central mountains of Idaho. The reservoir was once considered a world-class yellow perch fishery and was Idaho's number one sport fishery in the 1980's. It supported 300,000 to 400,000 angler hours of fishing pressure annually. Angler catch rates declined through the mid 1990's and by 1997 there were virtually no yellow perch caught. Population investigations in 1998 revealed that age-0 and age-1 fish made up over 95% of all yellow perch present. Investigations into causes of the decline were conducted from 1998 through 2000. We examined both historic and present water quality conditions and reservoir water management patterns. We conducted studies examining dam entrainment, food abundance and fish diseases. None of the parameters examined revealed a cause for the decline. Northern pikeminnow predation on yellow perch was also investigated using historical population data, present population data, bioenergetics modeling and predator exclosure pens. Predation by northern pikeminnow on yellow perch became our focus of investigations and possible road to fishery recovery. Therefore, in 2003 the Department proposed draining the reservoir to facilitate total fishery reclamation, but this proposal was eventually rejected. The Department then developed the next best strategy for yellow perch recovery; that of stocking large numbers of yellow perch and mass removal of adult northern pikeminnow. The Department transplanted 850,000 adult yellow perch and removed thousands of adult northern pikeminnow from 2004 through 2006. Since 2006 we have observed dramatic changes in species composition, age structure and growth of fish in Lake Cascade. Angling pressure increased 2.5 times from 2003 to 2009 and continues to increase annually. The reservoir's sport fishing economics will be discussed in relation to these fish population changes.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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Using Community Based Social Marketing (CBSM) to foster conservation through fishing license sales: An application of the Theory of Planned Behavior

Angler recruitment and retention is critically important for conservation in New Hampshire, as it is nationwide. Using the Theory of Planned Behavior we attempt to better understand the factors which affect motivations for purchasing a fishing license in NH. Because lapsed anglers have different views, it is important to understand those differences when examining variables that affect their decision to purchase a license. Those differences were then used in the framework of Community Based Social Marketing to develop specific strategies for supporting conservation through license purchasing. Our data collection includes the administration of 14 interviews of key informants, four focus group discussions with anglers, and a survey sent to a random sample of NH anglers. The results will be presented along with recommendations for the implementation of social marketing strategies to our project partners, the New Hampshire Fish and Game Department and The Recreational Boating and Fishing Foundation.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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Deadwood Reservoir: A Joint Venture to Improve Idaho's Kokanee Fisheries

Idaho Department of Fish and Game has used Deadwood Reservoir as the primary trapping and spawning site for early run kokanee salmon *Oncorhynchus nerka* since 1988. Cooperative efforts by fisheries managers and hatchery staff have provided a successful and sustainable broodstock, which has had positive effects on kokanee fisheries statewide. Picket weirs have been used at various times in reservoir tributaries throughout the Deadwood basin to control kokanee escapement. Beginning in 2009, Chinook salmon were introduced to provide additional control of kokanee numbers. Controlling the kokanee population, and the associated density-dependent adult size, has direct impacts on individual fecundity and egg collection operations. Adult size, expressed as total length, has experienced substantial fluctuation. Management has succeeded in minimizing annual size variation. Over the past eight years, total length has ranged from 256 to 335 mm with an average of 287 mm. In twenty three years of operation, total annual egg take has varied with requests and availability from a low of 74,140 in 1996 to a high of over 6 million in 2006. Through collaborative efforts, the past six years alone have accounted for over forty two percent of the total number of kokanee eggs collected at Deadwood Reservoir. Fertilized, green kokanee eggs embark on an extensive journey from Deadwood Reservoir to Cabinet Gorge Hatchery for initial incubation, and later to Mackay Hatchery for additional rearing. Through 2009, eggs were shipped directly from the trap site to each facility. Cabinet Gorge displayed consistently better survival rates to the eyed egg stage, and began receiving all green egg shipments in 2010. Hatchery reared products from this run are distributed as fingerlings into fifteen waters in five regions from these two hatcheries. Ten of these fifteen waters appear on the 2011 Idaho Sport Fishing Economic Report as the most financially important waters in their respective counties

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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Management of a Primal Fishery in Alaska: Chatanika River Whitefish

The Chatanika River (near Fairbanks, Alaska) has large migratory spawning populations of both humpback whitefish (Coregonus pidschian) and least cisco (C. sardinella). Prior to 1997 the river supported a very popular fall whitefish spear sport fishery. In 1992 a management plan was developed which specified maximum harvest rates at varying levels of abundance. Harvest rates increased and the whitefish population decreased resulting in restrictions and finally a closure of the spear fishery from 1998 to 2009. The sport fishery remains closed to spear fishing gear; however a personal use spear fishery was opened in 2007. A limited number of permits have been issued each year for the spear fishery resulting in an increased, but sustainable harvest of Chatanika River whitefish.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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Angler demographics and use of community fishing ponds in the southwest region, Idaho.

A major component of community fisheries in southwestern Idaho has been the use of small ponds, often located within municipal parks. In 2010, IDFG stocked approximately 114,000 catchable rainbow trout into community ponds, which equates to 41% of the region's catchable-sized trout allocation. Given the substantial resources that are currently directed towards providing and managing fisheries in southwestern Idaho community ponds, there is a need to evaluate this program. A roving-roving creel survey was conducted at Settlers Pond in Meridian, McDevitt and Riverside ponds in Boise, and Merrill Pond in Eagle from May 2011-April 2012. A total of 248 angler counts were conducted on 62 different dates to estimate angler effort during the survey. In addition, a total of 665 angler interviews were conducted at the ponds to estimate catch and harvest rates as well as other demographic and social metrics. Annual angler effort varied greatly among ponds, ranging from an estimated 19,546 + 10,671 h expended at McDevitt Pond to 3,986 + 2,985 h at Merrill Pond. A total of 20,152 + 16,938 rainbow trout were caught at the four ponds, suggesting a very high use of stocked fish. The mean age of anglers and their dependents taking the survey was 30. Most anglers were male (87%). Approximately 86% of anglers were Caucasian, and the mean travel distance for anglers surveyed was 5.9 mi. Only 33% of anglers surveyed were fishing with children. Despite belief by many that community ponds were primarily visited by novice anglers or families looking for close and convenient recreational opportunities the pond was largely frequented by very experienced anglers. Average years of fishing experience was 27.3 years, and anglers estimated that on average they fished 66.3 days/year. Anglers also estimated that over half of the trips they take each year are to a community pond. Overall angler satisfaction with ponds appears to be good and the majority of anglers consider catching rather than harvesting to be more important. Over 63% of surveyed anglers supported reducing the daily bag limit of rainbow trout from 6 to 2 fish, if it resulted in improved fishing.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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Improving Return-to-Creel of Hatchery Catchable Rainbow Trout in Idaho: Statewide Exploitation Rates and Evaluating Rearing Density

Idaho Department of Fish and Game (IDFG) hatcheries are integral to managing coldwater sport fishing opportunities in Idaho. Current hatchery production capacity and funding are not increasing, while demand for hatchery catchable trout remains steady or is increasing. A comprehensive evaluation of hatchery catchable exploitation rates has been lacking. Given the current economic climate for IDFG hatchery funding, efforts must be made to ensure that hatchery programs remain efficient while producing a quality product for Idaho anglers. In 2011, IDFG released 33,359 non-reward Floy®-tagged hatchery rainbow trout across 49 water bodies statewide, including lakes, reservoirs, urban ponds, and rivers, as part of a multi-year evaluation of exploitation rates. In addition to exploitation, a portion of these releases were intended to evaluate return-to-creel rates of fish reared at high, medium, and low densities. The statewide average total length of catchable rainbow trout tagged was 257 ± 0.3 mm. Average harvest and total catch (harvested and released) for hatchery catchable rainbow trout across all evaluated waters was 18.7% (± 4.0%) and 26.0% (± 5.5%). Mean total catch of rainbow trout was significantly different across rearing densities and across rearing hatcheries. Hagerman and American Falls hatcheries had similar average total catch of catchable rainbow trout (21.5% and 23.6%) and were significantly different from Nampa Hatchery (13.5%). When looking at the relative differences between treatments, the total catch of low-density treatment fish was 21.6% higher than high-density fish, on average. However, the higher return-to-creel of fish raised at low densities is not sufficient to offset the reduced number of fish raised and stocked. Additionally, we evaluated returns-to-creel based on season-of-release as well as length-at-release. For all water body types combined, summer release groups had the highest catch rates (31.1%) followed by fall (27.4%) and then spring (22.2%). For fish length, from 200 mm to 305 mm there was roughly a 5% increase in catch rates for each 25 mm increase in length at tagging. Future work will further evaluate the relationship between length-at-release and catch rates, and explore rearing options that result in maximizing rearing cost/return to creel relationship.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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Using species manipulation to improve alpine sport fisheries

Brook trout (*Salvelinus fontinalis*) have been introduced widely outside of their native range and have helped to establish many valuable sport fisheries in alpine lakes of western North America, many of which were historically fishless. When conditions are favorable for natural recruitment, however, brook trout often experience overcrowding, with subsequent decreases in growth, average size, and condition. Angler interest in and exploitation of these "stunted" fisheries are also often reduced. South-central Utah's Boulder Mountain has a long-standing reputation for producing quality-sized and trophy brook trout in many of its lakes, but naturally recruiting brook trout have often made sustaining quality sport fisheries a challenge. Between 2001 and 2007, fertile brook trout were removed from fourteen of Boulder Mountain's lakes, ponds, and reservoirs and were replaced with sterile trout (hybrid tiger, hybrid splake, triploid brook), native cutthroat trout, or a combination of both. Post project sampling documented increases in mean and maximum trout length, as well as mean body condition, in all project waters. In addition, public feedback and observations of angler activity indicated that the improved fisheries were highly satisfactory and, in fact, had become some of the most popular waters on the mountain.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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The South Fork Snake River Yellowstone cutthroat trout story: active managment of a world class fishery

The South Fork Snake River is one of the most popular resident trout fisheries in the state of Idaho and is home to the strongest remaining fluvial population of Yellowstone cutthroat trout within the state's borders. The significance of this robust population is increasingly apparent when considered in context of the recent trends and threats that other populations are experiencing elsewhere within the subspecies' native range. While robust, the South Fork's Yellowstone cutthroat trout population faces substantial threats to their continued persistence, namely hybridization and competition with non-native rainbow trout, water withdrawals for irrigation or aquifer recharge, water management within a hydroelectric and irrigation storage system, new hydroelectric projects, and climate change. The Idaho Department of Fish and Game has employed a three-pronged management approach to conserve native cutthroat trout in the South Fork including spawning tributary hybridization curtailment, mainstem spring flow management, and angler harvest of rainbow trout and hybrids. Initiated in 2004, these efforts were started when a surging rainbow trout population equaled a declining cutthroat trout population for the first time. Population models have indicated management has successfully limited the rainbow trout population growth rate, while cutthroat trout numbers have increased. While angler harvest of rainbow trout and hybrids have been promoted and incentivized, adverse effects on angler catch rates or effort have not been realized. In fact, total trout abundance has reached near record high levels in both the 2011 and 2012 fall population surveys. Yellowstone cutthroat trout may be a conservation reliant species in the South Fork Snake River and many obstacles remain in their path for long-term population persistence. However, the river remains a vastly popular fishing destination where liberal fishing regulations and bag limits affords all types of anglers opportunity, and native Yellowstone cutthroat trout can be conserved at robust population levels.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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Patterns of catch and harvest of rainbow trout in Idaho community fishing ponds

Community fishing ponds are important recreational fishing resources in Idaho. Community fishing ponds continue to increase in popularity, as they offer a low cost alternative for fishing close to home. New ponds are created frequently as community parks are developed in rapidly urbanizing areas, requiring additional allocation of hatchery resources. Idaho has more than 50 community ponds across the state, receiving about 215,000 stocked catchable-sized (215 – 280 mm) rainbow trout annually. Taken together, community ponds account for 10% of the total rainbow trout stocked by the Idaho Department of Fish and Game (IDFG). In southwest Idaho, IDFG stocks catchable-sized rainbow trout in 23 different ponds. The goal of this study was to evaluate patterns of catch and harvest of rainbow trout in community ponds. These data will help to more efficiently allocate hatchery stocking resources and inform fisheries management decisions. In 2011, we released 3,815 tags to evaluated return-to-creel of stocked rainbow trout in 16 community ponds throughout the state, including four ponds in the Southwest Region. We collected returned tags for one complete year after each release event. Tagged fish were caught quickly after stocking, but the rate varied widely among ponds. Across all ponds statewide, the median and average days at large for tagged fish was 8 and 19 days, respectively. On average, total catch (release and harvest) for these community ponds was 36% and 25%, respectively. Estimated harvest for individual tag groups varied widely across ponds, ranging from 0% to 100%. For community ponds in southwest Idaho, intense fishing effort and high catch rates results in the majority of fish being caught in a short amount of time. In the four ponds evaluated in southwest Idaho, total catch (harvest and release) for these community ponds was 50% and 68%, respectively, with the median days at large being only four days. Using these results, fisheries management staff adopted a 2-trout, daily bag limit in four highly used community ponds in the region. This change is intended to spread harvest over a longer period of time, increasing the time stocked trout are available to anglers.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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A Comparison of Seasonal Movements of Rainbow Trout in a Lake Drainage versus a River Drainage and their Availability to Anglers

The Iliamna Lake drainage of southwest Alaska and the Susitna River drainage of southcentral Alaska support healthy wild rainbow trout populations. The Iliamna Lake drainage is largely comprised of the largest lake in Alaska, while the Susitna River drainage is largely comprised of a large turbid glacially fed river with few major lakes. Both drainages have many tributaries that support significant recreational fisheries for rainbow trout. These rainbow trout fisheries are managed by the Alaska Department of Fish and Game to maintain historic size composition and provide a diversity of angling opportunity through the special management designations and regulations. The Department conducted radio telemetry studies in each of these large drainages to assess rainbow trout seasonal movements. In the Iliamna Lake drainage post spawn rainbow trout captured at a weir on Lower Talarik Creek, a small tributary of Iliamna Lake, were radio tagged. Tracking of tagged fish indicated that fish migrated from the creek after spawning and predominantly spent the summer in Iliamna Lake before returning to the creek in the fall to feed on sockeye salmon spawn and stage for spawning the following spring. Some of these fish overwintered in small headwater lakes of the Lower Talarik Creek drainage, while others over wintered in Iliamna Lake. This research indicated that for the majority of the year the large sexually mature rainbow trout are not vulnerable to angling due to their use of Iliamna Lake during the summer and spawning season closures in the spring; however these fish do support a well known sport fishery at Lower Talarik Creek during the fall. In comparison, rainbow trout of the Susitna River drainage exclusively use riverine habitat. Rainbow trout tagged during the fall in four tributaries of the drainage generally spawned and spent the summer in clear water tributaries providing opportunity for recreational anglers. During the fall these fish moved to the larger Susitna River to overwinter and are generally not available to anglers.

Making Fishing Better – How fisheries management has improved the recreational angling experience (Garren)

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Managing Chinook Salmon Fisheries in the Clearwater River Drainage to Increase Angler Satisfaction

The primary management objective considering adult hatchery origin Chinook salmon *Oncorhynchus tshawytscha* returns to the Clearwater River drainage is meeting hatchery brood needs, followed by providing sport fisheries. With more than a decade of Chinook salmon returns adequate to establish sport fisheries in the Clearwater River drainage, management strategies have continually evolved. Initially, sport fisheries were structured to maximize harvest above brood needs while offering a diversity of angling opportunity. Now, more recently, sport fisheries are structured to meet angler satisfaction to the best of our ability. Management strategies have changed significantly in recent years by increasing communications with our constituents. Preseason public meetings typically in four or five communities averaging 50-75 total attendants is where we would gain input on how to structure sport fisheries. Recognizing the need to increase input from the public, we surveyed anglers in the field and through a mail survey increasing our input from the public by nearly 1,000 responses on how to structure Chinook salmon sport fisheries. Results from our surveys show the most important aspect to anglers when structuring a sport fishery is having long uninterrupted seasons accomplished by 1) reduced bag limits 2) reduced number of days fished per week 3) closing river section when necessary. On average, nearly 230 river miles of the Clearwater River drainage open each spring for Chinook fisheries. Returns from multiple release areas pass through numerous communities and fishing areas, which all want their chance at the available harvest. Providing equitable harvest allocation throughout the Clearwater drainage will continue to require adaptive management due to the dependence on seasonal return estimates. The overall result of our surveys is that by keeping the public involved and informed has shown to increased overall angler satisfaction.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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The interactions of climate and biotic factors on life history characteristics and vital rates of Yellowstone cutthroat trout in a headwater basin

Habitat degradation and introduction of non-native salmonids have caused substantial declines in abundance and distribution of Yellowstone cutthroat trout. Additionally, global climate change is expected to exacerbate current threats through changes to thermal regimes, hydrology, stream productivity, and distributions of non-native species. Understanding how factors such as climate and local stressors (e.g., non-native species) interact to affect Yellowstone cutthroat trout is critical for developing management strategies to enhance future persistence. However, research investigating relationships among these factors and life history characteristics and vital rates of Yellowstone cutthroat trout is lacking. To address this need, we examined the influences of temperature, streamflow, food availability, and presence of brook trout on life history characteristics of Yellowstone cutthroat trout in Spread Creek, Wyoming. We used passive integrated transponder (PIT) tags and a combination of stationary and mobile PIT tag antennae within a capture-recapture framework to monitor growth, movement, and survival of Yellowstone cutthroat trout and brook trout throughout the Spread Creek drainage. Considerable differences existed in frequencies of movements between species and among tributaries. Significant differences existed among growth rates of trout in three tributary streams. Preliminary results suggest the observed differences were driven by the complex interactions of streamflows, fish densities, and prey abundances, rather than stream temperatures. We discuss our results in the context of maintaining diversity of life-history patterns within watersheds as a means to increase metapopulation resiliency. Our findings provide critical information needed to refine climate risk assessments and to better direct limited resources to ensure the long term persistence of the subspecies.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Wildfire and the impacts of shifting stream temperature on salmonids

The frequency and duration of large wildfires in Western North America has increased by nearly four times over the last two decades. This dramatic increase could be driven by altered land-use, changes in patterns of precipitation, and increases in temperature. Under current IPCC climate scenarios, wildfire burn areas are predicted to increase by 78% - 118% over the next century, thus exacerbating our need to better understand how wildfire effects impacted ecosystems and vulnerable species. We examined the short term impact of wildfire on temperatures and steelhead/rainbow trout (*Oncorhynchus mykiss*) bioenergetics and distribution in a California coastal stream. After the wildfire, mean daily stream temperatures were elevated by up to 0.6°C in burned compared to unburned reaches. Among burned reaches, light flux explained over 86% of the variation in altered stream temperatures, and 76% of the variation in light flux was explained by proximity to burn damage. We estimated an average salmonid had to consume an additional 63.7 mg of prey (dry mass) over 48 days to offset the 4.0% (1.46 Kilojoules) increase in resting metabolic demand during the first post-fire summer. Presumably due to fish emigrating from warmer reaches, we found a significant negative relationship between the change in total salmonid biomass over the post-fire summer and the average energy costs (Kilojoules•g-1•day-1) within a burned reach. This study demonstrates that wildfire can drive short-term increases in stream temperature, with rapid consequences for imperiled fish.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Potential demographic responses to climate change in bull trout populations of different spatial configurations and life-history strategies

The life histories of coldwater fishes are adapted to local environmental conditions, which are likely to change as the result of climate-related shifts in stream temperature and hydrology. We used a spatially explicit life-cycle model to assess potential effects of climate-driven habitat loss and altered stream flow regimes on the dynamics of three bull trout populations with different life-history strategies. We predicted isotherm shift rates based on current stream warming trends in conjunction with channel slope and lapse rate. We then estimated the amount of spawning habitat loss as a result of predicted isotherm shifts over 25 years and evaluated the demographic response to potential changes in associated carrying capacity for each population. We also assessed the potential population-level effects of increased egg mortality resulting from more frequent winter high flow events. The predicted loss of spawning habitat ranged between 15 and 33% depending upon the distribution of spawning habitat in relation to elevation, channel slope, and the location of tributaries relative to the current temperature isotherm. Changes in carrying capacity estimates based on spawning habitat varied from 10 to 27%, resulting in higher extinction probabilities for the populations with the greater habitat loss. Increased egg mortality led to higher extinction probabilities for populations with a greater resident component compared with a population composed of mostly migratory individuals. This research demonstrates the potential variation among populations in response to climate-driven habitat loss and changes in vital rates, and underscores the importance of protecting stream connectivity and life-history diversity.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Upper Salmon Climate Change Vulnerability Assessment

Climate change may cause serious changes to hydrologic processes threatening National Forest System watersheds and the ecosystems they support. A warming climate could especially affect the distribution and abundance of Bull trout (Salvelinus confluentus) whose populations are strongly associated with well-connected cold water headwater habitat patches and good habitat condition. The Sawtooth National Forest completed a pilot watershed assessment that identified important water resources, assessed watershed sensitivity and climate change exposure, and evaluated the relative vulnerabilities of watersheds to climate change. Changes to base and peak flows were assessed using the Variable Infiltration Capacity (VIC) hydrologic model using Global Climate Model results based on A1B warming scenario for the 2040s and 2080s. Water temperatures changes were assessed using a non-spatial multiple regression stream temperature model developed by the Rocky Mountain Research Station using local climate, flow, and water temperature data. Impacts to fish habitat and bull trout were evaluated using Bayesian belief network models. The VIC model projects that risk from mid-winter peak flows triggered by rain-on-snow events increases from 0.88 days under current conditions (1977-97) to 4.44 days by 2080. The VIC model also projects that summer baseflows may decrease from current conditions by 29% in 2080. Temperature models predict that summer maximum weekly maximum water temperatures could increase by 2.5 oC in 2080 resulting in a substantial decrease (35%) in cold water habitat by 2080. Predictions do not seem promising for long-term bull trout persistence. However, predicted changes are not uniform across the Sawtooth NRA and some populations will persist better than others. Results should provide for refinement of Forest restoration efforts, regional recovery strategies, and allow more efficient allocation of limited resources.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Interspecies synchrony in salmonid densities associated with large-scale bioclimatic conditions in central Idaho: review and reality check

Abundance of lotic salmonids varies substantially through time but the extent to which several sympatric species respond coherently to large-scale bioclimatic conditions has been investigated rarely for freshwater fishes. In this presentation, we review our recent study based on a large-scale, long-term monitoring data set. We compared correlations in salmonid density in central Idaho and examined relationships between changes in salmonid density and variation in large-scale bioclimatic conditions, indexed by stream flow, air temperature, drought, coastal upwelling, and number of Chinook salmon redds (a surrogate for nutrient influx and therefore increased stream productivity). Average densities of six stream-dwelling salmonids were highly synchronous, with declines from the mid 1980s to the mid 1990s, followed by a rebound through 2003. Models based on data from 1985-2003 correctly predicted the synchronous declines in fish density observed for all species from 2004-2009, suggesting that the bioclimatic indices we chose were useful surrogates for large-scale factors influencing temporal changes in salmonid densities in central Idaho. This case study has several lessons for efforts to link climate changes with fish population responses. First, fish abundance is inherently noisy and is typically influenced by a multitude of factors, thus a large-scale, long-term data set is required to detect a coherent signal from general monitoring data. Local factors will mask regional bioclimatic influences on fish populations at smaller scales. Second, a multi-species, multi-variable approach should increase power because the problem is inherently multivariate in nature. Third, more specific studies will be most useful if they can relate their findings to large-scale general monitoring data sets (such as presented here) to connect local ecological scales to the much larger climatological scale.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Seasonal Variation in the Bioenergetic Cost of Migration in Snake River Spring/Summer Chinook Salmon and Potential Selection for Earlier Migration in Response to Climate Change

Life-history diversity contributes substantially to resilience in the face of environmental variability. In salmon, variation in migration and spawn timing play a crucial role in regional biocomplexity. Salmon migrate up the Columbia River to spawning grounds every month of the year. Individual populations, however, have very restricted migration timing, reflecting local adaptation to diverse constraints associated with specific spawning grounds. I here explore how the bioenergetic cost of migration plus holding near the spawning grounds varies with migration date for particular populations. Detailed records of individual migration times and energy usage through dams and reservoirs provide a very rich picture of these costs. I test the hypothesis that current migration timing reflects the optimal timing predicted by bioenergetic constraints and thermal tolerances. I assess how changing hydrological conditions with global warming will shift the optimal phenology. By incorporating potential evolutionary and plastic responses to this shift in optimal phenology into population-specific life cycle models, I assess the impact of climate change on the diversity of life histories currently exhibited in the Columbia River Basin.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Rangewide vulnerability assessment for bull trout

Bull trout is one of the most cold-adapted species in freshwater in North America. The species is listed as threatened under the U.S. Endangered Species Act throughout its range within the contiguous United States. We are currently implementing a rangewide vulnerability assessment to conduct an analysis of threats from climate and non-climate factors, expressed as the independent or interactive influences of these factors on probability of persistence of local populations. The steps involved include mapping suitable habitat "patches" across the species' range with predicted stream temperatures from the NorWeST project, attributing patches with information on local and climate related threats, and modeling persistence of bull trout in relation to these threats. Our goal is to provide a quantitative and unified approach to evaluating threats from local and climate related factors, with upgradeable databases and models to provide decision support for climate adaptation and species recovery.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Predicting the impacts of climate change on river fish distributions using a space-for-time substitution

Climate change has already produced substantial changes in the geographic distribution of species, and future warming is likely to produce even greater range shifts. To keep pace with this warming, river fishes will need to shift their distribution upstream to remain within thermally suitable habitat. To date, there have been no studies documenting upstream range shifts in stream fish assemblages. A troubling explanation for the absence of documented range shifts in river fishes may be that moving upstream to track thermally suitable habitat requires moving to areas with unsuitable physical habitat. The decoupling of thermal and physical habitat may be especially acute at boundaries, such as the transition zones of mountain ranges. We present preliminary results from a space-for-time substitution to examine how well river fishes may track climate change, and we identify factors that may limit range expansions.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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The NorWeST Regional Stream Temperature Database and Model for High-Resolution Climate Vulnerability Assessments

Anthropogenic climate change is warming the Earth's rivers and streams and will have profound consequences for aquatic biotas this century. Effective resource stewardship will require unprecedented levels of interagency coordination and development of datasets and models for accurate downscaling of climate change effects to important habitat parameters and species distributions at local scales. Many broad-scale bioclimatic assessments have been done for salmon and trout in the Rocky Mountains but most rely on imprecise surrogates for stream temperature such as air temperature or elevation. Here, we report on a project funded by the Great Northern Landscape Conservation Cooperative to develop a comprehensive interagency stream temperature database and model for all streams across the Northwest U.S. (~350,000 stream kilometers). The NorWeST database consists of stream temperature data contributed by > 60 state, federal, tribal, and private resource agencies across Oregon, Washington, Idaho, Montana, and Wyoming. NorWeST may be the world's largest database of its kind; consisting of >45,000,000 hourly temperature recordings and >45,000 summers of monitoring effort at >15,000 unique stream sites. These data are being used with a new type of spatial statistical model for stream networks to develop accurate, regionally consistent sets of stream temperature climate scenarios at 1 km resolution. More than 13,000 summers of data across 80,000 stream kilometers in northern Idaho and northwest Montana have so far been modeled with good accuracy (R^2 = 90%; RMSE < 1 ˚C). The temperature data and stream climate scenarios from this project are available as ArcMap geospatial products for download through the NorWeST website. A series of related projects are being developed that use NorWeST spatial data, including: 1) biological vulnerability assessments, 2) definition of species' thermal niches, 3) improvement of bioclimatic models, 4) development of decision support tools, and 5) refinement of temperature and biological monitoring programs.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Estimating Thermal Regimes of Bull Trout and Assessing the Potential Effects of Climate Warming on Critical Habitats

Understanding the vulnerability of aquatic species and habitats under climate change is critical for conservation and management of freshwater systems. Climate warming is predicted to increase water temperatures in freshwater ecosystems worldwide, yet few studies have developed spatially explicit modeling tools for understanding the potential impacts. We parameterized a non-spatial model, a spatial flow-routed model, and a spatial hierarchical model to predict August stream temperatures (22 m resolution) throughout the Flathead River Basin, USA and Canada. Model comparisons showed that the spatial models performed significantly better than the non-spatial model, explaining the spatial autocorrelation found between sites. The spatial hierarchical model explained 82% of the variation in summer mean (August) stream temperatures and was used to estimate thermal regimes for threatened bull trout (*Salvelinus confluentus*) habitats, one of the most thermally sensitive coldwater species in western North America. The model estimated summer thermal regimes of spawning and rearing (SR) habitats at temperatures <13°C and foraging, migrating and overwintering (FMO) habitats <14°C. To illustrate the useful application of such a model, climate warming scenarios were simulated to quantify potential loss of critical habitats under forecasted climatic conditions. As air and water temperatures continue to increase, our model simulations show that lower portions of the Flathead River Basin drainage (FMO habitat) may become thermally unsuitable and headwater streams (SR) may become isolated due to increasing thermal fragmentation during summer. Importantly, spatially explicit models such as the one here can be used to conduct vulnerability assessments to identify populations and habitats at risk; develop monitoring and evaluation programs; inform future research and conservation needs; and develop adaptation strategies in response to or in anticipation of climatic changes and other important cumulative stressors (e.g., habitat loss and invasive species).

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Adult Pacific salmonids in hot water: behavior and survival studies from the Columbia River basin

Rising temperatures and water management practices in western North America have decreased the extent of anadromous salmonid freshwater habitat. Earlier spring warming, later fall cooling and higher mean and maximum temperatures affect salmonids at multiple scales, from individual fish behavior to fitness effects on regional populations. From 1996-2012, we conducted a series of radiotelemetry and archival tag studies of adult Chinook salmon, sockeye salmon, and steelhead in the Columbia and Willamette rivers and their major tributaries. We have used thousands of reconstructed migration histories to investigate relationships among water temperatures, adult migration behaviors, and survival to spawning at several spatial scales. In the lower Columbia River migration corridor, many tagged adults behaviorally thermoregulated during the warmest periods, using non-natal cool-water tributaries as refugia from the warm main stem Columbia River. Threshold temperatures of 19-21°C prompted extensive refugia use, with some fish (especially steelhead) holding for several weeks or more. Thermal refugia along adult migration corridors likely provide a mix of physiological and energetic benefits, and these small, patchily-distributed sites appear to be critical temporary habitats for many migrants. However, dense fish concentrations at refugia sites attract intensive fisheries and refugia use has resulted in lower migration survival for some populations. In several studies, we have found links between elevated prespawn mortality and high water temperature exposure during migration and near spawning areas. Negative temperature effects have typically been most severe for fish with additional risk factors, including poor physical condition, disease or parasite loading, high spawner density, and/or summer or fall migration timing. Importantly, entire study populations had high prespawn mortality rates in some years. Annual estimates exceeded 55% for endangered Snake River sockeye salmon and have been >80% for threatened spring-run (Middle Fork Willamette River, Oregon) and summer-run (South Fork Salmon River, Idaho) Chinook salmon. Our combined results highlight both the vulnerability and adaptability of adult salmonids to warming freshwater environments. They also demonstrate the importance of understanding among-population differences, effects of refugia use on vulnerability to fisheries, and a need to further investigate interactions among water temperature, behavior, physiology, pathogens, and other mortality risk factors in adult migrants.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Moving from climate change awareness to action: Case studies in vulnerability assessments and adaptation planning

Climate change is the most pressing challenge of our time, yet we continue to make management decisions that ignore its implications. Projected changes are likely to result in myriad impacts to species, habitats and physical processes. Current challenges (e.g., ongoing water resources conflict; residential development encroachment; and competing uses for federal lands) will only be exacerbated by climate change. Land managers and planners need to consider climate impacts on natural resources, communities, and social/economic values, and revise current practices in order to meet long-term goals. Vulnerability assessments and spatial analysis tools provide a path toward determining how species, habitats and services are threatened by climate change and improving management practice to better prepare for and respond to these changes. Yet understanding how managers and stakeholders use this new climate information in decision-making continues to be a challenge. I present several cases in which decision support tools and vulnerability assessments are employed to inform decision-making and the development of targeted climate adaptation actions, as well as lessons learned from these experiences. Two projects, one in California and another in Idaho are highlighted, in which we are working with U.S. Forest Service staff and regional stakeholders to use vulnerability assessments and spatial analysis tools to inform forest planning and other land management decisions (e.g. SWAP updates). Specifically, these projects involve: (1) assessing the vulnerability of selected terrestrial and aquatic resources to climate change, (2) using spatial analysis and expert input to prioritize conservation areas or actions, and (3) identifying implementable management responses to climate change. The project products will inform the Forest Plan Revision process and NEPA analysis for the plans, as well as support forest-level efforts to integrate climate change considerations under the Forest Service Climate Change Performance Scorecard. In the third case, I will highlight the different scales and approaches that were used to communicate downscaled climate information to diverse stakeholders in Washington, following the process of mapping vulnerability of watersheds in western Washington.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Using a multi-decade census to describe the ecological and evolutionary responses of several salmonids to climate warming

Salmonid fishes tend to be highly adapted and/or sensitive to local thermal regimes, suggesting that climate change will directly influence the ecology and evolution of these fish. Nevertheless, empirical studies of climate impacts on salmonid populations are rare, largely due to a paucity of data that can address this issue. As a case study of climate change impacts on salmonid fish we describe the long-term dynamics of multiple salmonid species in a rapidly warming stream in Southeast Alaska. Specifically, we describe long-term changes in several life history characteristics (migration timing, age structure, size, recruitment), associations between temperature and these characteristics, and evolutionary changes in a pink salmon population migrating into freshwater earlier than it did historically. We found consistent evidence for changes in migration timing and age structure across multiple species and life histories, but juvenile size and recruitment were stable over time. Although some trends or relationships with temperature were in the direction we would predict based on salmonid biology, many observations differed substantially from our expectations. Moreover, some of our observations were different than what has been observed in other locations, even within Alaska. Given this, we caution that predicting climate change impacts on salmonid populations may be extremely difficult. Importantly, there was strong evidence that a change in migration timing in a pink salmon population toward earlier dates of freshwater entry were due to rapid microevolution in response to natural selection. Also, the genetic diversity of this population has been quite stable over time. These later findings, coupled with the fact that all of the salmon populations in our study location are numerically stable, imply that these fish have some resiliency in the face of rapid temperature warming. Ultimately, protecting genetic and life history diversity within populations may be the best long-term conservation strategy given the variety and nature of observed responses to climate for multiple salmonid species at this location.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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A new demographic and genetic simulation framework for mapping population vulnerability of freshwater species in complex riverscapes

Accelerating climate change creates an urgent need to understand the influence of environmental variation and landscape features on the vulnerability of freshwater species. Here, we introduce a novel modeling framework for aquatic systems useful for evaluating population vulnerability in complex riverscapes by integrating spatially-explicit, individual-based, demographic and genetic (demogenetic) assessments with landscape and environmental variables. To show the utility of this framework, we simulated a hypothetical network of 19 populations of migratory bull trout (Salvelinus confluentus) using a riverscape connectivity and demogenetic model (CDFISH; Landguth et al. 2012). We assessed how stream resistance, a function of water temperature, might influence connectivity and hence demogenetic population vulnerability. We present both demographic metrics (abundance, immigration, and change in abundance) and genetic metrics (diversity, differentiation, and change in differentiation), and combine them into a single vulnerability index for identifying populations at risk. We considered four scenarios that illustrate the sensitivity of the six metrics and the combined vulnerability index: (1) maximum resistance as a function of high water temperatures throughout the network, (2) minimum resistance as a function of low water temperatures throughout the network, (3) increased resistance at a tributary junction caused by a partial barrier, and (4) complete isolation of a tributary, leaving resident individuals only. These simulations introduce a valuable new tool for assessing how stream resistance may affect genetic and demographic attributes of populations, thereby determining population viability. This demogenetic simulation framework, which is applicable to a wide variety of dendritic and fragmented stream systems, is illustrated in a web-based interactive mapping prototype (http://ptolemy.dbs.umt.edu/pvm/) and should be useful in guiding conservation and management efforts for freshwater species.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Tipping points to local extinction: the interactive effects of climate change, land-use and invasive species on stream-rearing salmon

Global climate change has already resulted in observable changes in the thermal regimes of many streams in the western United States, and forecasts of further warming will likely result in significant losses of cold-water salmon habitat over the next century. Predatory warm-water bass have also been introduced into many salmon streams and their range is likely to expand as streams warm, presenting an additional challenge to the persistence of salmon. In this study we intersected global climate forecasts with a high-resolution water temperature model to predict end-of-century stream temperatures in several streams in the Columbia River basin; we compared one stream that is already considered thermally impaired due to the loss of riparian vegetation and another that is cooler and has a largely intact riparian corridor. Using the forecasted stream temperatures in conjunction with fish-temperature models we predicted how subyearling Chinook salmon and bass distributions would change as each stream warmed. In the highly modified stream, end-of-century warming is forecast to result in the almost total loss of Chinook salmon rearing habitat and a complete inundation of bass into the upper watershed. In the less modified stream bass were thermally restricted from the upstream-most areas. In both systems, increases in temperature resulted in a much higher degree of overlap between subyearling Chinook salmon and bass in the early summer (from 23 km in 2009 to 40-62 km in 2080) and increased the predicted abundance of bass within the streams. We also evaluated the ability of a variety of spatially-explicit riparian restoration scenarios to reduce end-of-century stream temperatures and thus restrict the range expansion of bass while increasing Chinook salmon rearing habitat. We found that prioritized restoration could prevent the extirpation of Chinook salmon from the more altered stream, and could also restrict bass from occupying the upper 26 km of salmon rearing habitat found there. This information is critical to prioritize climate-change adaptation strategies now, before the predicted warming has occurred, and before salmonids are forced to cope with both warmer water and greater overlap with non-native predators.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Are Fish Distributions Changing as Predicted with Stream Warming in the Bitterroot River Basin, MT?

Climate trends apparent across the Rocky Mountain region include warmer air temperatures, earlier dates for peak snowmelt, and more winter precipitation coming as rain. These factors often result in low summertime base flows and warmer summertime water temperatures. Additionally, wildfires in the western U.S. have been more pervasive in recent years and climate change is expected to increase their severity and frequency, further affecting aquatic systems. Stream temperatures in tributaries within the Bitterroot River Basin have shown general warming trends over the last several decades with stream temperatures increasing 0.2 to 0.3 ^{o}C. In addition, a complex of wildfire burned 22% of the Bitterroot National Forest during the summer of 2000. Some watersheds had severe fires in the riparian zone resulting in maximum water temperatures that have been elevated 1.5 to 2.0 ^{o}C over reference streams for the last decade. In 2010 and 2011, we replicated sampling protocols at 77 sites in tributaries of the East Fork Bitterroot River which had been previously sampled in 1993-1995 by Rich et al. (2003) to investigate differences in the occurrence of bull trout (*Salvelinus confluentus*) associated with these changes in water temperatures. Using Program Presence, we estimated changes in bull trout occupancy between time periods considering large woody debris (LWD), stream width, gradient, temperature, and fire as covariates. Site-level extirpation rates were unrelated to LWD, width, and gradient but greater at warmer, low elevation sites. Persistence was not substantially influenced by wildfire. It is likely that occupancy of other species are changing as well and to broaden our understanding of how fish assemblages are changing in this system, we aggregated existing agency monitoring data and revisited sites to examine changes in the broader fish community across this time period. We relate occupancy to relative temperature and the presence of wildfire to explore how dispersal capabilities might influence fish responses to these broad landscape changes.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Validation of the VIC model for streamflow metrics on western U.S. streams

The ungauged basin problem is a persistent problem in the field of hydrology. Despite this well-known overarching issue, hydrologic science has largely proceeded by building new models recalibrated to individual basins, frequently losing sight of the fact that the interest is in times and places outside of the time and place being calibrated. Testing whether a model calibrated for one basin can be applied elsewhere and else-when requires comparing the model results to measurements across a several watersheds without local validation. Even more broadly, considering the complexity and differential temporal sensitivity of different model components (e.g. snowmelt, evapotranspiration, spatial precipitation), there is an interest in understanding which kinds of output metrics or summaries from a model are universally applicable and in which kinds of places the model reproduces most metrics with low error. Large scale land-surface models are well suited to this kind of learning from modeling because they can model relatively large areas with ease creating the potential to validate across a broad range of watersheds based on a minimal degree of calibration to larger basins. We compared outputs of the VIC model across the Pacific Northwest United States to streamflow data from 55 USGS gaging stations. We validated model predictions against both streamflow summarized at daily and monthly time scales as well as several seasonal to annual scale metrics related to aquatic habitat quality. While there were many streams where streamflows were well reproduced, basins with high baseflow indices indicative of large groundwater interactions tended to be more poorly simulated for monthly timescale flows. Despite high absolute errors at some stations, the modeled interannual pattern of flows was strongly correlated to observations, suggesting some capacity to describe differential climate effects with the model. Several summary metrics were reasonably reproduced across most sites despite errors at finer timescales. Differences between stations of flows in summer months tended to be more poorly simulated than other metrics. Center of timing estimates showed a systematic bias that appears to be related to the snowmelt modeling, with high elevation sites being modeled with earlier runoff and low elevation sites with late runoff. Our results indicate that it is possible to use VIC to accurately predict several ecologically relevant hydrologic metrics for entire stream networks, making it a useful tool for evaluating effects of climatic variations on aquatic species.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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River temperature and hydrology scenarios for the Pacific Northwest

Changes in streamflow and temperature associated with climate change are anticipated to increasingly affect aquatic species throughout the coming century. Managers, agencies and stakeholder groups require appropriate, up-to-date, and consistently-applied data in order to assess the relative impacts both within and among watersheds. We describe two projects that were developed to address these needs. The first is the Columbia Basin Climate Change Scenarios Project (CBCCSP; Hamlet et al., 2013), a comprehensive suite of hydro-climatic projections developed for the Pacific Northwest U.S. (PNW). The gridded database is web-accessible and includes detailed water balance summaries and streamflow data for 297 river locations. The second project we describe is a recent effort to simulate stream temperatures (and projected changes) for the PNW (Wu et al., 2012). The model uses a mechanistic approach, simulating the energy balance for the stream network, using gridded streamflow and temperature projections as input. In the proposed talk, we provide an overview of key results from these two projects – including projected changes in flow extremes (Q100, 7Q10) and projected changes in temperature for the region – as well as information on how the data can be obtained.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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High Resolution Geospatial Stream Temperature Data for the Northwest U.S., A Users Guide for the NorWeST Regional Database and Model

A collaborative group from the U.S. Forest Service-Boise Aquatic Sciences Lab, Trout Unlimited, CSIRO, NOAA, and USGS, is developing a regional stream temperature model (NorWeST) and consistent set of high-resolution climate scenarios for vulnerability assessments across the northwestern U.S. The project area covers portions of eight states from the Pacific Coast of Washington and Oregon, eastward through Wyoming and central Montana. In 2006, researchers at the Boise Lab began exploring the use of spatial statistical techniques for use with stream networks and interagency temperature datasets, with the goal of developing models for accurately predicting stream temperatures at landscape scales. A modeling process has been devised that incorporates a host of data inputs including recorded stream temperatures, GIS-based spatial covariates from nationally available layers, and climate variables. These multivariate inputs are processed through a spatial statistical model that incorporates stream network topology to generate summary temperature predictions. NHDPlus stream lines at 1:100,000 scale are segmented into 1 km intervals and attributed with the modeled stream temperatures for distribution to the public. In addition, these stream lines are aggregated into thermal habitat patches for juvenile bull trout rearing suitability. To develop the model, observed stream temperature data were acquired from approximately 60 cooperating agencies consisting of more than 45,000,000 hourly temperature recordings, at over 15,000 unique stream sites. Accurate stream temperature models (r^2 ~ 90%; average prediction error < 1 ˚C) are being developed from these data and used to generate climate scenario maps of mean August temperatures at 1 km spatial resolution across the project area. A variety of derived stream temperature products may be downloaded from the NorWeST website (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html) including: stream network shapefiles with mean August modeled temperatures, PDF format maps, point shapefiles of the observed temperature locations, and tables containing daily August summaries of the observed temperature data. This paper will present a brief history of the project, provide a summary and justification for the model inputs, describe potential uses for the data, and offer an overview of the NorWeST website for downloading the data.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Improved grazing practices and stream reconnection restore riparian habitat and build trout resiliency in a Nevada watershed

With so much private land encompassing trout habitats in the West (e.g., 50% of the historic distribution of Lahontan cutthroat trout is on private lands), promoting positive change with private landowners and the ranching community is essential if we are to improve the conservation status of western native trout and increase resiliency to climate change at landscape scales. We detail progress on a long-term collaborative grazing restoration and reconnection effort in Maggie Creek, NV benefiting the federally-listed Lahontan cutthroat trout (LCT). Restoration in this watershed was initiated in 1993 by a suite of partners, including BLM, Newmont Mines, Inc., and several mine-owned and private ranches. Habitat restoration has focused primarily on implementing a combination of seeding, grazing rest and strategic rotational grazing schemes. Additionally, in 2005 the three primary tributaries housing LCT were physically reconnected via culvert remediation and an irrigation diversion structure on the mainstem creek was reconstructed to enable LCT dispersal throughout the watershed. Riparian habitat has improved dramatically both in extent and quality based on remote sensing and BLM measurements of metrics such as pool quality, amount of woody riparian vegetation and width to depth ratios. An influx of beavers has had substantial effects on the system; for instance, the number of beaver dams more than doubled in a recent assessment from 2006-2010, adding nine miles of additional ponding. One of Newmont Mine's shallow monitoring wells in lower Maggie Creek has shown a two foot rise in groundwater over the course of the partnership. Since 2001 Trout Unlimited has monitored LCT at 44 sites in the three tributaries; data suggest populations are responding positively to the habitat improvements and restored connectivity, with a steady increase since 2005 in the number of age 1+ fish along with an improved age distribution, even in drought years. This project demonstrates the value of collaborative monitoring to document habitat improvements and trout responses to restoration efforts, and suggests that encouraging 'conservation ranching' and ameliorating fragmentation at larger scales could dramatically improve the resiliency of LCT to climate change.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Colorado River cutthroat trout habitat resistance and resilience to climate change

Colorado River cutthroat trout, *Oncorhyncus clarki pleuriticus*, occupy less than 12% of their historic range. Restoration and conservation of this species is currently under way across the Upper Colorado River basin, but guidance to inform management decisions related to the impacts of climate change is lacking. Shifts in the thermal distribution of freshwater fish have been documented, and will continue to occur as warming waters threaten cold-water habitat. Potential resistance and resilience to warming is determined using data from coupled air and water temperature loggers. These datasets provide insight into the effect that local air temperature has on stream temperature. Temperature loggers were deployed in the water, riparian zone and an upland location at 50 sites. Site selection was determined, employing a cluster analysis, from six habitat characteristics of each Colorado River cutthroat trout conservation population. These characteristics include solar input, elevation, watershed area, riparian vegetation, groundwater input and the 30 year mean maximum July air temperature. Results indicate that the relationship between air and water temperature in the Upper Colorado River basin is neither linear, nor one-to-one. Biweekly air-water temperature relationships (minus one anomalous site) fit very closely to the nonlinear relationship calculated from Mohensi's (1998, 2003) equation. Analysis shows that the median rise in daily maximum water temperatures is only 0.5°C to a 1.0°C increase in the median daily maximum air temperature. This indicates that there are characteristics beyond air temperature with a powerful influence on the temperature of streams. Additionally, there is variability in the air-water relationships across streams in the region. Analysis of habitat characteristics relative to these different air-water relationships will enable us to determine the characteristics of streams that are more or less resistant to increasing air temperature. This project involved the cooperation of the Forest Service, Park Service and Bureau of Land Management as well as state and private landholders. The results of this work will aid fisheries managers in Colorado River cutthroat trout restoration and conservation, allowing for the prioritization of projects in streams most buffered against climate change.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Jay Ver Hoef (NOAA National Marine Mammal Laboratory)

Tools for Spatial Statistical Modeling On Stream Networks: STARS & the SSN Package

Spatial statistical models are often applied to non-random, clustered data in terrestrial and marine systems because they provide unbiased parameter estimates and more accurate predictions when data exhibit spatial autocorrelation (e.g. violate the assumption of independence). However, in rivers and streams there is an extra complication because multi-scale processes, occurring within and between the aquatic and terrestrial environment, produce both Euclidean and in-stream patterns of spatial autocorrelation. Statisticians have developed sophisticated spatial statistical stream-network models that account for 1) spatial autocorrelation using both Euclidean and in-stream distance, 2) the branching structure of the network, and 3) directional flow. However, fitting these models to stream network data is challenging because it requires multidisciplinary skills in aquatic ecology/biology, geographic information science, and spatial statistics. This presentation will provide an overview of the geographic information system (GIS) and statistical tools that we have developed to allow users to 1) generate the data needed to represent spatial relationships in a stream network and 2) fit spatial statistical models to stream network data in R using the SpatialStreamNetwork (SSN) package.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Climate Change Research on the Copper River Delta: The Emerging Effect of Local Variation

The Copper River Delta, AK is the location of a collaborative research among between Pacific Northwest Research Station of the U.S. Forest Service, U.S.G.S. and several universities on the potential impacts of climate change on aquatic ecosystems. There were two areas of emphasis: (1) the timing of emergence of aquatic invertebrates in ponds across the entire Delta; and (2) variation in thermal regimes among streams and the associated salmon populations on the Delta. Work in 2010 showed a strong relation between the timing and emergence of aquatic invertebrates, primarily caddisflies and Odonates, and the nesting of rusty blackbirds and the fledging of their young. Warmer winters resulting from climate change could decouple the synchronization of these events and have consequences to the nesting success of the blackbirds and other bird species that depend on the invertebrates for food and energy during reproduction. The focus in 2011 was to better understand the potential variation in the timing of emergence of aquatic invertebrates across the entire Delta, which has a very strong temperature gradient. Preliminary results show that there is a wide variation in the timing of emergence of aquatic invertebrates – emergence was 3-5 weeks later on the cooler east Delta compared to the warmer west Delta. This suggests that the response of aquatic invertebrates to climate change will likely vary widely across the Delta, and that this local variation could mitigate the potential impacts on organisms dependent on aquatic invertebrates. We identified three general patterns of water temperature in streams on the Delta based the source of water. Groundwater systems had relatively constant temperatures across the year. Temperatures in stream dominated by surface water followed ambient air temperatures. Streams dominated by glacial flows were cooler than air temperatures in the summer but closely followed air temperatures during other times of the year. Spawning takes place later in the groundwater streams than the others because of the warmer winter water temperatures. Groundwater systems are also less likely to be impacted by climate change in the short term compared to the other stream types. Again, the variation in susceptibility could mitigate potential impacts on fish populations. The next phase of this work will examine the life-history and genetic diversity and characteristics of the eggs of the salmon populations in the different stream types to better understand the potential of the populations to adapt to climate change within given stream types and for populations from one stream type to move to another stream type.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Lee Benda (Earth Systems Institute)

NetMap and Climate Change: Assessing Vulnerability of Aquatic Ecosystems

The potential impacts of climate change on aquatic ecosystems are likely to be highly variable depending on the local setting and characteristics of a watershed. Availability of a web-based watershed analysis tool called NetMap provides an efficient means to conduct cursory vulnerability assessments of aquatic ecosystems with respect to climate change. For example, a warming climate can lead to increased wildfire occurrence and severity and thus landscape vulnerability assessments could target pre- and post-fire environments. Analyses would involve forest fuels, fire risk and severity, surface erosion, mass wasting, and sensitivity of aquatic habitats. Analysts search for overlaps among predicted high fire risk (including the impacts of altered climate), high erosion potential and sensitive stream reaches. Specific areas could then be targeted for actions to reduce impacts to water quality and aquatic resources. Use of digital watershed analysis tools, such as NetMap, to assess the vulnerability of aquatic ecosystems is economically efficient in an era of tightening budgets and reduced staff.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Incorporating Hydrology and Climate Data into Streamflow Management for Grayling in the Big Hole River Basin, Montana.

The upper Big Hole River Basin in southwest Montana provides habitat for the only confirmed, intact population of fluvial Arctic grayling in the lower 48 states. It also supports approximately 90,000 acres of grass hay and pasture irrigation. Efforts towards mitigating low flows and habitat degradation in the upper Big Hole River watershed have been ongoing since the inception of a program designed to address flow and habitat concerns for the potentially Federally-listed species. This program, Candidate Conservation Agreement with Assurances (CCAA), was implemented in 2006 by the U.S. Fish and Wildlife Service and three other partner agencies including the Montana Department Fish, Wildlife and Parks, the U.S. Natural Resource and Conservation Service, and the Montana Department of Natural Resources and Conservation. Improving flows and habitat for grayling while meeting the demands for water withdrawals provides unique challenges to State hydrologists and fisheries biologists charged with implementing the CCAA. Critical to these efforts is the ability to communicate the relevance of hydrologic, biologic, and climate data to the daily operations of ranchers, many whose families have ranched in the valley for over 100 years. Under the CCAA, participating landowners agree to reduce water withdrawals in response to low river flows. With a short growing season, the flexibility of the timing of their water use is limited and thus the ability to forecast and anticipate impending low flow conditions can be very helpful to these operators as well as natural resource managers. Snowpack and streamflow data compiled by several Federal Agencies provides an important data resource used to notify ranchers of potential drought conditions. An additional tool in development by Towler etal (publication forthcoming) presents a probabilistic risk-based framework that incorporates climate data into streamflow forecasting that can be useful for short term, and potentially long-term planning. This presentation emphasizes the challenges of incorporating hydrology and climate data into streamflow management for grayling in the Big Hole River Basin.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Potential influences of climate change on population dynamics of nonnative brook trout and native Yellowstone cutthroat trout in headwater stream networks

Potential effects of climate change on invasion, recruitment, and growth of nonnative brook trout and growth of native Yellowstone cutthroat trout were evaluated in the upper Shields River, a tributary to the Yellowstone River near Livingston, Montana. Invasion by brook trout increased during the past decade, which was one of the hottest and driest decades on record. We documented extremely high abundances of age-0 brook trout in 2012, when peak stream flows were extremely low. Passive integrated transponder tags were used to document movements and growth of brook and cutthroat trout during 2011 and 2012. Empirically estimated growth rates were similar to those predicted from laboratory-derived relationships between water temperature and growth (brook trout, McMahon et al. 2007; cutthroat trout, Bear et al. 2007) allowing evaluation of effects of climate change on different fishes by means of climate-stream temperature models. Cutthroat trout in a stream with few brook trout were primarily resident fish that exhibited little movement whereas more cutthroat trout exhibited migratory behavior in an adjacent stream that contained more brook trout. Because the pace of brook trout invasion has increased recently and very high age-0 recruitment was observed in 2012, urgent actions are probably needed to reduce or eliminate brook trout to conserve cutthroat trout in the upper Shields basin.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Dan Shively (USFWS)

Incorporating Climate Change Vulnerability into a Regional Aquatic Restoration Priorities Decision Support Tool

In partnership with the U.S. Fish and Wildlife Service, Ecotrust developed the Regional Aquatic Prioritization and Mapping Tool to support collaborative freshwater restoration planning efforts in Oregon, Washington, and Idaho. In an effort to include existing knowledge of climate change into conservation planning scenarios, we created a straightforward and easily updateable measure of sub-basin vulnerability to climate change to include in our decision support tool. We solicited guidance from regional climate change, hydrology, and fish experts to inform this approach. Based on their input and the availability of spatial data, we calculated the relative vulnerability of each sub-basin to the effects of climate change that would most directly impact freshwater habitat: water temperature, flow regime, and wildfire. We incorporated these measures, along with fish habitat, watershed condition and vulnerability to aquatic invasive species, into a dynamic, flexible tool that can produce and share a wide variety of prioritization approaches. Ecotrust is developing similar conservation planning tools for different geographies and partners, including the North Pacific Landscape Conservation Cooperative and BLM. These tools allow users to consider individual, watershed-summarized input data from the Climate Change Impacts Group, Scenarios Network for Alaska & Arctic Planning, and the USDA Forest Service. In this way users can consider an array potential climate change impacts in their conservation planning decisions. We will give an overview of the tools, focusing on the climate change component data and methods. We will also discuss future needs and potential datasets that could be very useful for forthcoming conservation planning efforts.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Daniel Isaak (USFS Rocky Mountain Research Station)

Developing regionally consistent thermal niche definitions through integration of massive fish and stream temperature databases

Aquatic organisms are adapted to specific ranges of water temperatures. Outside of this thermal niche, species suffer suboptimal metabolic performance, reduced growth and reproduction and population persistence. Accurate and geographically consistent descriptions of species' thermal niches are important for describing contemporary species distributions and projecting how these distributions may shift with the prospect of rising stream temperatures in coming decades. We are co-registering fish species occurrences from a massive regional survey database (> 10,000 unique sites) against stream temperature climate scenarios from the NorWeST temperature model to estimate the realized thermal niches of trout and other aquatic organisms in the Northern Rocky Mountains region. Important aspects of thermal niches associated with threshold (i.e., too warm, too cold) and optimal temperature are estimated via statistical analysis. We illustrate the approach using bull trout (*Salvelinus confluentus*) as an example, and compare results to previous efforts that relied on air temperature as a surrogate for stream temperature, as well as thermal requirements derived from laboratory studies. We also use the results to estimate the decline in suitable habitat for bull trout under climate change scenarios. The basic approach is generalizable to any aquatic species with the necessary georeferenced survey databases and efforts are underway to compile data for non-salmonid species.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Kevin McKelvey (Rocky Mountain Research Station, Missoula, MT)

Michael Schwartz (Rocky Mountain Research Station, Missoula, MT)

Daniel Isaak (Rocky Mountain Research Station, Boise, ID)

Broad-scale, high-resolution assessments of aquatic taxa: need and opportunity

Aquatic species are a national priority for conservation, and projections of future declines are spurring proposals for intensive management from supplementation to relocation. Validating that these declines are underway is a critical first step in assessing the effects of climate change, and existing databases from previous projects are the benchmarks for gauging changes in community composition and range shifts in species. Data sufficient for such assessments are widely available because a giant workforce of state, tribal, federal, university, and NGO biologists annually conducts routine sampling of many aquatic species. Organizing these data to make them broadly available, however, represents a major challenge in bioinformatics, as does reconciling differences among sampling methods and models and accounting for unsampled areas. Nevertheless, strategic data selection from waters undergoing rapid thermal changes or near species thermal boundaries may satisfy the most pressing needs. We also advocate building a biodiversity archive that relies on this broad professional network to provide a spatially comprehensive and thorough assessment of the biodiversity of fishes, mussels, crayfish, and amphibians. Such a sample analyzed with modern molecular techniques undertaken at an industrial scale could identify and map within-species conservation units (e.g., distinct population segments), delineate aquatic native species conservation areas, and likely discover several to many new species. Analyses of temporal trends would identify the species and locations undergoing rapid change, a biodiversity library would inform managers about what to save and where it is, and their combination would provide the foundation for action.

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

Panel - Agency perspectives on climate change and fisheries

Panelists: Phil Mote - CSC; Virgil Moore – IDFG; Michelle McClure – NOAA; Jason Vogel/Jay Hesse - Tribal perspective; Sean Finn – GNLCC; Scott Spaulding - USFS; Joe Adamski –BLM; Jack Williams – TU; Peter Anderson – TU; Helen Harrington – IDWR; National

New information regarding climate effects on aquatic resources in the western US: how do we use this stuff? (Isaak)

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Panel Discussion

In partnership with the U.S. Fish and Wildlife Service, Ecotrust developed the Regional Aquatic Prioritization and Mapping Tool to support collaborative freshwater restoration planning efforts in Oregon, Washington, and Idaho. In an effort to include existing knowledge of climate change into conservation planning scenarios, we created a straightforward and easily updateable measure of sub-basin vulnerability to climate change to include in our decision support tool. We solicited guidance from regional climate change, hydrology, and fish experts to inform this approach. Based on their input and the availability of spatial data, we calculated the relative vulnerability of each sub-basin to the effects of climate change that would most directly impact freshwater habitat: water temperature, flow regime, and wildfire. We incorporated these measures, along with fish habitat, watershed condition and vulnerability to aquatic invasive species, into a dynamic, flexible tool that can produce and share a wide variety of prioritization approaches. Ecotrust is developing similar conservation planning tools for different geographies and partners, including the North Pacific Landscape Conservation Cooperative and BLM. These tools allow users to consider individual, watershed-summarized input data from the Climate Change Impacts Group, Scenarios Network for Alaska & Arctic Planning, and the USDA Forest Service. In this way users can consider an array potential climate change impacts in their conservation planning decisions. We will give an overview of the tools, focusing on the climate change component data and methods. We will also discuss future needs and potential datasets that could be very useful for forthcoming conservation planning efforts.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (Mcllraith)

Sue Camp (Bureau of Reclamation) 1150 N. Curtis Boise, ID scamp@usbr.gov

Reclamation's Piece of the Pacific Lamprey Puzzle, Analysis of Project Effects and Ongoing Activities

Reclamation has completed an assessment of Reclamation Projects that may affect Pacific lamprey and continues to work collaboratively to resolve Reclamation's piece of the Columbia River Pacific lamprey puzzle. The assessment evaluated all Columbia River basin facilities but focused on the Yakima and Umatilla River Basins in Washington and Oregon, respectively. These rivers are tributaries to the Columbia River and provide spawning and rearing habitat for Pacific lamprey. Reclamation Projects in these basins typically consist of low-head diversions on the rivers as well as some storage reservoirs higher in the Yakima River basin. Possible effects were typically identified as either passage difficulties for upriver migrating adult lamprey, or possible entrainment of juvenile lamprey into diversions. Each individual facility was evaluated for site specific possible issues and data needs. Reclamation diversions in the Umatilla River all have adult lamprey passage facilities and we are evaluating passage efficiency. Diversions in the Yakima River are being evaluated for possible lamprey passage opportunities. Reclamation is also further evaluating the scope of juvenile entrainment into canals by conducting electrofishing surveys in the canals shortly following dewatering to determine prevalence of juvenile lamprey entrained. Furthermore, Reclamation is supporting agreements with the U.S. Fish and Wildlife Service to monitor adult migration in the Yakima Basin, with the U.S. Geological Survey to evaluate various screen materials for juvenile lamprey entrainment protection, and with the Yakama Nation and the Confederated Tribes of the Umatilla Indian Reservation for lamprey work in their respective river basins.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (McIlraith)

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Pacific lamprey passage at Columbia River dams: highlights from a 15-year data synthesis

We have conducted radiotelemetry and PIT-tag studies of adult Pacific lamprey (*Entosphenus tridentatus*) at Columbia River dams since 1997 and recently completed a synthesis that summarizes lamprey behavior, dam passage efficiency, and escapement data. The results have been used to develop a series of models to help with lamprey passage planning. More specifically, the models were designed to help prioritize investments in lamprey passage improvements at individual dams ('fishway bottleneck' models) and to prioritize investments among dams ('upriver escapement' models). These models allow users to predict the potential effects of passage improvements at specific fishway sites and assess the relative benefits of fishway improvements at a variety of spatial scales. The data synthesis indicated that full-dam passage efficiency by adult Pacific lamprey varies by a factor of two or more among lower Columbia River dams. Furthermore, there is up to a 10-fold difference in lamprey efficiency estimates among specific fishway entrances and the various routes used to pass the projects. Sites where lamprey chronically had difficulty moving upstream included fishway entrance areas, transitions between collection channels and fish ladders, and serpentine weir sections of fishways. Water velocity, turbulence, and the presence of predatory white sturgeon (Acipenser transmontanus) all were associated with lamprey passage rates. The bottleneck relief models indicated that the most effective locations for passage improvements differed among dams, and were largely a function of how many lamprey were present at each site and the proportion that turned around in each fishway segment. The upriver escapement models suggest that Bonneville Dam (the first main stem dam) should remain the highest priority site given the number of lamprey affected and relatively low dam passage efficiency (~ 50%). However, incremental improvements at multiple dams were also shown to provide significant upriver escapement benefits. Overall this approach will help direct conservation efforts across multiple hydroelectric projects. The synthesis report (University of Idaho Fish Ecology Research Lab Report # 2012-08) is available at:
http://www.cnr.uidaho.edu/uiferl/Reports.htm#Technical_Reports

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (McIlraith)

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Using High Throughput SNP Assays to Address Key Issues for the Conservation of Pacific Lamprey

Pacific lamprey (*Entosphenus tridentatus*) populations have been declining rapidly since the mid-1900s. This poorly understood anadromous fish requires a rapid response to mitigate for risk of extirpation in important regions of its natural distribution. Conservation management strategies currently being implemented include translocation/reintroduction, passage and habitat improvement, and research oriented use of artificial propagation. Better understanding of this species' life history and genetic diversity is required for efficient recovery efforts. We have utilized a dataset of paired-end restriction-site associated DNA sequences to develop 96 high throughput single nucleotide polymorphism (SNP) assays from a total of 4,439 quality filtered SNP loci that were identified in a previous genome scan. Four of these assays were developed because the SNPs were shown to be candidate adaptive markers which associated with geography, adult return-timing, and dwarf life history, and aligned with known genes using the genome browser available for sea lamprey. Two assays are diagnostic for two other lamprey species (Genus *Lampetra*) which are sympatric in the Columbia River Basin and are morphologically indistinguishable at early larval stages. The majority of SNP assays were chosen based on their informativeness for parentage analysis - i.e. putatively neutral with high minor allele frequency across the N.E. Pacific range. Here we demonstrate the power of these markers for parentage analysis, species identification, and characterizing associations of genes with life history and population structure. Further, we demonstrate ways they may address key conservation issues by 1) validating reproductive success of translocated adults, 2) documenting a recent natural reintroduction of 0-year larvae post-dam removal, 3) distinguishing genetic variants by their adult migration behavior, and 4) characterizing a remnant natural larval recruitment in the depauperate interior Snake River Basin. This study serves to underscore the value of a holistic genetic analysis that utilizes both adaptive and neutral markers, because the ability to address the scope of topics that we demonstrate with these lamprey markers would not otherwise have been possible.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (McIlraith)

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Evaluation of Pacific lamprey behavior in fishway environments of two Columbia River dams using Dual-Frequency Identification Sonar (DIDSON) acoustic imaging

Given the low passage rates of adult Pacific lamprey (*Entosphenus tridentatus*) at Columbia River dams, monitoring their migration behaviors at these dams is critical for identifying areas of difficult passage. From 2011-2012, we used Dual-Frequency Identification Sonar (DIDSON) acoustic imaging to observe lamprey passage behavior in fishway environments as part of efforts to identify sites and structural configurations that could be improved to increase lamprey attraction, passage, and collection at dams. In 2011, we used DIDSON to monitor an entraceway to a fish ladder and a junction pool within the fishway at Bonneville dam. Our goals were to characterize the vertical and lateral distribution of adult lamprey, the associations between lamprey and sturgeon activity, and the behavior of fish as they approached and entered the fishway entrance. For 2012, in addition to monitoring the two locations at Bonneville dam, we also evaluated lamprey passage and behavior at four locations within a fishway at John Day dam. Specific goals for the John Day monitoring were to qualitatively evaluate behavior in relation to a recently installed structure that would serve as a velocity refuge for lamprey (bollard field), quanitfy the vertical, lateral, and longitudinal distribution of lamprey, and to qualitatively assess behavior at a potential passage bottleneck (transition pool). Results from this study will help evaluate behavior and success at recent fishway modifications, provide insight on potential underlying mechanisms responsible for passage failures, and guide the design of future fishway modifications to improve lamprey passage.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (Mcllraith)

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Use of a recirculating culture system to investigate larval Pacific lamprey growth under four substrate treatments

Pacific lamprey (*Entosphenus tridentatus*) is of great cultural importance to Native Americans of the interior Columbia Basin. With declines in lamprey abundance, tribal treaty fisheries have been curtailed and a key component of tribal culture may be lost to future generations. While efforts to conserve lamprey are underway, alarmingly low adult returns to the upper Columbia and Snake rivers have prompted managers to investigate opportunities for lamprey culture. For this study, Pacific lamprey adults were collected in summer 2011 and held over winter at ambient water conditions. Eggs and milt were stripped from anaesthetized fish after they reached sexual maturity in early June 2012 (two females and three males). The eggs were incubated and newly-hatched larvae were housed in 10-L chambers with recirculating, UV-irradiated water at 14°C. Larval densities were maintained at 100 larvae/L under flow rates of 0.4 L/min. The larvae were fed a diet of commercially available algal cells and larval fish feed every other day for one month. Larval lamprey (ammocoete) growth and survival were compared for four treatment groups (five replicates each): no substrate, sand substrate, mud substrate, and filter floss. Lamprey growth was most rapid in mud and filter floss treatments, intermediate in sand, and poor in chambers with no substrate. These results indicate that Pacific lamprey eggs can be successfully incubated in recirculating culture systems and that larvae will feed and grow in high density cultures under recirculating conditions. Further, while difficult to maintain, mud substrates produced the most robust larvae. Lamprey were clearly stressed in conditions with no substrate and exhibited very poor growth. Hence, provision of appropriate substrate is clearly important for artificial propagation of Pacific lamprey ammocoetes.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (Mcllraith)

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Relationships between the Abundance of Pacific Lamprey in the Columbia River and Their Common Hosts in the Marine Environment

The returns of Pacific Lamprey *Entosphenus tridentatus* to the Columbia River over the past decade have declined significantly compared with the peak returns of the 1950s and 1960s, with no quantifiable mechanisms identified. To determine if the abundance of documented host species in the marine environment is related to adult returns of Pacific Lamprey, we examined stock assessment data, commercial fishery statistics, and counts of adult fish at Bonneville Dam between 1997 and 2010. Significant positive correlations were observed between lamprey returns and abundance indices of Pacific Hake *Merluccius productus*, Walleye Pollock *Theragra chalcogramma*, Pacific Cod *Gadus macrocephalus*, Chinook Salmon *Oncorhynchus tshawytscha*, and Pacific Herring *Clupea pallasii* throughout the U.S. Pacific Northwest. Commercial landings of these species in Washington and Oregon were also significantly and strongly correlated to lamprey returns, with the exception of Walleye Pollock. Several of these fisheries have demonstrated significant reductions in mean landings since the 1950s and 1960s, and adult lamprey returns have declined proportionally. We further examined large-scale and regional indices of oceanic productivity as a potential underlying mechanism. Multiple regression techniques indicated that host abundance was the principal factor in predicting lamprey returns, though inclusion of oceanic conditions increased the precision of the model. These results represent the first established relationship to recent trends of Pacific Lamprey returns to the Columbia River and indicate that spawning escapement is primarily a function of conditions experienced during the predatory phase of the life cycle.We hypothesize that Pacific Lamprey abundance in the Columbia River is cyclical in nature, but limited by availability of several host species over a potentially vast geographic range. Biologists and resource managers should reassess the relatively overlooked marine ecology of Pacific Lamprey.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (Mcllraith)

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Using the Juvenile Salmon Acoustic Telemetry (JSATS) system to evaluate adult Pacific lamprey movements and fate in Columbia River reservoirs.

Declining numbers of adult Pacific lamprey in the Columbia River basin highlight the need for a greater understanding of their movement and behavior. Substantial proportions of adult lamprey have been unaccounted for in the reservoirs of the lower Columbia River in past radio-telemetry studies. Radio tags are inadequate for monitoring overwintering behavior and movements in reservoirs due to limited battery life and detection range in deep water, respectively. We evaluated the effectiveness of a new acoustic telemetry system (Juvenile Salmon Acoustic Telemetry System [JSATS]) for monitoring the migration of JSATS-tagged adult Pacific lampreys in Bonneville reservoir using a stationary array of receivers during 2011-2012. We tagged 85 (2011) and 299 (2012) adult lampreys with JSAT tags at Bonneville Dam (rkm 235). Dam-to-dam escapement estimates were similar to estimates obtained using HD-PIT- or radio-telemetry in previous years. The majority (>80%) of tagged lamprey entering Bonneville Reservoir moved rapidly upstream through the upper sections of the reservoir as far as The Dalles Dam tailrace, indicating migration conditions and predation in the lower reservoir during the summer and fall did not strongly contribute to unaccounted losses and that overwintering likely does not occur below The Dalles Dam tailrace. Of the 299 lamprey tagged in 2012, 14% (n=42) were last detected within or at the mouths of monitored tributaries suggesting a significant number of unaccounted-for lamprey may enter the tributaries of lower Columbia River reservoirs in the summer and fall following tagging. An additional portion of unaccounted-for lamprey likely enter tributaries after overwintering in the reservoir. Of the 85 lamprey we tagged with JSATS transmitters in 2011, seven (8.2%) were subsequently detected in 2012. Five of these fish were last recorded in 2012 near the mouths of Bonneville Reservoir tributaries. The combined use of the three telemetry technologies is providing a more complete picture of the behavior, distribution and fate of the adult lamprey population migrating to the interior Columbia Basin.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (McIlraith)

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Habitat factors associated with the relative abundance and distribution of larval Pacific Lamprey in the Willamette River Basin

Addressing the ongoing, range-wide decline of Pacific lamprey *Entosphenus tridentatus* in western North America will require research and monitoring efforts directed at multiple life history stages. Recovery and conservation planning has identified numerous critical knowledge gaps for recovery, including information on distribution and habitat associations. The Willamette River Basin currently supports one of the few remaining harvestable Pacific lamprey populations and provides an excellent opportunity to make ecological inferences about the species across its range. Our objective was to identify critical larval lamprey (ammocoetes) rearing locations by estimating the relative abundance and assessing associated habitat features in the Willamette River Basin. In 2011-12, we sampled nine streams within sub-basins of the Willamette River, with each stream containing a lower, middle, and upper reach. Across both years of sampling, Pacific lamprey was collected from every stream sampled and in 26 of 28 reaches, but had varying catch-per unit-effort (CPUE) among reaches. Within streams surveyed, there was evidence of decreasing CPUE from downstream reaches to upstream reaches. Anthropogenic barriers appear to have constricted the distribution of larval Pacific lamprey in some areas of the Willamette Basin. Ammocoetes were positively associated with depositional areas containing deep, fine substrates, and particularly off-channel habitats (e.g., side channels, backwaters), where available. We also observed a positive association between Pacific and brook lamprey Lampetra spp., indicating similar habitat use among lamprey species. Our survey methods may be used to develop and refine a long-term monitoring program for Pacific lamprey ammocoetes. Our data will also allow managers to assess and prioritize management actions for conserving and recovering Pacific lamprey. Restoration actions that increase channel heterogeneity and recruit and retain fine sediments should benefit the ammocoete life history stage of Pacific lamprey.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (Mcllraith)

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Larval lamprey distribution and habitat use in mid-coastal watersheds in Oregon

In smaller rivers and streams, artificial migration barriers (e.g., culverts associated with road crossings) have substantially reduced habitat available to salmonids in Oregon coastal river basins. The effect of these types of barriers on Pacific lamprey populations has not been evaluated, in part because there is little information to describe their historical distribution and abundance. To address this, we are testing approaches to assess the longitudinal distribution and abundance of ammocoetes in streams where there are no known barriers to adult migration. Our specific objectives were to 1) estimate occupancy and detection probabilities of ammocoetes and 2) determine how their distribution and abundance are influenced by fish and habitat covariates at the habitat unit and reach scales. From August through October, 2012, we surveyed for Pacific and western brook lamprey ammocoetes in randomly selected reaches of several Oregon Coast watersheds. These included 8 reaches in the upper Smith River (Umpqua River basin), 7 in the West Fork Millicoma (Coos River basin), 4 in Wolf Creek (Siuslaw River basin) and 3 in the small coastal wilderness tributaries Cummins Creek and Rock Creek. In each reach, we sampled in three systematically spaced sites in which one pool and one fast-water channel unit were electrofished with a single pass. After the first pass, we conducted a habitat inventory of each channel unit. A subset of these channel units were revisited to determine occupancy and detection probabilities of ammocoetes. We sampled in reaches with mean wetted widths ranging from 2-20 m. Pacific and western brook lamprey ammocoetes were captured in all watersheds except for Cummins Creek and Rock Creek, respectively. Pacific lamprey ammocoetes were captured in channels with a mean wetted width as small as 4 m. These preliminary data suggest that artificially blocking access to even relatively small streams will adversely impact Pacific lamprey populations. We expect that our data will be used to develop criteria for habitat restoration and prioritizing barrier removal projects that benefit lamprey populations and to develop a standardized tool for monitoring management actions.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (Mcllraith)

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Adult Pacific Lamprey Translocation in the Snake Basin

The Nez Perce Tribe initiated an adult Pacific lamprey translocation effort in 2006, when adult lamprey were salvaged during winter fish-way dewatering operations at John Day Dam. These fish were held over winter, and the first release of 177 translocated adults into 4 Snake River tributaries occurred in spring 2007. To date a total of 800 adult lamprey have been translocated and released in 7 Snake River tributaries. This translocation initiative is in response to poor passage efficiencies at the 8 mainstem Columbia/Snake dams that these fish must pass en route to upstream Snake Basin spawning and rearing habitat. Essentially 50% of the adults attempting to pass individual fish ladders are not successful. The cumulative effect is devastating to fish destined for the Snake Basin, as demonstrated by extremely low counts of adult lamprey passing Lower Granite Dam, as well as the absence of lamprey from streams where they were once abundant. Adult translocation is being applied as a tool to thwart continued extirpation of lamprey from Snake Basin streams, until adequate mainstem passage is provided to support volitional migration. Summary information on translocation sites, post-released behavior, and evidence of production from translocated adults will be presented.

Pacific lamprey conservation and restoration: using data from the past, present, and future to better understand a complex critter (Mcllraith)

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Freshwater Migration and Spawning Activities of Adult Pacific Lamprey in the Willamette River Basin

With the rapid decline of Pacific lamprey (*Entosphenus tridentatus*) throughout its range, efforts have increased to fill critical knowledge gaps about its complex life cycle. The Willamette River appears to have one of the strongest remaining populations in the Columbia River Basin, and Willamette Falls is an important harvest site to many Native Americans. The goal of our study in the Willamette River Basin was to provide information that will facilitate recovery and conservation of Pacific lamprey. During 2009 – 2011, we collaborated with the Confederated Tribes of the Grand Ronde, Cramer Fish Sciences, and Normandeau Associates to track pre-spawning migration patterns of adult Pacific lamprey, using radio telemetry. These data indicated that 70% of adults remained in the mainstem, 14% migrated to the Santiam River, and 16% moved into the other 13 major tributaries. Cluster analysis resulted in nine distinct groups associated with net migration distance, tagging season, and migration profile (distance and direction traveled over time). Fish holding, or ceased migration behavior, in the mainstem was generally associated with increased water temperature, and this behavior occurred in habitats with large structures that provided cover. During spring of 2012, we conducted spawning surveys in three Willamette River sub-basins. Two segments were surveyed multiple times for each sub-basin, and we recorded numbers of adults and redds, geo-referenced spawning locations, and measured associated habitat attributes during each survey. Redd density varied among streams and segments within a stream, ranging from 17 – 165 redds * km-1. Spawning locations were along channel gradient breaks dominated by fine and coarse gravels, and cobble substrates, similar to findings of other studies. Overall, tagged adults had various spatial and temporal freshwater migration strategies and distributed themselves throughout the entire Willamette River Basin where anthropogenic barriers did not appear to limit access. Differences in spawning activity suggested suitable habitat may not be equally available within and among sub-basins and could also be related to barriers. Our research provided insight for this life history stage, but more effort is needed to address basin-wide access issues, monitor spawning activity, and analyze landscape-scale habitat attributes to aid recovery and conservation.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Multistock PBT recoveries in Chinook salmon ocean fisheries off California: a case study on the analytical developments required to make PBT useful to fisheries managers

In the past two years numerous studies have verified that parentage based tagging (PBT) with single nucleotide polymorphisms (SNPs) provides accurate and economical identification of the hatchery and cohort of origin for salmon sampled at any time in their life cycle. With these findings, PBT is positioned to become an important technology for tagging hatchery salmon and informing fisheries management. It is possible that PBT will displace coded wire tags (CWTs) as the dominant tagging technology for salmon. Before this occurs, fisheries managers will rightly want to know how the precision of estimates obtained from PBT will compare to those using CWT recoveries. For example, for a given level of tagging effort, how does the variance of a PBT-derived estimator of the contribution rate compare to a CWT-derived one? Or, how much extra information is gained by using genetic stock identification to identify the reporting unit of fish from populations that are not tagged by PBT? I will present analytical results for some of these questions and illustrate the consequences of the findings with an example taken from the Chinook salmon fishery off the coast of California.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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The Promise of Parentage Based Tagging for Evaluating Natural Fish Population Dynamics

Coded wire tags (CWT) have long been applied to harvest and hatchery operations. CWT data from previous years are compiled and used as input for models to forecast stock-by-age structure underlying fishery scenarios. While CWT allow exploitation metrics to be estimated, these metrics are at best an indirect, post-hoc representation of the natural and ESA-listed stocks about which we are actually concerned. Additionally, CWT are not used to manage catch or ESA impacts in-season. Parental Based Tagging (PBT) has been proposed as an alternative to CWT, and the method has been shown capable of providing facility and age identification. The potential 100% tagging rate of PBT affords some practical advantages over physical tags by lowering fishery sampling needs due do larger release groups. PBT also has capabilities different than physical tags, such as the heritability can be estimated for fitness related traits that may be affected by artificial propagation. Yet, PBT is fundamentally still using hatchery fish as a surrogate for natural fish. PBT could be used as a means to leverage data gathering efforts on wild fish. Examples of both basic operational enhancements and higher level life-history investigations are presented. The Battle Creek Restoration Project (Sacramento River – California) mediates access of target natural-origin species into restored habitat through a barrier weir. Yet, operationally, fish may evade barrier, the barrier is uncontrolled part of the migration season, and the three races of Chinook allowed access are not well identified by stock or origin. Incorporating PBT and population analysis into weir operations will allow monitoring the magnitude of undocumented passage and passage of mis-identified hatchery-origin Chinook. Beyond the mundane activities of fisheries management, PBT enables study of population dynamics and life-history for hatchery-origin and natural-origin fish spawning in-river. Application of genetic mark-recapture methods in the Coweeman River (Columbia River – WA) will elucidate juvenile life-history strategies (fry migrant and sub-yearling parr migrant life-histories by origin). The current management regime is based on hatchery fish because historically we have not been able to meaningfully track natural fish using physically tags. Having natural-origin fish as the information source is not necessarily a technical infeasibility so we could fundamentally shift management of harvest and monitoring population recovery using wild stocks by using PBT to integrate life-cycle and management-cycle.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Using PBT and GSI baselines to estimate the Snake River contribution to the harvest of Steelhead in Columbia River fisheries

The Idaho Department of Fish and Game (IDFG)coordinated with Washington Department of Fish and Wildlife (WDFW) and the Columbia River inter-Tribal Fish Commission (CRITFC) to collect tissue samples from Steelhead caught in sport and tribal fisheries in the mainstem Columbia River from August to October, 2011.. IDFG initiated this study because (1) there were no plans to use genetic data to estimate the contribution of Snake River hatcheries to the Steelhead harvest and (2) evaluation of IDFG Steelhead hatchery programs requires more precise estimates of harvest in downriver fisheries than are possible using CWT's. Using the existing Steelhead harvest estimates from mainstem Columbia River sport and tribal fisheries harvest that are published by the Technical Advisory Committee (TAC) to the US v Oregon Management Agreement and results from PBT/GSI analysis we:

1. Estimated the contribution by the Snake River and each Snake River hatchery to sport harvest in Zones 1 – 5.

2. Estimated the proportion of the unclipped Steelhead caught in the Zone 6 tribal fishery that were hatchery and wild origin.

3. Estimated the proportion of Snake River wild and hatchery stocks in the Zone 6 tribal harvest.

4. Estimated individual Snake River hatchery contribution (clipped and unclipped) in the Zone 6 tribal harvest.

5. Assigned punitive wild Steelhead into reporting groups using GSI and estimated the proportion of harvest from each reporting group in the Zone 6 tribal harvest.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Comparison of reproductive patterns in *Oncorhynchus* species in California using parentage based tagging.

As the implementation of parentage based tagging in salmonid hatcheries progresses, information of reproductive patterns and life history traits are becoming available for multiple species and multiple stocks within species. California hatcheries produce three species of anadromous salmonid: steelhead, Chinook and coho salmon. Pilot projects initiated routine broodstock sampling for several hatchery programs several generations ago, and the first multi-generation pedigrees from these projects are now available and can be used for cross-species and cross-stock comparisons, and subsequent expansion of broodstock sampling will soon increase the amount of such comparative data. We draw from these projects and describe the distribution and variance in family sizes, age of maturity, and rates of inbreeding for all three species, as well as rates of iteroparity and migration between stocks of steelhead.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Genetic Estimation of Stock Abundance and Run-timing of Interior Columbia River Steelhead Passing Bonneville Dam

Accurate estimates of stock abundance for hatchery and wild steelhead are critical for population viability assessment and are particularly useful information for fisheries managers when combined with stock run-timing trends in the Columbia River Basin. In this study, we used a set of 180 single nucleotide polymorphism (SNP) genetic markers and determined that genetic stock identification (GSI) analysis could accurately distinguish 16 reporting groups (stocks) of steelhead within the Columbia River Basin. Further, we genotyped unknown origin wild and hatchery adult summer-run steelhead sampled at Bonneville Dam during each of four years between 2009 to 2012 (n=2468, 1760, 1394, and 1486 respectively) and performed GSI on these mixtures to obtain estimates of run-timing and abundance for each stock. Stock abundance was calculated by first pooling mixture samples into 10 biweekly strata representing >98% of the total summer-run from April to October, and then multiplying GSI-estimated stock proportions for each stratum with the total abundance of steelhead tallied at the Bonneville Dam fish counting window. Aside from improving spatial resolution of GSI applications, SNP markers also provide an efficient way to perform large-scale parentage based tagging (PBT) analyses, which are used to identify an individual's parents. A large-scale PBT baseline has been completed for all 2008-2011 Snake River steelhead hatchery broodstock, and we demonstrate the utility of this PBT baseline by using it to assign 1-ocean, 2-ocean, and 3-ocean-age steelhead from the 2010-2012 Bonneville Dam mixtures back to their hatchery parents. The benefit of these two genetic tools, PBT and GSI, is maximized when the tools are applied in concert. This is because PBT provides highly accurate hatchery-level assignments and age information for Snake River hatchery steelhead, and GSI provides stock-level information for wild steelhead as well as for hatchery fish that were not assigned with PBT. We demonstrate potential for improving management of Columbia River steelhead fisheries evidenced by high accuracy of stock-/parent- assignments and the ability to estimate hatchery and wild components of stock abundance, and to characterize stocks by life-history traits (e.g. ocean-age, length, and run-timing).

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Estimating the proportion of hatchery-origin spawners using parentage-based tagging

For salmon populations in the Columbia Basin, many of which are listed under the U.S. Endangered Species Act of 1973, reliable estimation of the proportion of hatchery-origin spawners in spawning areas, p, is needed to make inferences about trends in abundance of wild-origin salmon. To help identify hatchery-origin spawners, some hatchery releases are visibly marked (VM). The estimation of p is challenging because different VM fractions are used at different source hatcheries. Without knowing the hatchery of origin of each hatchery-origin spawner, it is impossible to know what value to use to expand the counts of VM spawners (unless all source hatcheries use the same VM fraction). In this case, to estimate p, it is essential to have either coded-wire tag (CWT) data or parentage-based tag (PBT) data to estimate how many of the VM spawners came from each source hatchery. PBT has the potential to tag nearly 100% of the fish released from a hatchery. By genotyping hatchery broodstock (parents), their progeny are effectively genetically tagged. Progeny can be non-lethally tissue sampled as juveniles or adults, and can be assigned back to their parents to identify their age and hatchery of origin. We derived a new maximum likelihood estimator that allows multiple source hatcheries, and uses PBT to identify hatchery of origin of a subsample of individuals collected from carcass surveys. The estimator was applied to data collected in the South Fork Salmon River, Idaho.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Parentage Based Tagging of Endangered Snake River Sockeye Salmon

The Snake River Sockeye Salmon population was listed as endangered under the Endangered Species Act in 1991 when only a handful of fish returned the prior year. In that same year, a captive broodstock program was inititated to maintain the population and prevent species extinction. The goals of the program were twofold: 1) Conserve the population in the short-term by reducing demographic, genetic, and environmental risks that could lead to extinction and 2) Re-introduce and re-build the Snake River Sockeye Salmon population. Progeny are reintroduced to the Sawtooth Valley Lakes in Idaho at different life-history stages using a variety of release options including: 1) eyed-egg releases to lake incubator boxes, 2) pre-smolt releases direct to the lakes, 3) smolt releases to outlet streams and to the upper Salmon River, and 4) pre-spawn adult releases direct to the lakes. Using 13 microsatellite loci and parentage analyses, every fish in the program was genotyped and ~95% of the returning fish could be assigned back to a release strategy. In addition, important measurements such as the number of recruits per spawner, effective population size and genetic diversity could be calculated and used to evaluate the different release strategies. This information was used to not only determine the best direction for recovery but also to help with broodstock selection. Genetic marking has shown to be a valuable tool for the monitoring and evaluation of many conservation hatchery programs and will provide invaluable information to this program.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Using RAD Sequencing to Develop a Panel of High-Resolution Markers for Chinook Salmon

Successful genetic resource management is predicated on the ability to discover molecular markers which accurately reflect underlying population structure. Here, we present a pipeline using restriction site associated DNA (RAD) sequencing to develop a panel of single nucleotide polymorphisms (SNPs) useful in elucidating the population structure of four closely related Chinook salmon lineages in Alaska. Sequencing and SNP discovery on the RAD tags resulted in 26,567 candidate SNPs from these fish. We then developed a series of filtration steps to choose a panel of 96 true SNPs to distinguish among our populations. Taqman assays were developed for these putatively useful SNPs and screened on sets of 96 individuals from multiple populations in each lineage. Our initial RAD to Taqman conversion rate was close to 90%, which represented a significant improvement over previous attempts in our lab to develop assays from transcriptome sequence data. Once the 96 SNP panel was constructed and validated, we incorporated the new panel into an evaluation of 288 SNPs for western Alaska. We then constructed the best 96 SNP panel for GSI from these 288 SNPs and tested its ability to assign fish of unknown origin back to their natal lineage. The ability to screen thousands of markers and develop high-throughput assays for a select few high-resolution SNPs will prove to be a useful tool for genetic resource management.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Comparison of Parental Based Tags (PBT) to PIT tags and Coded Wire Tags (CWTs) for estimating escapement and harvest of hatchery-origin Chinook salmon in the Snake River basin

The Idaho Department of Fish and Game (IDFG) operates six Chinook salmon fish hatcheries in the Snake River basin funded by the Lower Snake River Compensation Plan (LSRCP) and the Idaho Power Company (IPC). Coded wire tags (CWTs) and Passive Integrated Transponder Tags (PITs) tags have traditionally been used to assess multiple monitoring and evaluation metrics for these hatchery programs. In 2008, the IDFG initiated a large-scale study to assess the utility of a genetic technology called Parentage Based Tagging (PBT) for monitoring and evaluating these hatchery programs. It was hypothesized that this tool could provide managers the ability to address many research and management needs. During the 2012 return year, we used PBT to generate stock and cohort specific estimates of adult hatchery-origin Chinook salmon returns to Lower Granite Dam and compared them to estimates derived from PITs. During this same year, we also used PBT to estimate the stock and cohort composition of hatchery-origin Chinook salmon harvested in a fishery within Idaho and compared it to the estimate derived from CWTs. Results indicated that the PBT method produced a more accurate estimate of the stock specific Lower Granite Dam escapement compared to PITs. Results of the harvest estimate comparison showed that, while the estimates were similar for the two methods, the increased number of sampled fish identified with PBT provided a more precise estimate of the stock composition. Overall, results support the hypothesis that the use of PBT will provide more precise and accurate estimates for both of these metrics. Other examples of how PBT could be used to provide useful information are also discussed.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Stratification and Allocation of Sampling Effort Using Parentage-Based Genetic Tagging to Estimate Steelhead Harvest

Hatchery fish currently provide the only harvestable population of steelhead *Oncorhynchus mykiss* in sport fisheries throughout Idaho. To evaluate the effectiveness of Lower Snake River Compensation Plan hatchery productions, hatchery-specific estimates of harvest are needed. Historically, contribution of various hatchery groups to harvest was estimated using proportions of coded wire tags (CWTs) recovered in the fishery. Coded wire tags were sampled using a non-probabilistic stratified design that consisted of 17 spatial and 10 temporal strata. However, the Idaho Department of Fish and Game is in the process of replacing CWTs with parentage-based genetic tagging (PBT) as a batch mark to estimate hatchery-specific harvest. Not only will the switch to PBT greatly increase the number of marked fish, but will allow for a robust probabilistic survey design. Historic CWT data from 2001-2010 were used to evaluate the effects of simplifying the current CWT survey design by reducing strata. Monte Carlo simulations were then used to determine the effect of various sampling effort allocation strategies and the reduction in strata using ten years of data. Variance was similar when the number of spatial and temporal strata were reduced compared to the current stratification scheme. However, results from Monte Carlo simulations showed that bias was several orders of magnitude higher with the reduced stratification scheme. Neyman, proportional, and equal allocation resulted in similar bias. The observed bias was a result of unevenly dispersed harvest of hatchery cohorts throughout the fishery both spatially and temporally. Potential bias and precision should be balanced against the costs and complexity of planning and implementing PBT surveys for estimating hatchery-specific harvest of steelhead.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Parentage-based genetic mark recapture for estimation of naturally spawning salmon and steelhead spawner abundance

Parentage-based tagging has been introduced as a method for use in mark-recapture models of population abundance in naturally breeding populations. However, this genetic mark recapture (GMR) method has not been widely applied nor critically evaluated. We recently undertook projects using parentage-based tagging to estimate naturally spawning Chinook abundance in several Puget Sound rivers, and are also critically evaluating the method using simulated data. Simulations show that under a variety of conditions, the GMR method produces unbiased, precise estimates of population abundance when sample sizes are adequate and standard closed population Lincoln-Petersen mark-recapture model assumptions are met. Some common characteristics of salmonid biology and life history may make implementation difficult for some species, and some management activities may, if undetected, cause significant biases in abundance estimates. I will briefly describe the method, illustrating using an example from one of our Puget Sound Chinook projects, and I will briefly discuss the applicability of this method to other systems and species.

Parentage Based Tagging: From conception to implementation (Campbell and Narum)

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Parentage Based Tagging: From Conception to Implementation

The role of molecular methods in fisheries management has reached another milestone. Parentage-Based Tagging (PBT), an emerging genetic-based tagging methodology, was only recently envisioned but is already providing information that previously was impossible or impractical to collect with traditional tagging methods. The principle management application of PBT in fisheries is to provide information on the stock origin and age of hatchery fish (similar to coded-wire tags), but it can do this much more efficiently; by sampling and genotyping a single parent pair, all resulting offspring (thousands of juveniles) are permanently genetically "tagged". In addition, there is no loss of a genetic tag and no tag related mortality, and PBT information can be recovered via non-lethal sampling methods. Besides information on stock origin and age, PBT can also provide estimates of genetic diversity, effective population size, relative reproductive success, and heritability of specific traits; all information not available with traditional mechanical tagging technologies. PBT technology was developed by scientists at NOAA's Southwest Fish Science Center and is actively being used as part of research projects in California, Oregon, and Washington. One of the largest PBT program currently in development is part of a collaborative project between IDFG and CRITFC. Since 2008, cooperating state, tribal, and federal agencies have genetically sampled Chinook salmon and steelhead broodstock at all hatcheries in the Snake River Basin in Idaho, Oregon, and Washington. This regional implementation of PBT has genetically tagged approximately 12 million smolts per year for each species. The IDFG and CRITFC are committed to using PBT technology to complement existing mechanical tagging evaluations, or in some cases replace mechanical tags for assessments where their use may have limited precision or uncertain accuracy. Collaborative efforts are underway to extend this technology throughout the Columbia River Basin.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Read range, coverage, and architecture - lessons learned.

The advent of effective and reliable in-stream PIT tag detection systems (IPTDS) has followed a trajectory similar in nature to prior technologies such as radio and sonic telemetry. The novelty of the approach spurred a proliferation of IPTDS installations and infrastructure innovations. The Integrated Status and Effectiveness Monitoring Program in the Snake River Basin has operated 29 IPTDS for up to four years. This talk summarizes what we have learned with regard to the placement of IPTDS infrastructure and the resulting information value of detection data. Specifically we discuss the effects of read range, channel coverage, and placement of antennas with regard to accuracy and bias of metrics that utilize detection data. This talk will target individuals interested in implementing IPTDS as well as groups that are advancing the technology.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Tucannon River Steelhead Migration into the Snake River: Straying and Population Viability

The Washington Department of Fish and Wildlife has attempted to monitor hatchery and wild steelhead returns to the Tucannon River for the past 30 years. However, data were limited in scope due to problems with surveys; so our understanding of wild steelhead population status and viability was incomplete. Further, coded wire tag recoveries from fisheries indicated that some of our hatchery steelhead were straying into the upper Snake River Basin. We increased the use of PIT tags in both hatchery and wild steelhead from the Tucannon River to better understand overall returns to the Snake River and examine straying of our hatchery steelhead to areas above Lower Granite Dam. Concurrently, an in-stream PIT Tag detection array was installed in the Tucannon River in 2005. PIT tag detections from the 2005-2011 run years indicated 60-70% of Tucannon River wild and hatchery origin steelhead that cross Ice Harbor Dam pass above Lower Granite Dam. Detections also indicate that few of these (10-20%) return to the Tucannon River. The mechanism(s) causing these migration patterns are not fully understood, but we hypothesize that it could be related to stock history or run timing, the hydropower dams, Tucannon River stream flow and temperatures in late summer, overwinter refuge preference, and a natural behavior with the addition of the hydropower dams preventing downstream passage. With the knowledge that our steelhead are straying to other systems, we queried the data from the Tucannon PIT Tag Array to see if other steelhead populations were straying into the Tucannon River. Raw detections indicate that as high as 20% of the hatchery fish and 35% of the wild fish are from other steelhead populations. Based on the PIT Tag data, this straying problem is not limited to Tucannon River steelhead, but includes other wild steelhead populations from the mid-Columbia River. The Tucannon River steelhead population is at high risk due to low numbers of wild origin returns (<200 annually) and a high proportion of other stocks within the basin. The use of PIT tags to assess the status and viability of the Tucannon River steelhead has been invaluable.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Using a PIT tag antenna array to identify movement strategies of fishes in a desert tributary stream network

Stream fish ecologists seek to understand how community composition differs across local and regional scales. Fishes often require diverse habitats throughout their lives, and those habitats are often distributed throughout a riverscape. Thus, fulfillment of different life stages will require movement among those habitats. Within stream networks, confluence zones often serve as areas of exchange of fishes between habitats. Therefore, confluence zones can serve as an explicit junction of local and regional scales. Dispersal between scales is one explanation for the processes that can shape patterns of community composition. Our objective was to classify movement strategies of native and nonnative species throughout a tributary network in the San Juan River basin. To test fish movement strategies and species exchanges through confluence (local) and tributary (regional) habitats, we deployed portable and stationary Passive Integrated Transponder (PIT) tag arrays along with a tagging protocol inclusive of all large bodied and long-lived fishes >115 mm representative of the current fish community in sites throughout McElmo Creek, Yellow Jacket Canyon, and the San Juan River. Fish detections relied on three stationary PIT antenna arrays throughout the McElmo Creek system complimented by three portable PIT antenna used at the confluence of McElmo Creek and Yellow Jacket Canyon. We deployed over 2,000 tags in 9 species in the San Juan River system to add to the endangered and other native fishes already tagged by the San Juan Recovery Implementation Program and the Colorado Parks and Wildlife. PIT tag antenna array detection data allowed for native and nonnative species to be classified into movement strategies based on their movements through and within certain habitats. Besides an innovative way of testing local to regional confluence-exchange fish community dynamics, this study highlights the benefits long-lived species and remote and continuous detection methodology offer to resource managers. Depending on the amount of detections per species, these methods could aid managers in identifying habitats in need of different management strategies such as rehabilitation or conservation. Future goals will attempt longer duration of portable antenna deployments to compliment stationary antenna operations.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Estimating Survival and Movement Rates of PIT-tagged Salmonids in the Cache la Poudre River, Colorado

Brown trout removal was examined as a management option for increasing the survival and retention of whirling disease resistant rainbow trout strains introduced to the Cache la Poudre River, Colorado. Radio Frequency Identification (RFID) Passive Integrated Transponder (PIT) tag technology was used to track brown trout and two strains of rainbow trout (Hofer × Colorado River Rainbow [H×C] and Hofer × Harrison Lake Rainbow [H×H]) in a reach in which brown trout were removed (removal section; 0.6 mile) and in another in which they were not (control section; 0.8 mile). Brown trout removal occurred in August 2010. All brown trout removed were returned to the river fifteen miles downstream below The Narrows. The Narrows is a high gradient river reach and was thought to be a barrier to upstream movement. Brown trout upstream and downstream of the removal section were RFID PIT tagged during the removal operations. Brown trout upstream, downstream, and within the control section were also RFID PIT tagged. Following removal, two thousand PIT tagged rainbow trout, one thousand each of the H×C and H×H strains, were stocked into both the removal and control sections. Paired RFID flat-bed loop antenna arrays were deployed at the upstream and downstream ends of both the removal and control sections (8 antennas) and were used to monitor movement of the PIT tagged fish. Antennas were paired to determine directionality of movement. Apparent survival (ϕ) and movement (ψ) probabilities were obtained using a multistate modeling approach in Program MARK. Results suggest that introduction of rainbow trout to sections where brown trout were not removed had a negative impact on the brown trout population. Although brown trout removal appears to have a positive effect immediately following introduction, there appears to be little benefit of removal on the long-term survival and retention of the introduced rainbow trout, primarily due to the movement and redistribution of fish over the winter.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Estimating Regurgitation Rates of Intragastric Radio Transmitters by Adult Summer Steelhead with the Use of Instream PIT-Arrays

Radio telemetry has become a well established and common tool used for monitoring adult salmonid life history characteristics and survival. In many instances, radio telemetry studies have been used to estimate spawner escapement of one or more populations tagged within a run at large containing unknown stock proportions. While gastrically implanted tags have been shown to reduce fish handling and recovery times relative to surgically implanted tags, a proportion of gastric implanted tags are inevitably regurgitated. Estimation and recognition of tag regurgitation has proven to be difficult, if not impossible without the ability of recapture and unique identification from a secondary tag. Telemetry studies using gastrically implanted tags should account for regurgitation to minimize misinterpretation of data leading to biases in survival and adult escapement estimates. In the Yakima Basin, instream PIT-arrays and associated PIT Tag detections were used to estimate radio tag regurgitation rates for Summer run steelhead. The preliminary results from year 1 of a 3 year study demonstrate the potential bias in expanded abundance estimates if tag regurgitation is not accounted for. Further, the study provides an empirically-based estimate of gastrically implanted radio tag regurgitation occurring in the natural environment for summer run steelhead.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Effects of PIT tagging upstream migrating adult Columbia Basin sockeye salmon

PIT tagging adult salmonids can provide important information on stock composition, migratory characteristics, and survival. However, the impact of tagging adults is of importance both to interpret study results as well as to regulatory agencies concerned with impacts on stocks being studied. As with juvenile salmonids, where a recent study generated controversy by estimating PIT tag-induced mortality of as much as 33.3%, it is difficult to assess mortality. One method of testing impacts of tagging adult salmonids at Bonneville Dam has been to compare the percentage passing McNary Dam upstream with that of salmonids tagged as juveniles. Doing this with Chinook in 2012 suggests a PIT tag-induced mortality of 21.4% but sockeye showed a PIT-tag induced benefit of 21.9%. However, in both cases, the stock composition of juveniles with PIT tags is very different than that of adults tagged at Bonneville Dam. Between 2010 and 2012 we have PIT tagged adult sockeye salmon at Bonneville, Priest Rapids, and Wells dams allowing comparisons of survival from these points to upstream detection sites. These studies have estimated a tagging impact ranging from negative 9.2% to positive 6.3%. Tagging does not appear to have a significant impact on migration rates and migratory timing.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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The Use of PIT Tags As A Component To Evaluate Burbot Recovery In The Kootenai River, ID

In the Kootneai River drainage in Idaho and Montana, operation of Libby Dam for hydroelectric power and flood control created major changes in the river's nutrient concentration, temperature, and seasonal discharge, particularly during the winter when burbot spawn. It is currently hypothesized that changes such as these have largely contributed to the decline in the burbot populations. Restoration of the burbot fisheries has been identified as a primary goal for the Kootenai River and Kootenay Lake; however, multiple factors complicate efforts to do this. With each passing year, burbot stock limitations become an increasing factor constraining rehabilitation. Thus, a collaborative effort among the Kootenai Tribe of Idaho, Idaho Dept. of Fish and Game (IDFG), BC Ministry, and the University of Idaho Aquatic Research Institute is underway to (1) mitigate habitat changes and (2) supplement the wild population through intensive culture and extensive rearing ponds. Although a primary limiting factor to spawning is hypothesized to stem from winter dam operations, efforts to re-establish spawning to historic spawning tributaries are underway. These efforts consist of annually stocking age-0 burbot into known, historical spawning tributaries in order to evaluate survival, movement and habitat-use. Release sites were chosen in several tributaries in order to determine if age-0 larvae released into the tributaries would return to the locations to summer, overwinter, or spawn. The IDFG operates a PIT tag array (Biomark Inc) at one of these release sites in Deep Creek tributary. The array, located seven river kilometres (rkm) from the confluence with the Kootenai River, collected data from a recent stocking of 3,000 PIT-tagged, age-0 juveniles released 13-26 rkm upstream from the array. The data indicated that 98% of the age-0 juveniles were undetected, suggesting that they may have survived to overwinter in the tributary during their first year. In addition, other year classes from prior stocking events that were located 45-75 rkm downstream from the array were detected, suggesting that these fish were using the tributary for either summer feeding or over-wintering. These results provide valuable and previously unknown insight into the importance of tributaries in the early-life stages of burbot.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Using PIT Tags to Estimate Stage-specific Survival of Anadromous Salmonids

When used in a capture-mark-recapture (CMR) framework, continuous detections of PIT tagged fish from stationary PIT antennas coupled with data from live recaptures on discrete sampling occasions can provide a powerful means to obtain simultaneous yet separate estimates of true survival and emigration over some portions of the anadromous salmonid life cycle. Refinements to the multistate CMR model that merge these continuous and discrete data have been key. Recent advances in PIT technology have allowed the use of PIT antennas in larger tributaries and moderately-sized rivers that before now have been restricted to smaller streams. These advances have included materials to improve read ranges for antennas that are secured flush to the stream bottom (pass-by antennas as opposed to pass-through antennas) thereby increasing the period when detections can be made because the chances of antenna failure during high flow events is minimized. Related advances include multi-antenna controllers that are capable of simultaneously recording data from up to 24 antennas at a single site so that in moderate to large systems it is now possible to deploy antenna arrays that span the wetted width on a year-round basis. Thus it is quite feasible to detect PIT-tagged adult salmonids like coho salmon and steelhead that typically return to freshwater during high flow periods. When lower river arrays are used in conjunction with headwater arrays, the multistate model can be extended in a straightforward way to encompass the anadromous life cycle from young-of-the year to returning adult thereby allowing stage-specific estimates of survival. We show an example on the Russian River, CA that makes use of this study design for coho salmon.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Too much of a good thing? PIT scanning repatriated razorback sucker in Lake Mohave, AZ-NV

Since 1991 over 200,000 razorback sucker *Xyrauchen texanus* implanted with passive integrated transponder (PIT) tags have been stocked into Lake Mohave in an effort to replace the senescent and declining wild population. Annual netting efforts at fixed locations have been used to monitor this 'repatriated' population and these efforts have provided an invaluable time series of population estimates. These estimates along with mark-recapture estimates of post-stocking survival indicate that although a repatriate population has been established, post-stocking mortality is high and the population size remains below 5,000 individuals. Due to a lack of recaptures, analyses designed to specifically identify factors that contribute to post-stocking mortality have been inconclusive beyond the paradigm that bigger fish survive better. Advances in PIT technology and the advent of the 134.2 kHz PIT tag has provided an opportunity to increase contact with razorback sucker post-stocking without increased handling of this endangered species. Since 2011, portable remote PIT scanning systems have been deployed throughout the reservoir in an attempt to contact a greater proportion of the razorback sucker population in Lake Mohave. Totals of 3,262 and 8,330 scanning hours resulted in contact with 1,042 and 2,748 razorback sucker in 2011 and 2012, respectively. Use of remote PIT scanning has provided nearly a ten-fold increase in number of contacts with repatriated razorback sucker in Lake Mohave which is both a blessing and a problem. Handling data (release and capture) and remote PIT scanning data are collected by a cooperative group of biologists from multiple agencies and are each maintained in a separate but nearly complete database. While the handling database has slowly grown to over 200,000 records in over 20 years, the remote PIT scanning database recently exceeded 300,000 records in 2 years. The ability of PIT scanning to generate data at such a high rate requires not only a concise understanding of the reasons for collecting the data, but also a solid data management plan prior to the first deployment.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Innovative Uses of PIT-tag Detection Technology:Examples from the Colorado River Basin

Radio Frequency Identification or RFID was introduced into the realm of fisheries science in the Pacific Northwest in the mid-1980's with the introduction of the Passive Integrated Transponder (PIT) tag. PIT-tags were first used to evaluate survival of anadromous salmonids through the hydroelectric projects in the Columbia and Snake rivers. Innovations such as multiplexing antenna readers, smaller high performance tags, and larger more robust antennas have resulted in the widespread application of PIT-tag technology as a fisheries data collection tool. PIT-tag detection antennas have traditionally been used in the form of fixed antenna arrays detecting PIT-tagged fish as they move through specific areas of a river covered by the antennas. As the use of PIT-tag technology becomes more geographically widespread, the need for alternative detection techniques and methods has become apparent. The Colorado River Basin presents some unique challenges in fish detection whether using more traditional sampling techniques (e.g., electro-fishing, seining, trammel netting, hoop netting) or when using PIT-tag technology. In this basin we are dealing with long lived fishes that do not predictably migrate annually to the exact same spawning grounds and have very diverse habitat use over their life span. Innovative new styles and types of fish detection antennas have been developed and tested, driven by the needs and ideas of biologists working in the field. These new methods allow biologists to detect fish "actively" instead of "passively" waiting for the fish to move past a fixed point. These innovative methods open up the possibilities to expand the use of PIT-tag data from traditional mark-recapture studies to habitat use studies. I present a number of these projects where smaller, temporary, mobile, and floating antennas have been successfully used to detect pit-tagged fish where traditional sampling methods have been less effective.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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"PIT Tags Don't Kill Fish, People Kill Fish" and Other Reasons to Assess and Address the Assumptions in Your Study Designs and Analyses

Researchers and resource managers in the Columbia Basin rely extensively on PIT tag mark/recapture data collected, and publicly shared, by numerous independent study projects. The assumptions made during each study's design and implementation, and the methods used to collect and vet the data, are generally not shared with the same vigor as the raw data sets. Researchers generating PIT tag data sets, and analysts appropriating those data, should be aware of the potential consequences of the unintended misuse of the data.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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A Study of Migration Rate and Migration Behavior of Adult Spring/Summer Snake River Chinook Salmon Using Graphical Visualization of PIT-Tag Detections

Adult Chinook salmon returning to the South Fork Salmon River and the Upper Salmon River must endure long migrations with large elevation gain, necessitating a careful use of energy resources and a balance between optimizing in-transit conditions vs. spawning timing. The movement of these populations through the mainstem Columbia and Snake rivers and dams has been extensively studied, but less is known about the factors influencing migration behavior from above the dams on the Lower Snake River to the spawning grounds. The recent installation of in-river PIT-tag detectors at locations proximate to these distant spawning locations has the potential to answer many questions but also to raise new ones. Using a new graphical visualization method for analyzing PIT-tag detection data, I have identified two common trends for these Chinook salmon populations: 1) a linear increase in overall migration rate over the span of the run, and 2) a bifurcation of the run into two groups with markedly different migration rates. Possible environmental and behavioral explanations for both of these phenomena will be discussed.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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HD-PIT technology and the development of aids to adult Pacific lamprey passage at dams.

Adult Pacific lamprey exhibit poor passage success at both large Columbia River mainstem dams and small irrigation diversion dams in tributaries. To promote lamprey passage at these obstacles, we have designed and installed a variety of lamprey specific structures (i.e., lamprey passage structures, refuge boxes). Half-duplex (HD) PIT technology has been key to the monitoring and evaluation of these structures. HD-PIT antennas are integrated into lamprey passage structures to evaluate collection efficiency, passage efficiency and passage rate. This monitoring has allowed evaluation of lamprey structure performance and the efficacy of structural and operational modifications. In addition, HD-PIT monitoring allows interannual comparisons of route selection and relative use of lamprey structures. HD-PIT technology will continue to be the basis for region-wide lamprey escapement estimates, in addition to providing detailed information on the use and efficacy of structures designed specifically for lamprey.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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A case study of adult sockeye salmon passage under intensive trapping operations in the Wenatchee River, Washington

With over 150 million hatchery salmon released in the Columbia River annually, capture of adults for broodstock, research, and management has become tradition. In order to assess the potential effects of trapping, we analyzed sockeye salmon passage using passive integrated transponder tags where the entire migration was handled during research activities conducted between 2004 and 2010. Median delays below the trap peaked at 8.7 days in 2010; 38% (>21,000 adults) of the return was subsequently blocked from access to upriver spawning habitat. A limited trapping schedule was implemented in 2011 and median delays decreased to six minutes for two consecutive years, with nearly all sockeye salmon successfully ascending upriver. Significantly improved passage of sockeye salmon compared to previous years exemplifies the potential effects of intensive trapping and why resource managers must consider possible repercussions relative to desired outcomes before implementing such activities. We emphasize that trapping effects, facility limitations, interaction with non-target species, and passage goals with rigorous monitoring be contemplated as a part of adult salmon trapping efforts in the Columbia River.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Use of PIT tags and PIT antennas to monitor coho populations in the Russian River, CA.

Monitoring efforts for the Russian River Coho Salmon Captive Broodstock Program in California have come to rely on PIT tags and fixed-place PIT antennas to estimate survival and movement patterns of hatchery-released coho salmon. Each year, PIT-tagged juvenile coho salmon of multiple genetic cross-types are released into Russian River tributaries in the spring and fall. PIT tag detection systems are used with and without outmigrant traps to estimate pre-smolt survival, emigration and smolt abundance directly using CMR models. We show how our approach can be used with the 2-trap DARR estimator to estimate smolt abundance as well as how to implement a multistate CMR model to obtain un-confounded freshwater estimates of pre-smolt true survival and emigration. By PIT-tagging and measuring individuals during pre-smolt life stages we are also able to relate survival and movement patterns to size, stream, release season, and genetic cross-type.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Snake River Steelhead: To There and Back, a Tale of a 1,000 Tags.

High precision estimates of natural steelhead adult abundance returning to designated populations in the Snake River Basin has been identified as a high priority, resulting in increased studies addressing this important question. The life history plasticity of juvenile and adult of steelhead requires study techniques that address this complexity at the population scale. The systematic trapping and marking (with a Passive Integrated Transponder (PIT) tags) of steelhead adults over the entire migration period at Lower Granite Dam (LGD) represents a known proportion of all wild/natural steelhead adults that cross LGD. This marked PIT tag group, coupled with detections/recaptures of these marks at strategically placed paired instream arrays, provides a unique opportunity to monitor steelhead adults from LGD to specific spawning populations, and back to LGD as kelts. Results from this study include; population specific arrival timing both at LGD and at basin specific PIT tag arrays, the duration of spawning and spawner residency time, dip-in behavior, the relative proportion of spanwers by basin that successfully migrated (kelted) back to LGD, and finally an estimation of the total proportion of wild/natural adult steelhead that spawned above LGD and successfully kelted back to LGD. Obtaining population scale natural steelhead information will provide the tools to better design monitoring and management strategies to hopefully move these populations towards recovery.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Use of PIT Tags to Estimate Salmon and Steelhead Harvest in Columbia River Fisheries

The number of juvenile anadromous salmon and steelhead PIT tagged in the Columbia River has been increasing over the last two decades. PIT tags have been used to estimate adult and juvenile survival, travel time, straying, predation, abundance, and other metrics. However, there is an opportunity to use PIT tags to estimate adult harvest in the mainstem Columbia River and tributary fisheries. Harvest estimates based on PIT tags could be valuable because they can be done in real time, and in some cases provide finer resolution than traditional coded-wire-tag estimates. In this presentation, we present statistical models developed to estimate harvest rates, discuss the challenges of implementing this approach, such low tag recoveries, estimates for untagged populations or groups, and incorporating uncertainty into our estimates based on sampling designs and PIT tag detection rate of less than 100%. We illustrate the feasibility of this approach to estimate harvest rates with data collected during the 2010 and 2011 fishing seasons.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Lessons Learned from Evaluating the Use of PIT Tags to Estimate Returns of Adult Hatchery Chinook Salmon and Steelhead in Idaho

Since 2009, the Idaho Department of Fish and Game (IDFG) has used adult return estimates, based on PIT tag expansions, to help guide fisheries management for Chinook salmon and steelhead. These estimates have provided real-time adult return information that is used to establish and manage fishing seasons in Idaho as fish migrate through PIT arrays in four of the hydroelectric dams in the Columbia and Snake Rivers. Since adult PIT tag expansions estimates were first used for these purposes, the IDFG has evaluated the accuracy of these adult returns estimates using multi-antenna PIT tag arrays installed in the ladders of adult traps at hatchery facilities. Similar to previous studies, we observed that PIT expansions consistently underestimate adult returns and this negative bias can be highly variable across groups. Potential explanations for this negative bias include tag shedding and differential mortality of tagged and untagged fish. Data from these arrays, in combination with cohort-specific trapping estimates, is used to correct the expansion rate for each group of PIT tagged fish returning to a hatchery trap. More recently, these corrected PIT estimates have been compared to return estimates generated from sampling adults for Parentage Based Tags (PBT) at Lower Granite dam (LGD). These results show that corrected PIT expansions at LGD are comparable to PBT results. Uncorrected in-season PIT estimates provide minimum return estimates that are more accurate than pre-season forecasts and provide useful information for managing fisheries. However, managers are cautioned against applying an in-season correction factor, based on previous year's data, to PIT estimates due to their uncertain negative bias when making management decisions.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Using PIT tags to partition resident and anadromous *O. mykiss* production in a highly sympatric population

The steelhead trout (*Oncorhynchus mykiss*) exhibits perhaps the most diverse life history of any Pacific salmonid. Included in the diversity of this species is the variable expression of anadromous and resident life histories. The anadromous form may smolt and migrate to the ocean after one, two, or three years of freshwater residency and return to its natal stream after spending between one and three years in the ocean. In contrast, the resident life history form, also known as rainbow trout, spends its entire life in freshwater. Our understanding of this species is further complicated by the fact that both forms can interbreed and produce offspring of the opposite type. Federal mandates have required the development of recovery plans that will facilitate recovery of Mid-Columbia steelhead. A final draft of the Yakima Steelhead Recovery Plan has been developed and identifies key uncertainties associated with steelhead recovery in the Yakima Major Population Group. One key uncertainty identified in that recovery document was the relationship between resident and anadromous life histories present in the Yakima Basin. The interplay between the resident and anadromous forms of *O. mykiss* deserves attention because it is poorly understood and there is a strong potential for the resident form to either contribute to, or to limit recovery of the anadromous form. In this study, we describe the research technique we have adopted in the Yakima Basin to improve our understanding of resident/anadromous interactions in this highly sympatric population.

PIT-Tag Technology: Progression from Novel to Standard Fisheries Tool (Anglea)

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Quantifying adult natural steelhead at sub population and population scales in the Columbia and Snake river basins

Currently there is limited quantitative information on natural adult steelhead populations (*Oncorhynchus mykiss*) in streams in the Columbia and Snake River Basins. Current methodologies use steelhead adult abundance for the aggregate of populations determined from fish ladder counts at Dams and permanent and portable weirs. These contemporary methods are limited throughout most the upper Columbia and Snake River drainages due to geographic inaccessibility and high stream flows during the spawning period, additional techniques need to be developed to estimate population abundance. The Integrated Status and Effectiveness Monitoring Project (ISEMP) initiated a project to determine whether innovative methods can be employed to increase the accuracy and precision of juvenile and adult steelhead trout abundances at the subpopulation and population scales. This project generates wild/natural adult escapement estimates through adult marking and recapture program. Mark consist of passive integrated transponders (PIT) placed in adult fish at Priest Rapids and Lower Granite dams, with the recapture event occurring via PIT tag detections from flat panel pass-over PIT tag arrays currently operating within the upper Columbia, Snake and Salmon River basins in Idaho, Oregon, and Washington . This methodology requires that adults are representatively PIT tagged at these Dams with enough PIT tags applied to get sufficient stream detections for calculation of precise escapement estimates. This methodology integrated with existing monitoring and evaluation tools quantifies adult and juvenile salmon and steelhead for both natural and hatchery populations in a more robust and comprehensive manner than what was achieved in the past. This comprehensive monitoring and evaluation tool will provide high quality data to ensure that fish managers are making informed decisions.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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The Building of the Redband Database: It Wasn't Done in a Day…

Monitoring and assessment of threatened and endangered fish populations can be a difficult and costly endeavor. Developing a standardized data management system for these species can benefit natural resource agencies in their management goals. In 2002 the Inland Cutthroat Trout Protocol (ICP) was developed to provide an integrated GIS database detailing occupied habitat and specific demographic information important to the persistence of Westslope cutthroat trout (*Oncorhynchus clarki lewisii*). Since this initial population assessment, the ICP has been applied to Yellowstone, Colorado River, Bonneville, Rio Grande, Greenback and Lahontan cutthroat trout. However, with each new ICP database, new and/or modified approaches to managing the data had occurred, leading to potential issues when comparing summary results between species. To remedy the potential issue of 'database drift', we invoked a process to consolidate and standardize all of the current ICP databases. The creation of a single data structure has two primary advantages, data summaries will be consistent and comparable between species, and custom data management tools can be easily implemented to speed update and reporting processes. These past efforts were leveraged by the Redband working group to compile a comprehensive, range-wide dataset describing the historic and current distributions of this species. As demands increase on natural resource agencies and the species they manage, this approach has proven to be a model for future cross-agency and cross-species collaborations.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Michael Mizell

Arleta Agun

Distribution Patterns in Washington State

To further our knowledge about redband trout in the Columbia Plateau region that covers eastern Washington State, maps were created using ArcGIS that show historic and current presence of these resilient fish as well as streams where genetic analysis needs to be done to verify their presence. In addition, we field tested a protocol to assess redband trout presence in Washington State.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Hydroturbine passage related barotrauma research in the Columbia River Basin: How far have we come?

Within the past decades, most of the research related to hydroturbine passage has centered on seaward migrating juvenile salmonids. Throughout the years the techniques and technologies used to study barotrauma have evolved as have our understanding of the causal pathways. Tools that are used to measure pressure changes fish are exposed to when passing turbines, such as the Sensor Fish, have also improved considerably. Research has also begun to be done on other fish types such as lamprey and sturgeon. This past research has led to a rethinking of the fundamental way that turbine survival studies are conducted and evaluated and how past research should be viewed. Having a comprehensive understanding of the effects of barotrauma in fish is increasingly important as the need to expand energy output of current hydropower facilities exists. This presentation will provide an overview of past, present and future research on hydroturbine passage and will detail stumbling blocks experienced upon the way and common misconceptions about turbine survival research.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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National Forest Conservation of Redband Trout

The USDA Forest Service is a major federal land management agency within the range of redband. The expansive redband range includes 20 National Forests and extends across four National Forest Regions, including the Pacific Northwest, Pacific Southwest, Intermountain, and Northern regions. Sources for Forest Service redband management direction include the Forest Service Manual, the respective National Forest Land Management Plans, and indirect benefits associated with sympatric Federally listed fish species. These elements create a patchwork quilt of protection for the species. Forest Service Manual direction includes policies to maintain the viability of all native and desired non-native fish and wildlife populations, maintain diverse and productive fish and wildlife habitat, and ensure that species do not become Threatened or Endangered under the Endangered Species Act (ESA) due to Forest Service actions. The Manual provides direction for Regional Foresters to designate Sensitive Species, for focused conservation management strategies. Redband are designated Sensitive in all but the Intermountain Region. Most National Forests within the range of redband operate under Forest plans amended by the Inland Native Fish Strategy or the Northwest Forest Plan, where riparian reserve areas are established along water bodies to protect them from management actions and accelerate recovery. In the reserves, riparian dependent resources receive primary emphasis. Standards and guidelines provide specific direction to conserve aquatic biota and their habitat. These Forest Plans also emphasize watershed analysis, watershed restoration, and monitoring. The other 5 National Forests operate under one of two more localized Forest Plans; the 2008 Southwest Idaho Ecogroup Forest Plan and the 2004 Sierra-Nevada Framework in California. Those Forest Plans are more locally developed, but provide comparable protections to aquatic species and their habitat. The range of redband overlaps with the range of federally listed species, indirectly benefiting redband through additional habitat protection and restoration actions. For example, most of the range of redband overlaps with bull trout, listed as Threatened under the ESA. Redband indirectly benefit from the ESA recovery plans and critical habitat. The Forest Service Manual, Forest Plans, and other federally listed fish species create a patchwork quilt of protection and restoration emphasis for redband throughout its range on National Forest Lands.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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When Is A Redband Trout Not A Redband Trout?

What is a redband trout? In this talk, I trace the evolution of ideas about redband trout that arose over the last century as ichthyologists discovered and then rediscovered these fish in landlocked, arid basins of the Northern Great Basin. Genetic and morphological differences in the rainbow trout and suggest that the species originated near the Gulf of California and moved northward entering the Columbia River 50-32 thousand years ago. Internal connections through the Oregon desert basins between the Columbia River and the Sacramento and Klamath Rivers may have been a major avenue for that dispersal. During episodes when geological and climatic changes isolated these fish in different internal basins they diverged, evolving unique traits in some areas while retaining many of the traits of their common ancestor. Confusing as these patterns were to curious ichthyologists, they suggested that persistence and diversity of redband trout was linked to the persistence of large river systems and the ability of the species to adopt multiple life-history strategies, such as anadromy, adfluvial migration, and residency.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Initiation of a Range-wide Status Assessment for Interior Redband Trout

In 2009 a workshop was held in Portland, Oregon involving six states, three federal agencies, and six Tribal Nations that collaborated to review the current range-wide status of redband trout *Oncorhynchus mykiss spp.* One recommendation generated from the workshop was to build a geo-referenced database of information pertinent to the current status and conservation of redband trout populations throughout the distribution. In 2011 a WNTI-funded effort was initiated to assemble a database on all non-anadromous populations of redband trout, using protocols and parameters similar to those previously employed for each interior cutthroat trout subspecies. Thirteen data collection workshops, attended by 108 professionals, were held throughout the range to populate a database specific to redband trout including information detailing genetics, habitat condition, barriers, historical distribution, and population parameters. Currently, the range-wide redband trout steering team is nearing completion of a conservation agreement and will subsequently develop a range-wide conservation plan.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Public Lands and Managing Redband Habitat

BLM-administered lands provide a significant amount of habitat for redband trout. As a result, management of these lands has and continues to have significant effects on the status of redband trout. The presentation will outline past and current management and restoration of redband habitat on public lands.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Status of Nevada's Redband Trout

The Nevad Redband Trout Species Management Plan was written in 2004 and has provided management direction for improving the species status. There are currently 186 stream redband trout populations that occupy 650 miles of stream in the Snake River drainage of northern Nevada. A majority of these streams have been surveyed , but recent surveys of some previously unsurveyed streams on private lands have increased our knowledge of redband trout in Nevada. Redband trout status has been improved through culvert fish barrier replacements; both mechanical and chemical nonnative trout removal projects; involvement in a cooperative holistic grazing management group has resulted in stream habitat improvements to benefit redband trout; successful redband trout introduction into a barren stream, a private reservoir, and reintroduction into a formily occupied stream; and State acquisition of some redband trout occupied lands resulted in management actions that have improved stream habitat. On the horizon is a project that will remove old mine tailings, restore stream connectivity and improve water quality.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Spawning migrations and overwintering of redband trout in the Sanpoil Subbasin, Lake Roosevelt, WA

The construction of Grand Coulee Dam eliminated anadromous salmonids from the upper Columbia Basin in 1942. The resultant residualized population of redband steelhead/rainbow trout *Oncorhynchus mykiss gairdneri* utilizing the Sanpoil subbasin and Lake Roosevelt (formed by Grand Coulee Dam) has significant cultural, subsistence and recreational benefits to members of the Confederated Tribes of the Colville Reservation. Additionally this population is part of a popular harvest fishery for rainbow trout in Lake Roosevelt, WA. In spite of their multi-cultural importance, little is known about the basic ecology of the naturally reproducing *O.m.gairdneri* population in the Sanpoil subbasin. In this study, we used radio telemetry to monitor the movements of rainbow trout during spawning and overwintering phases of lacustrine-adfluvial (n=74), fluvial-adfluvial (n=36), and resident-fluvial (n=15) life history forms. Migration of the lacustrine-adfluvial life history form was first observed in late February. Spawning in tributaries peaked in mid-April but ranged from mid-March to early June. Spawning of the resident-fluvial form in a mid-basin tributary was not observed until late June. Lacustrine-adfluvial rainbow trout made migrations of 11 to 103 km upstream while fluvial-resident forms made movements of <50 m to spawning locations. One instance of repeat spawning was observed with likely fidelity at the tributary scale. A unique fall-migrating lacustrine-adfluvial form was also monitored with individuals overwintering in the Sanpoil River and continuing upstream migration in the spring to spawning areas.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Long-term assessment of redband trout populations in Southwest Idaho

As part of a long-term redband trout *Oncorhynchus mykiss gairdneri* monitoring effort in southwest Idaho, Idaho Department and Fish and Game employees sampled over 60 stream sites within the Bruneau, Owyhee, and Snake river drainages. Approximately two-thirds of these sites had been sampled twice previously in an effort to determine population status and trends (Zoellick et al. 2005). This subset of sites was sampled initially during 1979-1982, re-sampled in 1993-2003, and again during the present efforts, 2008-2012; and therefore, represents population trends over a roughly three decade period. Sites were well dispersed throughout this arid region and ranged in elevation from 1,450 to 1,800 m. Redband trout populations were sampled predominantly with backpack electrofishing equipment using block nets and depletion methods. On a few occasions, where stream width exceeded 3 m snorkeling was used to estimate abundance. Redband trout abundances ranged from 0 to 172 fish/100 m^2. Within this small portion of their range, the percentage of occupied sites and mean density of redband trout has remained stable over the last thirty years.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Conservation and Managment of California's redband trout

California's fishery managers have benefited from the 2012 Rangewide Interior Redband Trout Status Assessment by assisting managers with setting priorities for management and conservation activity. The upper McCloud river, upper Pit River, Goose Lake and Surprise Valley support the majority of redband trout in California. The Assessment has informed existing and planned conservation activities for populations of special concern. The Status Assessment has highlighted areas with missing information that are now considered in priorities for monitoring, distribution surveys and genetics status research. Revised Conservation Strategies are in different stages for upper McCloud and Goose Lake redbands.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Status of Redband Trout in Lake Roosevelt, Washington

The anadromous form of redband trout were eliminated from the upper Columbia River after the construction of Grand Coulee Dam in 1939. Native stocks of redband trout continued to persist after inundation and the upper Columbia River continues to support several populations that exhibit a variety of freshwater life histories. Redband trout are culturally, socially and economically important to the region and have been identified as a priority species by natural resource managers. Despite their importance, detailed information related to genetic stock structure, hybridization, life history strategies, recruitment, harvest, and escapement is lacking. The Colville Confederated Tribes, Spokane Tribe of Indians, and the Washington Department of Fish and Wildlife cooperatively developed a plan to evaluate the status of redband trout in Lake Roosevelt and the upper Columbia River using standardized methodologies. Information gathered will be used by the co-managers to implement actions that will balance conservation with recreational angling and subsistence harvest objectives.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Estimating abundance of redband trout in the Great Basin

Redband trout (*Oncorhynchus mykiss newberrii*) in the Great Basin occupy a landscape characterized by spatial and temporal variability in environmental conditions, and this variability likely influences abundance of redband trout. Developing long-term monitoring protocols and effective conservation plans will require an understanding of spatial and temporal variability in abundance of redband trout as well as an understanding of the trade-off between sampling intensity and precision of abundance estimates. The objectives of this study were to 1) estimate abundance of redband trout at the sub-basin and population levels, 2) determine the sample size necessary to achieve abundance estimates with a precision of ± 20% at the sub-basin level and ± 40% at the population level, and 3) evaluate inter-annual variation in redband trout abundance over a six-year timespan. Multiple-pass electrofishing was conducted at about 30 to 40 sample sites within each of six sub-basins annually from 2007 through 2012 and at about 30 sample sites per population within each sub-basin twice during the six year study. Electrofishing data were used to produce site level abundance estimates that were extrapolated to the population level, sub-basin level, and entire study area. Abundance varied from about 554,000 to about 983,000 redband trout throughout the study area. Trends in abundance were generally stable within sub-basins over the six-year study; however, inter-annual variation was observed in some sub-basins. Desired precision of abundance estimates was not achieved at the sub-basin level based on a sample size of 30 to 40 sample sites per sub-basin. Desired precision of abundance estimates was achieved at the population level for about 50% of the population by year combinations. Sample size estimates indicated that from about 50 to over 300 sample sites may be required to achieve the desired precision of ± 20% at the sub-basin level and that from about 30 to 55 sample sites may be required to achieve the desired precision of ± 40% at the population level. These data show that obtaining precise abundance estimates for redband trout in the Great Basin will require intensive sampling. Alternative sampling methodologies or levels of precision should be considered.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Status of redband trout in the upper Snake River basin of Idaho

Redband trout are likely the most abundant and widely distributed native salmonid in the Columbia River basin, yet their current distribution and abundance across the landscape has not been well documented. We sampled 1,032 randomly distributed stream sites (usually 100 m in length) across more than 60,000 km of stream network (1:100,000 scale) to assess redband trout occupancy, abundance, and genetic purity in the upper Snake River basin. Study locations were more often dry in desert sub-basins (49% of sites) than montane sub-basins (20%), and 25% of the dry "stream sites" had no discernible stream channel whatsoever, indicating an incessant lack of flowing water, perhaps for millennia. Redband trout were estimated to occupy 13,485 km of stream (22% of the total), and were captured more often (389 sites) than brook trout (128 sites), bull trout (37 sites), or brown trout (16 sites). Redband trout were also the most abundant species of trout, with an approximate abundance of 3.5 ± 0.4 million (90% confidence interval) of all sizes, followed by brook trout (1.5 ± 0.3 million), bull trout (159,503 ± 117,796) and brown trout (43,064 ± 25,382). Approximately 0.8 ± 0.1 million redband trout were adults. From 1913 (oldest period of record) to 2001, roughly 43 million hatchery rainbow trout were stocked in streams in the study area, 17.5 million of which were of catchable size (i.e., > 200 mm total length); since 2001 all catchables have been sterilized prior to stocking. Genetic results from 61 study sites suggest that redband trout hybridization with hatchery rainbow trout was more likely to occur in streams that were directly stocked with catchables from 1913 to 2001. Applying these results across the landscape, we estimated that redband trout likely remain pure in about 68% of the streams occupied in the upper Snake River basin.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Status and Conservation of Resident Redband Trout within the Western United States

We describe the historical range and current status of resident (non-anadromous) redband trout (*Oncorhynchus mykiss ssp*.) throughout the western United States using data and expert opinion provided by fisheries managers. Redband trout historically occupied an estimated 60,295 km of stream habitat and 152 natural lakes. Currently, redband trout occupy an estimated 25,417 km (4 2% of historical) of stream habitat and 124 lakes or reservoirs. Bootstrapped estimates of the proportion of historical habitat currently occupied by redband trout indicate generally low bias within and among geographic management units. A total of 11,695 km (46%) of currently occupied streams were assumed to support non-hybridized populations; however only 3,836 km (15%) were genetically tested. Approximately 47% of the occupied stream length occurs on private land, 45% on lands managed by government agencies, and 8% in protected areas. A total of 210 populations were identified as "conservation populations", which encompassed 15,252 km of stream habitat (60% of the current distribution) and 95,158 ha of lake habitat (52%). Although 40% of conservation populations were relatively small, isolated populations (1,141 km), large and interconnected metapopulations occupied much more stream length (14,111 km, or 92%). We developed a Conservation Population Vulnerability Index (CPVI) to assess biotic, abiotic and demographic risks to persistence. Non-native species, habitat degradation, and habitat fragmentation were the primary threats influencing the vulnerability of conservation populations to further decline and extirpation. We conclude that while redband trout currently occupy only about 42% of historical habitats, this species is not at imminent risk of extinction because they are: (1) widely distributed; (2) many populations are isolated by physical barriers; and (3) active conservation is occurring for many populations. However, because of the relatively high potential for introgressive hybridization with nonnative salmonids and limited genetic data, the actual genetic status of redband trout is probably less certain than these data suggest. We recommend collecting additional genetic information and estimating the distribution of redband trout following a more rigorous sampling design to reduce these uncertainties. We also recommend continued use of the ICP database to facilitate evaluation of the status of redband trout through time.

Rangewide Status Assessment for Interior Redband Trout (Lentz)

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Status and Management of Interior Redband Trout in the Crooked River Watershed, Oregon.

Habitat degradation, unsuitable water temperatures, inadequate flows, and passage barriers have depressed historical distributions of redband trout (*Oncorhynchus mykiss*) in central Oregon. The Oregon Department of Fish and Wildlife conducts regular monitoring activities to assess the response of these populations to management activities. Three specific examples include the Lower Crooked River, Deep Creek and South Fork Crooked River projects. The Chimney Rock section of the Lower Crooked River is located directly below Bowman Dam and contains the healthiest population of redband trout in the watershed. A mark/recapture study is conducted annually to measure the effect of angling impacts, environmental conditions, and anadromous salmonid reintroductions on native redband populations. Additionally, a creel survey is planned for 2013 to assess the impacts of angling on redband trout and reintroduced anadromous fish. The Deep Creek project entails monitoring redband trout populations in headwater streams on the Ochoco National Forest. Streams within the Deep Creek watershed are severely degraded from land management practices such as livestock grazing, road building and timber harvest. Backpack electrofishing using removal/depletion methodology is employed every three years to monitor trends in redband trout density in response to land and fish management activities. The redband trout population in the South Fork Crooked River was extirpated in the early 1980's. Restoration projects and changes in livestock management were conducted to improve the habitat quality. In addition, locally adapted stocks of redband trout from nearby streams were used as broodstock to reintroduce trout to the river. Results suggest that the wild broodstock program has been successful in reestablishing a naturally reproducing population.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Periphyton and Pacific Salmon: Understanding the connection by modeling the linkages

Marine derived nutrients, in the form of adult salmon, are considered to be an important subsidy in many streams. However, the influence of this subsidy on biological communities can be hard to predict, and is likely mediated by environmental conditions. For stream periphyton communities, for instance, spawners can enhance production by alleviating nutrient limitation, and can also reduce production via redd building. Empirical studies illustrate that the magnitude of these two processes can vary widely across different streams, resulting in periphyton responses that range from net enrichment to net disturbance. Reconciling these disparate responses necessitates the use of techniques that explicitly account for the numerous environmental conditions and feed-back loops that influence periphyton dynamics. Here, we present a system dynamics model that mechanistically links periphyton to salmon spawners. This model was used to assess how environmental conditions might mediate the response of periphyton to salmon. Our simulations illustrated that the response of periphyton to spawners was strongly linked to background nutrient concentrations and the proportion of the stream bed that contained substrate sizes suitable for spawning. Net enrichment responses were observed when both background nutrient concentrations were low (i.e., nutrient limiting conditions), and little of the bed was suitable for spawning (i.e., large substrate sizes). In contrast, when nutrient concentrations were higher or larger proportions of the bed were suitable for spawning, a net disturbance response to salmon spawners was observed. On an annual basis, model simulations suggest that salmon spawners are unlikely to significantly enrich or disturb periphyton production (i.e., annual primary production). Our simulations corroborate the results of experimental studies that have shown that the net effect of salmon contributions is limited for periphyton, indicating that fish responses to marine derived nutrients are more likely to occur via direct trophic pathways (i.e., direct consumption of carcasses). Overall, our modeling approach provides a framework for evaluating periphyton response to salmon subsidies, information which can be used to generate hypotheses, plan field experiments, and guide data collection.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Response of whole-stream metabolism to low densities of spawning Chinook salmon: the importance of environmental context versus marine-derived nutrients

Pacific salmon have been shown to have seasonal affects on ecosystem structure and function in streams. For instance, nutrients from returning adults and their carcasses can increase stream productivity, whereas disturbance of substrate from redd construction can simultaneously reduce productivity. Stream metabolism (i.e., gross primary production and community respiration) can integrate these contrasting changes in river productivity caused by adult salmon. However, most studies exploring the relationship between salmon and stream metabolism have occurred in small streams with high densities of returning adults (0.1-0.9 fish/m2). Here, we explore the potential effects of wild spring Chinook salmon (Oncorhychus tshawytscha) at low densities (<0.05 fish/m2) on stream metabolism in three mid-size rivers in the Methow River watershed, central Washington. We used a before-after-control-impact design to test differences between upstream reaches with no or very low spawning to downstream reaches with relatively higher spawning activity. We observed a consistent reduction in gross primary production and community respiration in our control reaches, but responses in spawning reaches were more variable. Similarly, periphyton biomass (chlorophyll-a and ash free dry mass) did not differ between spawning and no spawning reaches. We explored possibility that environmental or landscape factors may influence stream metabolism. Preliminary analyses suggest that substrate size may be positively related to primary production. Lastly, we used a mechanistic model to explore potential reasons why we did not observe a clear response to spawning salmon and to estimate the number of returning adults that would be needed to detect a response. These results suggest that environmental conditions may be more important in determining the magnitude of production in rivers with few spawning salmon than marine derived nutrients.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Spatiotemporal complexity in stream food web responses to salmon subsidies

Nutrient mitigation to enhance fish production in stream ecosystems assumes strong bottom-up effects, yet many stream salmonids obtain food resources from freshwater, marine, and terrestrial sources. Subsidized trout may also influence lower trophic levels through top-down control, but the effects may be lagged, and detection of those effects may require multi-year experiments. From summer 2008 through 2011 we conducted an experiment across nine tributaries of the N. Fork Boise River, Idaho, consisting of 500-m stream reaches treated with salmon carcasses (n=3), salmon analog (pasteurized and pelletized salmon tissue) (n=3), and un-treated reference reaches (n=3). We observed 2-8 fold increases in streambed biofilms in the 2-6 weeks following additions of either salmon subsidy treatment. Adding salmon carcasses caused a 1.5 fold increase in biomass of aquatic insect larvae (especially Chironomidae midges), but only over the first year of the experiment. Analysis of diets of resident trout indicated direct consumption of salmon carcass and analog contributed to 17% and 6% of annual production, respectively. In streams treated with carcasses, 7% of annual trout production was fueled by consumption of maggots that had colonized carcasses exposed to air or transported to riparian areas by animals. Both treatments caused 2-3 fold increases in annual production of resident trout. However, this did not translate into differences in trout population biomass or density, perhaps owing to shifts in fish size distribution or emigration of trout from treated reaches. Over the four years of the treatments, responses across trophic levels suggest that by year 2, trout in treated reaches cropped any additional benthic invertebrate biomass, reducing them further in year 3. Our findings indicate that nutrient mitigation programs must incorporate stream-riparian linkages into existing frameworks to better account for the multiple pathways that salmon subsidies can directly and indirectly influence trout production. Our results further indicate that bottom-up food web patterns are not predictable through time, as opposing top-down forces may mask these effects.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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A detritus-based perspective on the effects of nutrient enrichment on food webs in headwater streams: insights from Appalachia.

Much of the discussion surrounding the use of nutrient amendments as a tool for mitigating oligotrophication has focused on how nutrients may stimulate foodweb production through algal-based pathways. For instance, many studies have shown that nutrients can positively influence fish populations through a stimulation of algal and invertebrate production. In contrast, little attention has been paid to how nutrient amendments may affect fish productivity in small headwater streams, where leaf- and soil-derived detritus may fuel the bulk of foodweb production. Here, we present a case study from southern Appalachian streams where nitrogen and phosphorus were experimentally amended over a five-year period. We compared the foodweb- and ecosystem-level responses in the treated stream to an adjacent reference stream before and after the nutrient enrichment. During the first two years of enrichment, secondary production of primary consumers and predators increased by ~100-200%, despite a nutrient-induced reduction in the quantity of benthic detritus. In years 3, 4, and 5 of the enrichment, detritus decomposition rates increased to such an extent that there were large portions of the year in which coarse detritus was virtually absent. In addition, during the later years of the study, we measured reduced efficiency of energy transfer between primary consumers and predators, whereby primary consumers continued to increase, while predators declined to levels comparable to the pretreatment period. This 'trophic decoupling' was driven by a nutrient-induced reorganization of foodweb production. Specifically, a single taxon (Trichoptera: *Pycnopsyche*) dominated primary consumer production in years 3-5, and this taxon was invulnerable to predation because of its relatively large body size. Our research demonstrates that nutrient amendments to small, but critically-important, detritus-based streams may have a neutral, or even negative, effect on consumers at the top of the food web. This perspective should be considered when using fertilization as a mitigation tool in detritus-based streams.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Biological assessment and nutrient restoration of a oligotrophic large river

The 7th order Kootenai River is part of the Upper Columbia River ecosystem located in Idaho, Montana, and British Columbia. Though the river was moderately nutrient-limited historically, the construction of river levees and a large dam have further reduced nutrient availability by separating the river from its historic floodplain and interfering with nutrient transport from upstream sources. As a result, habitat diversity, biological productivity, and other important ecological functions in the Kootenai River have suffered. Presently, important fish species to the region are rare, threatened or endangered, including Kootenai River white sturgeon (*Acipenser transmontanus*), burbot (*Lota lota*) and bull trout (*Salvelinus confluentus*). Starting in 2002, an annual multi-trophic level monitoring program and mesocosm testing were initiated to determine if nutrient limitation was affecting food web development. Based on the combined monitoring and mesocosm results (i.e. low nutrient levels, algal growth, aquatic invertebrate biomass at most river sample sites; and, increased algal growth and macroinvertebrate biomass in mesocosms tests), the Kootenai Tribe and the Idaho Department of Fish and Game initiated a large-scale nutrient addition experiment in the Kootenai River in July of 2005 adding liquid agricultural-grade phosphate. After eight seasons of large scale nutrient addition in the Kootenai River, responses of the algae, macroinvertebrate and fish communities have been very positive. Key performance metrics (e.g. abundance, biomass and species richness) throughout the food web are indicating that nutrient addition is helping project managers attain their goal of increased food web productivity and diversity. For example, algae chlorophyll density has increased nearly 20 fold after nutrient addition began, while macroinvertebrate density and biomass have increased approximately 5 fold in the nutrient addition zone. Mayflies, stoneflies, caddisflies and chironomids have all shown significant increases after nutrient addition in the Kootenai River. Significant increases in fish biomass and abundance have also occurred.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Bioenergetic calculations evaluate changes to habitat quality for salmonid fishes in streams treated with salmon carcass analogs

One of the main predictions of nutrient addition to streams is an increased production of fish populations by bottom-up increases in invertebrate abundance producing increases in food availability for stream fishes. Such changes in food abundance may increase fish production by improving habitat quality for stream fishes. In this study we apply bioenergetic calculations to estimate changes to habitat quality based on predicted increases in net energy availability by the addition of salmon carcass analogs. We compared changes in invertebrate drift abundance and estimated increases in energy availability in streams treated with salmon carcass analogs versus untreated control streams. Our results revealed increases in invertebrate drift abundance in treated streams after the addition of salmon carcass analogs in both years of the study. Measures of the energetic profitability of stream habitat for salmonid fishes had minor increases in net energy availability for treated streams over control streams. Seasonal differences in temperature and stream flow had much bigger constraints on the amount of energetically suitable habitat than did treatment with salmon carcass analogs. Our data indicate that a much larger increase of drifting invertebrates as a result of analog treatment would be required to significantly increase habitat quality for drift-feeding fishes.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Salmon analogs influence stream food webs at multiple levels of biological organization

We used an experiment and a mark-recapture study of juvenile coho salmon (*Oncorhynchus kisutch*) in natural streams of the Cedar River, USA to test the hypothesis that resource availability, habitat structure, and local density contribute to variability in the productivity, dynamics and composition of stream organisms. In a relatively small-scale mesocosm study, we examined the responses of primary producers, invertebrates, and fish to manipulation of habitat structure (small wood) and resource availability (salmon analogs) in a fully factorial design. In six nearby stream receiving adult salmon inputs 100× lower than used in the mesocosm experiment, we examined the relative importance of natural variability in prey resource availability, in-stream wood abundance, and local fish density on juvenile coho growth. Adding salmon analogs led to higher concentrations of total phosphorus and nitrogen in water. Despite higher nutrient levels, algal biomass was ~2× lower in channels with analogs perhaps because of enhanced invertebrate consumption. Analogs had multiple positive effects on select invertebrates and life stage: Chironomidae and Baetidae, the dominant benthic invertebrates, were two taxa most affected by analog additions. Chironomidae adult emigration was about 4.3× higher and coho consumption of these adults 3× higher in channels with analogs. This increased flux and consumption of Chironomidae was linked to increased coho body size. Elevated stable carbon (δ13C) and nitrogen (δ15N) isotope ratios of coho in channels with analogs indicate substantial assimilation of marine-derived elements likely mediated by Chironomidae population dynamics. Habitat structure (small wood) was associated with reduced emigration rates of Chironomidae and Baetidae, and algal biomass. In the field, prey flux was positively associated with coho growth after accounting for total fish density, whereas wood abundance had no measureable effect. Similar to the channel experiment, coho in natural streams were predominantly feeding on Chironomidae and other Diptera. Taken together, our study highlights the specific links between individual performance of a fish predator and lower trophic levels, with the mesocosm experiment indicating these linkages may depend upon inputs of nutrients and carbon delivered by adult salmon.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Three years of experimental carbon and nutrient additions in upper Salmon River Basin streams using salmon carcass analogs: what have we learned so far?

Anadromous fishes represent an important linkage between marine and inland aquatic and terrestrial ecosystems. These fishes carry organic matter and marine-derived nutrient (MDN) subsidies across a vast landscape, often with profound influences on recipient ecosystem food web structure and function. In the Columbia River Basin, century-long declines in the abundance of anadromous fish populations have lead to the implementation of mitigation efforts designed to address MDN deficits. As part of the Salmon River Basin Nutrient Enhancement project, we are conducting a large-scale experiment designed to evaluate the efficacy of artificial carbon and nutrient treatments (e.g., salmon carcass analog or SCA) intended to increase the freshwater productivity of streams in the upper Salmon River Basin. Specific project objectives include the quantification and assessment of both structural and functional components of the stream food web in treatment streams receiving two levels (high and low) of SCA additions and control streams that do not receive SCA additions. We used upstream-downstream and before-after comparisons in control and treatment streams (Multiple Before-After Control-Impact or MBACI design) across a broad spatial and temporal scale. Our preliminary results indicate that stream food web response to SCA is influenced by loading rates (i.e., treatment level) and is at times equivocal. For example, dissolved nutrient concentrations were higher following SCA treatments, while biofilm standing crop did not respond to any treatment level. Meanwhile, whole-stream and benthic gross primary productivity and community respiration increased markedly, but only in a stream receiving high analog treatments. Concurrently, responses were evident for stream food web consumer groups. Benthic and drift macroinvertebrate abundance and biomass increased following SCA additions. However, bioenergetics modeling demonstrated that although drift abundance increased in the short-term, the proportion of suitable habitat available for salmonids, as measured by net energy intake rates, did not respond significantly. Finally, trophic (or direct) transfer of SCA to autotrophic and heterotrophic biofilm communities and macroinvertebrate and fish consumer groups was evident in nitrogen stable isotope measures, but the pathways for assimilation of MDN from SCA and into these producer and consumer groups remains unclear.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Effect of nutrient addition on benthic macroinvertebrates in an ultra-oligotrophic reach of the Kootenai River below a hydroelectric dam

The 7th order Kootenai River is part of the Upper Columbia River ecosystem located in Idaho, Montana, and British Columbia. Though the river was moderately nutrient-limited historically construction of river levees and a large dam further reduced nutrient availability by separating the river from its historic floodplain and interfering with nutrient transport from upstream. Hence, important ecological functions in the Kootenai River have suffered. To help remediate the degraded conditions, a nutrient addition program was initiated at the Idaho-Montana border in 2005. Post-dam productivity of macroinvertebrates in the Kootenai River has been very low. Since macroinvertebrates occupy an important intermediate tropic position between primary and tertiary producer communities, their recovery is important to river and fishery managers. Therefore, to assess the success of nutrient addition, macroinvertebrate data were examined for changes over the pre- and post- nutrient addition periods (2003-2004, and 2005 through 2010). Nonmetric multidimensional scaling (NMDS) was used to explore ecological similarities and dissimilarities in the data. The NMDS analysis produced distinctive clusters related to predefined geological reaches along the river as well as discernible patterns within those reaches that corresponded well to the pre- and post-nutrient addition periods. Before-After Control Impact (BACI) analyses were subsequently used to measure the influence of the large-scale nutrient addition program. Both analyses clearly indicated positive invertebrate responses to nutrient addition, relative to the untreated control zone. Within the nutrient addition zone, increases in macroinvertebrate abundance, biomass, and various species diversity measures were evident. These results are consistent with the nutrient addition responses observed for other trophic level data such as algal growth (chlorophyll) and indicator fish species in the Kootenai River. Together, the positive responses seen in primary, secondary, and tertiary trophic level data confirmed that the nutrient addition program has improved the ecological conditions of the river.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Integrating ecosystem science into fisheries-targeted nutrient enhancement programs aimed to mitigate for the loss of Pacific salmon

Mitigation activities designed to supplement organic matter and nutrient delivery to streams and rivers due to the loss or decline of Pacific salmon intend to enrich productivity via both direct (consumption by fish and macroinvertebrates) and indirect (uptake by microbes and transmission up the food web) pathways. Yet, the microbial dynamics and nutrient uptake patterns that underpin this indirect pathway are rarely studied in the context of these mitigation activities. Here, we report results from two studies in central Idaho designed to address this knowledge gap and that are unique partnerships between fisheries managers, fish ecologists, and ecosystem ecologists who study interactions between organisms and the transformation and flux of energy and matter. In the first study, we added salmon carcasses or salmon carcass analog (pasteurized, pelletized fish meal) to 500-m reaches in tributaries of the Boise River. We observed up to 6 fold increases in total and dissolved nutrient concentrations and 2–8 fold increases in biofilm standing crop 28-days following treatment. However, we estimated that nitrogen (N) demand to fuel this increased biofilm standing crop equaled only 5–8% of the added N, and that approximately 15% of the added N was exported from the treatment reaches in the same time period. In the second study, we added salmon carcass analog to 3-km long reaches in tributaries of the Salmon River, and found that biofilm standing crop did not increase but that biofilm primary productivity and respiration increased 1.5–4 fold one month following addition. Yet, these respiratory losses accounted for <1% of the carbon added. Our combined results suggest that biofilms may process only a small amount of the nutrients added during supplementation, likely because they are constrained by a suite of interacting biotic and abiotic factors. Other likely fates of supplemented nutrients include direct consumption by stream macroinvertebrates and fishes, storage as unprocessed material, transfer to hyporheic zones, or export downstream. Future studies would benefit from construction of nutrient budgets that examine and quantify all of the possible fates of supplemented nutrients in the context of natural stream cycles of nutrient input, transformation and export.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Nutrient enrichment as a fish habitat restoration tool for streams on Vancouver Island, British Columbia.

The addition of limiting nutrients (P and N) to oligotrophic streams on Vancouver Island was first investigated as a tool for restoring fish habitat in 1983. Results from the first three years of enrichment on the Keogh River indicated that juvenile Steelhead and Coho experienced a positive growth response, and a major shift to younger Steelhead smolts was observed in the annual out-migrant population. The technique was later applied to the Salmon River as mitigation for a BC Hydro diversion's operational and footprint impacts in 1989. A significant decline in many Vancouver Island Steelhead populations in 1998 led to development of a regional Steelhead Recovery Plan which included expanding nutrient enrichment to affected watersheds as part of a larger restoration initiative. Other funding sources were secured to support a growing number of enrichment projects which peaked in 2007 at 28 streams in 13 watersheds for a total treatment distance of 272 linear stream kilometers. Increasing pressure from funding organizations to demonstrate measurable biological and fish production effects, beyond the juvenile life stage, has resulted in fewer projects and a shift in monitoring efforts. Recent work includes monitoring the cessation of nutrient enrichment on the Salmon River following 20 consecutive years of treatment, and a more focused assessment of treatment effects in other watersheds.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Managing and mitigating MDN for wildlife: linear solutions for a non-linear problem?

Nutrient amendments to streams to mitigate the loss of salmon nutrients (mdn) is not a new management strategy, except as it might benefit wildlife. However, the affinity that between MDN and the diversity and health of wildlife communities suggests that loss of salmon impacts wildlife and so such impacts should be mitigated. However, studying MDN in relationship to wildlife is challenging. Using isotopes (δ15N and δ13C) to evaluate whether MDN traveled through the food web, we attempted to measure isotope signatures in small mammals, songbirds, and meso-carnivores. However, the ecology and behavior of these species in combination with the characteristics and deployment methods of our treatments limited the assessment of these treatments for wildlife benefit. For example, because of their role in transporting MDN from the river to the riparian ecosystems when directly consuming salmon, we hypothesized black bears (*Ursus Americanus*) would be a good indicator of ecosystem recovery as a result of MDN mitigation. And because insect populations often increase in response to MDN, we also hypothesized bat activity would increase near streams mitigated with MDN and that bats would indirectly consume MDN through the insects. However, neither bears nor bats in our study area exhibited isotope ratios enriched with MDN and we found no significant difference in activity or foraging rates of these species between MDN treated and control streams. The large temporal and ecological mismatch between mitigation applications and the ecology of many wildlife species makes measuring wildlife responses to MDN mitigation problematic. Our lessons learned include: 1) Baseline MDN levels within selected terrestrial species need be established in context to anadromous fish runs, either where salmon runs are largely unaffected or where historical sampling of wildlife species sympatric with anadromous fish runs is available. 2) MDN treatments compounded over multiple reaches are necessary to affect no less than a basin/watershed(s) scale for terrestrial level mitigation match. 3) Temporal scaling of MDN mitigation must fit the natural history of the species to insure MDN pathways and response measurements are appropriate over time.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Nutrient restoration in Dworshak reservoir, Idaho: A bottom up approach enhancing a kokanee fishery

In 2007, the Idaho Department of Fish Game and the U.S. Army Corps of Engineers began a nutrient supplementation project designed to restore declining N:P ratios and lost productivity to Dworshak Reservoir, a 6,900 hectare reservoir in north central Idaho. Ammonium nitrate was applied for nearly four seasons, suspended in late July 2010, and resumed in the spring of 2012. Applications did not result in any violations of water quality standards set forth by the U.S. Environmental Protection Agency and the Idaho Department of Environmental Quality. The project has resulted in increases to the density of picoplankton and the edibility of the phytoplankton community. These increases are presumed to be responsible for increased density and biomass of Daphnia. When comparing kokanee size between supplementation and non-supplementation years with similar fish densities, fish were larger during the supplementation period, particularly in years of high fish density. Kokanee biomass during the supplementation period was 20% higher than the non-supplementation period. The highest biomass observed during supplementation was 40% higher than the highest observed during a non-supplementation year. Increased fish size at a given density is expected to produce higher catch rates in the sport fishery. These results are similar to what has been observed in Kootenay Lake, BC following nutrient supplementation.

Silver bullet or so much fertilizer? Synthesis and dialogue regarding the science and management of nutrient amendments as mitigation tools (Ross and Baxter)

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Nutrient amendments vs salmon runs: What are we trying to accomplish and are we seeing the bigger picture?

Marine nutrients and energy (carbon) from Pacific salmon runs have been shown to boost food web productivity and fish growth and condition throughout the Pacific Northwest and Alaska. Freshwater ecosystems throughout this region are typically oligotrophic, so nutrient additions, either naturally through salmon runs or artificially via nutrient mitigation programs, would be expected to, and do, influence food webs at some scale. But, can we expect artificial nutrient additions to streams, especially when carried out at a characteristically small scale, to have similar effects as real salmon runs? By their nature salmon runs cannot be adequately mimicked by human actions, in spite of our best efforts. In properly functioning salmon ecosystems, multiple salmon species spread nutrients throughout nearly the entire drainage, and asynchrony in the timing of spawning, both within and among multiple salmon species, spreads inputs over much of the year. Some of this material is buried in sediments, frozen in place in winter, and sequestered in biota, further stretching subsidy effects over much of the year. Fluctuating stream flow and terrestrial vertebrates further distribute salmon tissue and nutrients throughout the surrounding terrestrial habitats. Nutrients then stimulate primary producers, but as we've further learned, DOC, detritus from deteriorating salmon carcasses, and salmon eggs and young fry are eaten directly by a myriad of consumers, including aquatic invertebrates and fishes, imparting watershed-scale benefits far beyond what artificial nutrient additions provide. We caution that at best, nutrient augmentation should be viewed as a possible short-term (albeit small scale) tool for temporarily boosting local basal food resources in oligotrophic systems. We recommend that managers considering nutrient amendments proceed with caution, have a good understanding of the extent to which salmon nutrients have declined in a given watershed, and have a well-informed application and watershed monitoring plan in place.

Status, Managment, and Biology of Colorado River Fishes (Stewart)

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Seasonal fish community distributions and movements in two perennial tributaries to the San Juan River

Fish conservation in the Colorado River Basin is primarily focused on native fishes, either threatened and endangered species or native fish experiencing declining ranges such as the “three-species” complex of bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*C. latipinnis*), and roundtail chub (*Gila robusta*). Current research strategies have relied on expanding spatial scales inclusive of tributary streams to determine their roles in supporting the native fish community. We characterized abundance and dispersal of fishes across broad spatial scales, with a focus on two perennial tributaries in the San Juan River: McElmo Creek and Chaco Wash. To identify movement patterns and quantify tributary use of the San Juan River fishes, we tagged individuals >115 mm with passive integrated transponder (PIT) tags in tributary and mainstem San Juan River sites in 2012. Fish detections relied on a stationary PIT antenna array that continuously logged fish movement at the mouth of McElmo Creek complimented by portable PIT antenna that provided periodic measurements of movement at the confluence of Chaco Wash and the San Juan River. We seasonally sampled fish and habitat at standard sites in McElmo Creek and Chaco Wash in June, August, and October of 2012 and March 2013. PIT tag data suggest tributary confluences were used frequently by endangered species and channel catfish, *Ictalurus punctatus*. Sampling data showed McElmo Creek and Chaco Wash differ in species abundances and diversity although both appear to be used seasonally by Colorado pikeminnow, *Ptychocheilus lucius*. McElmo Creek is a notable stream in that it supports all five species of concern, but these species differ in their movement strategies and distribution, especially in more upstream habitats away from the San Juan River. These results suggest perennial tributary habitats are potentially important for multiple life stages of native species but also may provide spawning and foraging habitats for nonnative fishes, especially channel catfish. Future objectives will be to identify ecological correlates to enhance predictions of movement patterns in fishes.

Status, Managment, and Biology of Colorado River Fishes (Stewart)

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Razorback sucker research and monitoring on Lake Mead, Nevada and Arizona

The unique, wild razorback sucker (*Xyrauchen texanus*) population in Lake Mead has been studied since 1996 with collaboration from multiple entities. Several integrated methodologies have been employed to assess wild recruitment, movement patterns, habitat use, and population trends. Sonic telemetry has aided in locating sonic-tagged individuals and unknown spawning areas, and trammel netting in spawning areas has helped capture new, wild razorback suckers. Mark-recapture data has been used to construct population estimates and describe the demographics of this population. In addition, collection of larval razorback suckers and trends in reproductively active adult captures helped determine reproductive success and shifts in annual spawning site locations. This particular population appears to be an anomaly in terms of wild razorback sucker persistence throughout the Colorado River drainage which is plagued with the persistence of non-native fish. To date, nearly 700 unique razorback suckers have been captured from Lake Mead, and a total of 395 have been aged to illustrate the continued recruitment of wild razorback sucker from 1978 through 2008. Aging data demonstrates differences amongst year class strength in Lake Mead, and it is hypothesized that variation is linked to cover conditions within the lake. Annual fluctuations in lake levels, and subsequently changes in the abundance and composition of cover, provide optimism that we will continue to find young, wild cohorts during future efforts. Furthermore, adult movement patterns demonstrate that Lake Mead razorback sucker continue to utilize several areas of the lake during the spawning season. Observations of sonic-tagged fish movements from the Colorado River inflow area into the lower Grand Canyon lend further insight into the role that the river proper may play for this unique razorback sucker population. Finally, a pilot study was initiated in 2012 to focus on juvenile razorback sucker which begins to provide information regarding why Lake Mead razorback sucker are able to demonstrate natural recruitment. Continued research concentrating on this rare life stage should aid in the understanding of recruitment in Lake Mead and provide application to other systems within the historic range of the species.

Status, Managment, and Biology of Colorado River Fishes (Stewart)

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The Lower Colorado River Multi-Species Conservation Program

The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) was created to balance the use of the Colorado River water resources with the conservation of native species and their habitats. The program works toward the recovery of species currently listed under the Endangered Species Act (ESA). The program area extends over 400 miles of the lower Colorado River from Lake Mead to the southernmost border with Mexico, and includes lakes Mead, Mohave, and Havasu, as well as the historic 100-year floodplain along the main stem of the lower Colorado River. The plan will benefit at least 26 species, most of which are state or federally listed endangered, threatened, or sensitive species. The LCR MSCP is committed to the conservation of federally endangered fish along the Lower Colorado River. This fisheries conservation effort is composed of three distinct, but related components: fish augmentation, system monitoring, and species research. The goal of the native fish augmentation program is to conserve the population and genetic diversity of the once flourishing native fish community and contribute to the recovery of the razorback sucker and bonytail. Monitoring the existing populations of razorback sucker, bonytail, and flannelmouth sucker in the system is a key component in the development of a management plan.

Status, Managment, and Biology of Colorado River Fishes (Stewart)

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Adaptive Management of Colorado River Fishes in Grand Canyon: An Overview

The Glen Canyon Dam Adaptive Management Program is a federal advisory committee comprised of 25 stakeholder groups that advises the Secretary of Interior on the effects of dam operations and related management actions on Colorado River resources in Glen and Grand Canyons. Key resources include biological resources such as native and nonnative fishes, sediment, cultural resources, and recreational opportunities. The program's research and monitoring efforts for fish and the aquatic ecosystem, overseen by the US Geological Survey's Grand Canyon Monitoring and Research Center, are focused on native humpback chub *Gila cypha*, an endangered species, and nonnative rainbow trout *Oncochynchus mykiss*, which provide a popular sport fishery. Monitoring activities provide information on fish population status and trends, species distribution and habitat use, as well as status and trends of the aquatic foodbase. Research is directed at minimizing or resolving key areas of uncertainty. These include identifying and understanding factors that control humpback chub and rainbow trout population dynamics, determining the implications of interactions between native and nonnative fishes, and evaluating the effects of dam operations on the aquatic ecosystem. Information on fish and the aquatic ecosystem is collected, analyzed, and provided to managers and stakeholders in support of the ongoing adaptive management process which is designed to protect and benefit downstream resources by improving Glen Canyon Dam operations.

Status, Managment, and Biology of Colorado River Fishes (Stewart)

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A History of Fish Conservation in the Colorado River System

On May 27, 1825, Colonel William H. Ashley wrote from the banks of the Green River near present day Ouray, Utah that his exploration party had been subsisting on fish from the river and that "We find them of an excellent kind of a different speeces (sic) to any that I ever before have seen similar in appearance to our pike." This portentous event marked the European settler's first encounter with the Colorado pikeminnow and a manifest destiny that would challenge the very existence of the fish of the Colorado River System. Subsequent settlement and land development in the west seduced the newcomers into taming the river, and the habitat of the 30 native fish species began to change forever. In 1973, the Endangered Species Act brought the plight of this unique fish community to the attention of the American people, and prompted the need for a better understanding of how to conserve these species and the river ecosystem. Today, six conservation or species recovery programs help to conduct and coordinate research and management of the Colorado River fishes: Upper Colorado River Endangered Fish Recovery Program, San Juan River Basin Recovery Implementation Program, Glen Canyon Adaptive Management Program, Lower Colorado River Multi-Species Conservation Program, Native Fish Work Group, and Lake Mead Razorback Sucker Workgroup. Altogether, these programs expend about $25 million per year to monitor the fish populations, implement management actions, and work to conserve nearly 1,500 miles of the river ecosystem, while balancing the demands for water, flood control, hydropower, and recreation for nearly 40 million people in 7 western states. Ongoing drought-induced water shortage and an increasing human demand continue to challenge biologists, managers, and administrators alike over the conservation of this ancient and most unique of North American fish faunas.

Sturgeon Management and Conservation: what have we learned and where are we headed (Lepla)

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The long and short of it – White sturgeon juvenile growth differences among two Snake River reaches

The Snake River in Idaho currently supports two stable to increasing core populations of white sturgeon. The first, a 106 km impounded reach downstream of Bliss, Idaho, has been sampled annually for age-0 white sturgeon since 2006 and has shown to be capable of producing natural recruitment when favorable spring flow conditions exist. Based on metrics gathered during mark and recapture, the observed juvenile growth rates of white sturgeon in the Bliss reach are among the highest rates observed within the species range. The second, a 224 km impounded reach downstream of Hells Canyon Dam, supports the largest population of white sturgeon in Idaho and displays a stock structure dominated by juvenile white sturgeon < 100 cm fork length. The Hells Canyon reach is currently undergoing its second stock assessment conducted over the last 15 years and is providing the first glimpse of individual growth metrics since the widespread use of pit tags. Preliminary information has shown growth rates of recaptured juvenile white sturgeon in the Hells Canyon reach are among the lowest observed in the Snake River basin, and little is known regarding natural recruitment trends. Although each of these reaches show similar abundance estimates (Bliss 4,051 in 2010 - Hells Canyon 4,171 in 2000) the more desirable length frequency histogram of the Hells Canyon reach may mask the reduced potential for future increasing abundance when compared to the Bliss Reach where white sturgeon presumably reach reproductive size at an earlier age.

Sturgeon Management and Conservation: what have we learned and where are we headed (Lepla)

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Determination of initial inflation of the swim bladder and vulnerability to barotrauma in white sturgeon

During development, larval and juvenile sturgeon drift downstream with river flow and may drift hundreds of kilometers. In the Columbia River Basin, developing sturgeon may pass multiple hydroelectric dams potentially making them vulnerable to injuries. For example, fish passed through turbines commonly suffer from barotrauma as a result of rapid decompression. Barotrauma has been strongly associated with expansion of gasses in the swim bladder of fish. However, it is unknown at what life stage sturgeon fill their swim bladders, which would make them more susceptible to barotrauma. The purpose of this investigation was to determine at what age sturgeon first fill their swim bladders with gas in an effort to assess vulnerability to barotrauma of larvae and juveniles that may pass through turbines of hydroelectric dams. Using hyper/hypobaric pressure chambers, white sturgeon of varying life stages were exposed to pressure decreases. With an inflated swim bladder, exposure to these pressure decreases will cause the fish to become positively buoyant and float upward and possibly expel gas from their swim bladder. Alternatively, if swim bladder inflation has not yet been developed, the fish will not become positively buoyant. As an additional confirmation, x-ray examination of the fish for presence of gas bubbles in the swim bladder or other locations was done to support conclusions from the pressure testing. Although evidence of barotrauma was observed previously, the first filling of the swim bladder was not noted until 11.5 weeks after hatching, well after they had grown out of the larval stage. The presence of gas in the swim bladder was documented by both fish expelling gas from their swim bladders and the presence of gas in the swim bladder visible on x-ray imagery. There was also substantial variation in both the timing of inflation and the size of inflated swim bladders among individuals. However, this study was conducted under controlled laboratory settings and thus results may differ in the wild. Work of this nature has never before been conducted on developing sturgeon and results should improve current understanding of how larval and juvenile fish are affected by hydroturbine passage at dams.

Sturgeon Management and Conservation: what have we learned and where are we headed (Lepla)

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Improving sturgeon management and aquaculture through next generation sequencing

Next generation sequencing is a powerful technique that involves the production of millions of DNA sequence reads in a massively parallel fashion. Recent advances in next-generation sequencing technology now allow the procurement of huge amounts of genetic data on a genome-wide scale both quickly and within the scope of a modest research budget. This method and associated output have the potential to revolutionize fisheries practices and management and to inform fish conservation strategies. Because of a lack of existing knowledge and the duplicated and complex nature of their genomes, next-generation sequencing would be a particularly valuable tool when conducting research on sturgeon species. In this presentation, we will discuss how next generation sequencing can be used for sturgeon genetic marker development (including a marker that is significantly associated with sex assignment), population dynamics and demographic model improvement, and exploration into the mechanisms that govern genetic variation, evolution, adaptation, morphology, and behavior as well as our current research efforts in these areas.

Sturgeon Management and Conservation: what have we learned and where are we headed (Lepla)

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Kootenai River Habitat Restoration Program: An evolving ecosystem-based approach to sturgeon recovery

The Kootenai Tribe of Idaho is implementing a large-scale ecosystem-based habitat restoration program in the Idaho portion of the Kootenai River designed to support recovery of endangered Kootenai River white sturgeon (*Acipenser transmontanus*) and other native fish populations. Habitat alterations including extensive diking, conversion of wetlands, and construction and operation of Libby Dam, have resulted in near extinction of Kootenai sturgeon and significant declines of other native fish populations. Kootenai sturgeon recruitment has been limited or absent since the mid 1950s to 1960s and the population has declined steadily since the 1970s. Kootenai sturgeon were listed as endangered in 1994. The current remnant population of aging wild fish is thought to number less than 1,000. The Tribe, in partnership with other agencies, is implementing a multi-pronged approach to recovery that incorporates research, monitoring, conservation aquaculture, flow management, and habitat restoration. The Tribe's Kootenai River Habitat Restoration Program reflects an evolution in thinking about how to restore Kootenai sturgeon. Initial recovery efforts focused on identifying one or two "silver bullets" such as flow augmentation or substrate placement, to restore natural recruitment. Over time it became increasingly clear that a single species and single life stage focused approach to restoration was potentially detrimental to other components of the ecosystem, failed to address uncertainties about the causes of recruitment failure, and was also short-sighted in terms of long-term survival of Kootenai sturgeon. Another key lesson was the need to incorporate a multi-disciplinary approach when identifying both problems and solutions. The Tribe's refined habitat restoration approach incorporates implementation of a suite of treatments designed to address limiting factors related to morphology, aquatic habitat, riparian habitat and river stewardship. This approach seeks to address larger ecosystem functions in order to restore conditions that support all life stages of Kootenai sturgeon as well as other native fish populations.

Sturgeon Management and Conservation: what have we learned and where are we headed (Lepla)

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Growth of white sturgeon and passage time of fishing tackle after implantation in the digestive system

Angling for white sturgeon Acipenser transmontanus provides a popular fishery in Idaho. However, the fishery has caused managers to consider whether fishing tackle lost by anglers and ingested by white sturgeon is having negative effects on the growth, reproduction, or survival of populations in Idaho. Using hatchery white sturgeon, we implanted circle and J hooks in offset and inline configurations at three levels (1 hook, 5 hooks, and 5 hooks with a monofilament leader and a swivel) into the stomachs of 118 study fish to assess the effects of ingested hooks on growth. We also assessed the length of time tackle persisted in the digestive systems of study fish. After 17 months, all groups showed positive growth, however, data suggests no differences in the fork length, vent length, pectoral girth, or hematocrit levels of fish containing hooks at all treatment levels when compared to controls. X-ray examination of the hooks over time suggests that hooks corrode and break apart in the digestive system of white sturgeon at a faster rate when multiple hooks are present, likely due to the abrasion of surface coatings as hooks rub against each other, exposing the core of the hooks to digestive juices more quickly. Regardless, most of the study fish still retained hooks, or pieces of hooks, 17 months after implanting; only three fish completely eliminated all tackle. Our study provides a glimpse of what happens to white sturgeon and fishing tackle after ingestion. We will use this information as a comparison for a companion study assessing the passage of fishing tackle over time through the digestive systems of wild white sturgeon and as a basis for further experiments.

Sturgeon Management and Conservation: what have we learned and where are we headed (Lepla)

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An investigation of metal ingestion in white sturgeon in the Hell's Canyon Reach of the Snake River, Idaho

Over the past five years, managers at Idaho Department of Fish and Game have observed multiple white sturgeon mortalities in the Hell's Canyon Reach of the Snake River to Lower Granite Dam. Necropsies of these mortalities found hooks and terminal fishing gear within digestive tracts. Because sturgeon are a long lived, late maturing fish species, concerns including decreased condition and increased mortality have risen regarding the potential impacts hook ingestion may have on the population. Such concerns have sparked researchers to look at the possible impacts hook ingestion has by conducting hook and line studies across the Hell's Canyon Reach. A total of 324 sturgeon were sampled in the 2010 - 2011 field seasons to quantify metal ingestion within the population using metal detector scans and x-ray imaging sampling. Overall catch-per-unit-effort was 0.19 and 0.03 fish/hr in 2010 and 2011 respectively. Of the 324 sturgeon sampled, 295 were scanned for metal. In 2010 and 2011, 34% of the 161 and 30% of the 134 sturgeon scanned detected positive for the presence of metal within their digestive tracts. Based on the x-ray imaging of digestive tracts, sturgeon hooks comprised 65% of the hook types found with smaller hooks, likely used for steelhead and bass fishing, making up the remaining 35%. Larger size classes of fish (>150 cm) had a higher occurrence of metal within digestive tracts (>50%). The use of a handheld metal detector to determine metal presence in sturgeon digestive tracts was 97.1% accurate when verified with x-ray. Between the 2010 and 2011 field seasons, a total of 41 sturgeon were recaptured and rescanned for changes in metal disposition. Five sturgeon had a change in metal disposition from metal to no metal being detected in their digestive tracts. This data suggests that, in some cases, metal is being processed out of sturgeon.

Sturgeon Management and Conservation: what have we learned and where are we headed (Lepla)

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Using Physical Habitat Mapping to Better Understand Spawning Requirements for White Sturgeon on the Kootenai River in Idaho

Habitat loss resulting from the construction and operation of Libby dam is thought to be a leading factor in the decline of the Kootenai River white sturgeon (*Acipenser transmontanus*) population. Although conservation aquaculture programs administered by the Kootenai Tribe of Idaho have been successful, significant wild recruitment has not occurred since the 1970's and the wild population is fewer than 1,000 individuals, consisting mainly of old-aged adults. Subsequently, Kootenai sturgeon were listed as endangered in 1996. Recruitment failure occurring at the egg to larvae stage on the spawning grounds is thought to be a major factor for the recruitment failure. Understanding the physical characteristics of where Kootenai sturgeon are spawning is paramount for designing habitat enhancement programs. Idaho Department of Fish and Game (IDFG) is funded by Bonneville Power Administration to monitor and evaluate the effects of Libby dam operations on all life stages of Kootenai Sturgeon. One of the components of this monitoring and evaluation program is determining the spatial and temporal distribution of spawning events by sampling for eggs with egg mats. In a cooperative effort with IDFG and other agencies, United States Geological Survey (USGS) implemented a multi-year program to characterize the physical habitats of selected post-Libby dam spawning sites determined by egg mat sampling. USGS used an acoustic Doppler current profiler (ADCP) to survey flow characteristics including the velocity magnitude and secondary flow structure and backscatter intensity. In addition, USGS also conducted multi-beam hydrographic surveys and underwater videography. Data from both IDFG and USGS field components were imported into a geographic information system for map generation to develop a better visual understanding of the relation between the river morphology and flow velocity structure. These data were used to enhance our understanding of spawning behavior, spawning site selection, and physical habitat characteristics at the current spawning sites. Ultimately, these maps and analyses are being used to guide the design of habitat restoration projects in the spawning reach.

Sturgeon Management and Conservation: what have we learned and where are we headed (Lepla)

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Improving Sturgeon Management and Conservation with Genetic Management Plans: Case Studies from Both Coasts

Genetic management plans (GMPs) use genetic data to make recommendations for improving the management and conservation of fish or wildlife species. Often included in GMPs are recommendations for genetic diversity conservation, the design of genetic monitoring programs, and the prevention of inbreeding and outbreeding depression in supplementation or reintroduction programs. In this presentation, we will discuss the elements of a GMP that would be most valuable for sturgeon management and conservation. The Genetic Stocking Guidelines developed for lake sturgeon in the Great Lakes Basin will be examined as a case study of how GMPs may improve sturgeon management. We will also provide an update on progress towards the development of a GMP for management of Snake River white sturgeon.

Sturgeon Management and Conservation: what have we learned and where are we headed (Lepla)

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Chris Lewandowski (Kootenai Tribe of Idaho)

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

In 1991, the Kootenai Tribe of Idaho constructed an experimental Kootenai River white sturgeon aquaculture facility to determine the feasibility of using wild broodstock to artificially spawn and rear year classes to reverse population decline due to a lack of natural recruitment. The Kootenai Tribal Hatchery began operation in 1992, and has been successfully releasing year classes since 1999. Over the years, the Kootenai Tribal Hatchery was upgraded several times to better serve its purpose; however, the facility still has several limitations that cannot be remedied due to multiple constraints. Therefore, the Kootenai Tribe is currently in final design and pre-construction planning of a new conservation aquaculture facility ("Twin Rivers Hatchery") that will improve and expand white sturgeon and burbot aquaculture in order to restore those species in the Kootenai/y River and Lake. The Twin Rivers Hatchery will increase water supply capabilities with three intake sources (Kootenai River, Moyie River, and groundwater); improve water temperature control; increase rearing capacity to reduce rearing densities; and increase number of families, allowing for incorporation of more wild adults to ensure proper genetic contributions. The goal of the future program is to produce more families while reducing the number of juveniles per family in order to balance genetic considerations with overall population structure considerations. During the design of the new facility, staff knowledge of white sturgeon culture, the necessity to improve certain aspects, and the input from co-managers in terms of current and future Kootenai River white sturgeon 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 program. 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.

The management and science of upriver bright fall Chinook in the Columbia River basin-What are we learning and how can we use it? (Fryer)

Jeffrey Fryer (Columbia River Inter-Tribal Fish Commssion) 729 NE Oregon Street Portland, OR fryj@critfc.org

Factors affecting recovery rates of natural Hanford Reach PIT and coded-wire tagged juvenile fall Chinook salmon

What is likely the largest tagging program on a naturally produced salmon in run is conducted annually on Hanford Reach juvenile fall Chinook where, since 1987, Pacific Northwest fisheries agencies have cooperated to annually coded wire tag up to 200,000 wild Columbia River fall Chinook pre-smolts. This project is funded by the Pacific Salmon Commission to monitor exploitation rates and distribution in fisheries ranging from California to Alaska. Recovery rates of hatchery-tagged Chinook from the adjacent Priest Rapids Hatchery have consistently exceeded those of juvenile Chinook tagged on the Hanford Reach, seemingly challenging the conventional wisdom that naturally reared salmon have higher survival rates than hatchery salmon. Data from juvenile PIT tag studies suggest that this difference can be attributed to survival from release to McNary Dam, which since 1987 has averaged 68.3% for Priest Rapids Hatchery releases compared to 37.4% for Hanford releases. Priest Rapids Hatchery juvenile Chinook are released at a much larger size and have a much quicker migration to McNary Dam than do juvenile Hanford Reach fall Chinook, both of which likely contribute to higher survival. Tagged Priest Rapids Chinook also benefit from a less arduous and disruptive capture and tagging process, and a much longer recovery period from this process, than do tagged Hanford Reach Chinook.

The management and science of upriver bright fall Chinook in the Columbia River basin-What are we learning and how can we use it? (Fryer)

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Fall Chinook Salmon Redd Counts In The Snake River – Moving Toward A New Methodology

Redd counts of Snake River fall Chinook salmon are used to aid resource managers in monitoring this ESA listed fish population. Both shallow-water (aerial - helicopter) and deep-water (remote underwater video) survey methods are used to conduct annual redd searches within the main Snake River. To facilitate the safety of biologists, a new method for conducting aerial surveys is being developed. During the spawning seasons of 2011 and 2012 two types of unmanned air systems (UAS) were tested for conducting redd surveys. Both craft are multi-rotor platforms, are small and lightweight (weighing less than 3 lbs), have auto-stabilizing flight properties, and are able to be pre-programmed to fly specific sets of waypoints. Each craft also have the ability to carry different camera payloads, including video and still photography. In 2011 we tested the application of collecting video at 17 index sites within the Snake River. Each site was able to be surveyed once per week over an eight week period. Data from the video was used to calculate an estimate of total shallow water redds (1,922), and this compared favorably with what was reported by biologists using the traditional helicopter method (1,949). In 2012 we tested the application of collecting still photography at 28 index areas within the Snake River. We again attempted to survey each area once per week over an eight week period. This data is presently being processed; however, redds and fish are clearly visible in the photographs, and we expect a favorable comparison with the traditional helicopter method. In our opinion the use of a small UAS is technically effective, can help reduce overall project costs, and is ultimately safer than traditional helicopter methods.

The management and science of upriver bright fall Chinook in the Columbia River basin-What are we learning and how can we use it? (Fryer)

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Effect of Priest Rapids Dam operations on Hanford Reach fall Chinook salmon productivity

Priest Rapids Dam (PRD) marks the upstream boundary of the Hanford Reach, which supports one of the largest spawning populations of fall Chinook salmon in the Pacific Northwest. PRD is part of a seven-dam hydroelectric complex on the mid-Columbia River that is operated under a load-following mode to meet electrical demand. Therefore, discharge in the Hanford Reach is governed largely by hydropower generation, which can result in substantial hourly and daily fluctuations in discharge. Without operational constraints, these fluctuations could lead to widespread dewatering of redds and stranding or entrapment of juveniles. Therefore, the interim Vernita Bar Settlement Agreement (VBSA) was enacted in 1984 and included management constraints to prevent redd dewatering. In 1999, additional constraints were implemented by the interim Hanford Reach Fall Chinook Protection Program Agreement (HRFCPPA) to limit stranding and entrapment of juveniles. The objectives of our analyses were to 1) determine if alterations to PRD operations as implemented by the VBSA and HRFCPPA altered the pre-smolt/egg productivity of the Hanford Reach fall Chinook salmon population, and 2) identify specific variables that may have affected productivity. We used stock-recruit analyses and analysis of covariance (ANCOVA) to test for a change in density-independent mortality across periods (pre-VBSA , VBSA, and HRFCPPA) to determine whether alterations to dam operations affected productivity. We used decision tree analyses and simple linear regression to identify specific dam operation variables that affected productivity. Results from the ANCOVA indicated there was a significant difference in productivity among periods ($P = 0.01$). The resulting Ricker α (productivity parameter) equaled 0.29 for the pre-VBSA period, 0.63 for the VBSA period, and 0.82 for the HRFCPPA period. Pairwise comparisons revealed that productivity was significantly higher during the VBSA and HRFCPPA periods compared to the pre-VBSA period ($P < 0.05$). The difference in productivity between the VBSA and HRFCPPA periods was not significantly different ($P = 0.58$). Observed relationships from the regression analyses indicated productivity was highest when spawning flows were managed to reduce the elevation at which the majority of redds were built and minimum incubation flows were sufficient to keep redds watered during critical incubation stages.

The management and science of upriver bright fall Chinook in the Columbia River basin-What are we learning and how can we use it? (Fryer)

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Modeling Spatially Explicit Life History Strategies In Juvenile Fall Chinook Salmon: Using Multiple Chemical Signatures to Improve Determination of Source Location

Anthropogenic changes have recently and significantly altered the river system and spawning habitat of Snake River fall Chinook salmon. With these changes have, presumably, come changes to the selective pressures experienced by historical populations. The population has recently undergone major changes in juvenile life history expression, with a large proportion of the population adopting a longer freshwater rearing phase, compared to the historical norm of subyearling migration. Previous work has shown that these life history changes are spatially structured within the spawning areas and may be correlated with stream temperature. In addition, modeling has indicated that the yearling life history may confer higher fitness than other life history strategies. Understanding these life history changes, and modeling their fitness trade-offs, requires a solid understanding of the sources of juvenile fish within the basin. Using both trace elements and strontium isotopes we discuss improvements in our ability to determine the location of wild and hatchery fish within the basin. Otolith microstructure also provides information on growth rates in alternative habitats (rearing, overwintering, estuary and ocean) and the timing of movement between habitats. We discuss integrating these data into a stage structured model of juvenile migration to explore the life history trade-offs in the context of the spatially explicit environmental factors that may be influencing migration timing. Ultimately, these methods will inform our understanding of how mitigation actions can improve the survival of salmonids within spatially variable habitats.

The management and science of upriver bright fall Chinook in the Columbia River basin-What are we learning and how can we use it? (Fryer)

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Assessment of losses of juvenile fall Chinook salmon in the Hanford Reach of the Columbia River in relation to flow fluctuations, 2011 and 2012

The Hanford Reach (Reach) is located on the Columbia River (rkm 557-639) in southeastern Washington State and produces the largest naturally spawning population of fall Chinook salmon in the contiguous United States. Conditions in the Reach are influenced by operation of a seven-dam hydroelectric complex. Constraints on hydroelectric operations were first implemented in the 1980's to provide protections during the spawning and incubation periods. A new agreement was implemented in 2004, which increased protections to include early rearing of salmon fry. The new agreement included provisions to monitor and estimate losses of salmon fry during the years 2011-13. Fluctuations in discharge can cause mortality when fry become stranded on or beneath dewatered substrates or entrapped in isolated pools. Multiple studies of stranding and entrapment have been completed, but this is the first to produce a Reach-wide estimate for the entire period of susceptibility. The first two years of monitoring are completed and the third will begin during March 2013. A stratified random design was used and a total of 2022 sites have been visited. A total of 5413 fry were sampled from 1951 isolated pools and 116 fry were sampled from 84.4 hectares of dewatered shoreline. A hydraulic simulation model was used to generate estimates for the total number of entrapments created and area of dewatered shoreline. The data on fish are highly variable and two-stage bootstrapping was used to generate estimates of total fry losses and variation. It was estimated that a total of 718,664 (21.3/ hectare and 1.4/entrapment) fry were lost during 2011 and a total of 1,627,062 (10.9/hectare and 3.3/entrapment) fry were lost during 2012 due to stranding and entrapment. A recently completed study estimated that approximately 14-184 million pre-smolts were produced annually for brood years 1986-2004 and methodologies are being developed to provide appropriate context for losses of fall

Chinook salmon fry in the Hanford Reach due to stranding and entrapment. Furthermore, this and other studies in the Hanford Reach provide a rich dataset that can be used to better understand stranding and entrapment and guide future protections for upriver bright fall Chinook salmon.

The management and science of upriver bright fall Chinook in the Columbia River basin-What are we learning and how can we use it? (Fryer)

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Introduction to the management and scine of upriver bright fall Chinook in the Columbia River basin: What are we learning and how can we use it?

The management and science of upriver bright fall Chinook in the Columbia River basin-What are we learning and how can we use it? (Fryer)

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Getting Lucky? Are the Hanford Reach fall Chinook salmon highly productive because we know what we are doing, or it is by happenstance?

The Hanford Reach (Reach) of the Columbia River is located in southeastern Washington State and extends from Priest Rapids Dam to the head of McNary Pool (Rkm 557-639). This 82 kilometer reach supports the largest spawning population of fall Chinook salmon in the contiguous United States, which is highly valued for its ecological function and contribution to sport, tribal, and commercial harvest in local, regional, and international fisheries. A new operating license was issued for the Priest Rapids Project in 2008, which included several provisions relating to fall Chinook salmon in the Reach. A cohesive, phased study plan was developed and implemented to investigate the effects of hydroelectric operations on this population of salmon. The general approach was to conduct a productivity assessment in Phase I to identify beneficial or limiting factors when fall Chinook salmon are in the Reach. The second phase is intended to identify the source and magnitude of effects in life-stages where productivity limitations were identified. The third phase will identify and, if appropriate, suggest implementation of measures to avoid, reduce, or mitigate for adverse effects. This presentation will provide a brief overview of results from Phase I studies including hydrodynamic simulations of hydrologic conditions, adult fallback, egg-to-fry survival, life-stage specific productivity, an individual-based life-cycle model, studies on stranded and entrapped fry, hatchery monitoring, and spawning behavior. The stock-recruitment analyses indicate this population is among the most productive in the Pacific Northwest, and the only flow related variables associated with productivity suggested a positive effect (see Harnish et al. in this symposium). Thus, Phase II is focused on filling data gaps such as potential for predation, potential for redd super imposition, data mining for insight into stranding and entrapment of fry, investigation of dissolved oxygen in redds as a source of mortality, and additional PIT-tagging of natural-origin pre-smolts. The results from studies completed during Phase I suggest the

current protections for fall Chinook salmon in the Reach are effective. Furthermore, new insights are shifting our perceptions about how hydroelectric operations effect fall Chinook salmon in the Reach.

The management and science of upriver bright fall Chinook in the Columbia River basin-What are we learning and how can we use it? (Fryer)

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Acclimation Enhances Postrelease Performance of Hatchery Fall Chinook Salmon Subyearlings while Reducing the Potential for Interaction with Natural Fish

One form of pre-release acclimation of hatchery anadromous salmonid *Oncorhynchus spp.* juveniles is to truck the fish to remote points for extended holding at low densities in rearing vessels (e.g., tanks, raceways, in ground ponds) supplied with river water. We conducted a three-year study to determine if such acclimation enhanced postrelease performance of hatchery fall Chinook salmon *O. tshawytscha* subyearlings, and reduced the potential for interaction with natural fall Chinook salmon subyearlings. When compared to hatchery subyearlings released directly to the river just downstream of the acclimation facility: acclimated hatchery subyearlings (1) passed downstream to the third dam encountered during seaward migration faster, (2) passed the dam earlier, and (3) survived from release to the dam tailrace at higher rates. The differences in downstream passage rate and dam passage timing were also much greater between acclimated hatchery and natural subyearlings than between directly released hatchery and natural subyearlings. Thus, acclimation provided a survival advantage to the hatchery fish while reducing the potential for (1) aggressive and non-aggressive social interaction with natural fish when in transit in the three reservoirs, and (2) confinement with natural fish at the three dams where fish collection and raceway holding were followed by transport in tanker trucks. Our findings support acclimation as a method for enhancing postrelease performance of hatchery subyearlings and reducing potential interactions with natural con-specifics.

The management and science of upriver bright fall Chinook in the Columbia River basin-What are we learning and how can we use it? (Fryer)

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Abundance and population composition of hatchery- and natural-origin Snake River fall Chinook salmon from 2005 – 2012 estimated by run reconstruction.

Accurate abundance estimates of federally listed Snake River fall Chinook salmon are critical to evaluating the effectiveness of management actions and natural productivity. We estimated abundance and population composition of Snake River fall Chinook from 2005 – 2012 using run reconstruction methods on fish captured by systematic sampling at the Lower Granite Dam (LGR) trap. Total abundance was determined by the window count after adjusting for night passage and re-ascension using Passive Inductive Transponder (PIT) tag analysis. Population composition was calculated by proportional assignment of the sample count by age, origin, sex and juvenile rearing life history (subyearling or yearling) using age/length tables. Natural-origin abundance was estimated by subtracting the estimated number of unmarked hatchery from the estimated number of unmarked fish in the population. Results demonstrated that run reconstruction estimates of total annual abundance at LGR averaged 5.4% lower than published counts after accounting for night passage and re-ascension, with window counts underestimating adults and overestimating jacks (based on length) compared to the run reconstruction analysis. Estimation of adults and jacks (i.e., one year ocean residents) based on ocean age revealed a higher proportion of jacks, likely resulting from an increased number of adult-sized (>57 cm) one ocean fish with yearling juvenile life histories (both hatchery and natural). Generally, 25% - 45% of the natural-origin adults demonstrated a reservoir-rearing juvenile life history. Natural-origin adult abundance averaged 6,341, ranging from 3,335 in 2008 to 10,983 in 2012 and averaged 26% of total returns and 32% of adult returns. Age composition was significantly different between natural- and hatchery-origin fish, with a higher proportion of ages 4 and 5 fish in the natural population. There was no significant difference in sex composition between hatchery- and natural-origin fish for total fish and adults. Annual adult stray rates, determined by tag recovery expansions, were below 5%. These 2005 – 2012 results indicated that returns of both hatchery- and natural- origin Snake River fall Chinook demonstrated increasing trends and natural-origin returns to the Snake River consistently exceeded the recommended minimum annual viability threshold for delisting (3,000 adults).

The Science of Science Communication: The Art of Telling Compelling Stories in a New Media Environment (Swanson and Ebert)

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Sharing Information with the Public

Scientists need to think about their audience when they want to share their knowledge with the public. It doesn't necessarily mean dumbing down your message but instead crafting your message for the people you expect to read it. They need to say why people should care and appeal to the audience's specific interests. Avoid process when possible. People care about people, critters and places

The Science of Science Communication: The Art of Telling Compelling Stories in a New Media Environment (Swanson and Ebert)

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Jeremiah Osborne-Gowey

Introduction to Key Concepts in Science Communication

This talk is the introduction to the overall symposium. In it we define the format, structure, and process for the rest of this unique, hybrid workshop/symposium. We discuss some of the key concepts critically important to effective science communication. Communicating science between scientists and to non-scientists is a continual challenge. It is important to understand your target audience and medium of communication be it a journal article, poster, conference presentation, newspaper, Facebook post, or tweet as the process for communicating in each can be quite different. Know your audience. Target your product appropriately by addressing the level of technical complexity, language and terminology, and use of graphics. Tailor and hone your message. Share your passion. You are the expert on your research; don't be afraid to show that expertise. Interact with others in a professional manner and maintain your integrity in your research and interactions. When you take a stand on an issue or topic, expect and welcome the debate that may result. Embrace new and novel forms of communication (e.g., social media, blogs, wikis, and other mediums) as they are developed. Investigate them, pick the ones that work best for your personal style and goals, and then actively participate. When at all possible, make your work widely available to others. There's nothing worse than hitting a paywall or restricted website when trying to find information. Write your text and then read it. Aggressively edit and re-edit. Ask for an independent review(s) but don't be afraid about the results. A good review can sometimes be hard to accept but in the end will be constructive and result in a stronger end product. Lastly, actively take part in the discussions. The best discussions are multi-way, not unidirectional. After all, the discussion is already happening. It is high time you helped shape those discussions to ensure your messages are interpreted and applied correctly.

The Science of Science Communication: The Art of Telling Compelling Stories in a New Media Environment (Swanson and Ebert)

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Taking Back Power for Yourself and Your Message

A casual look at the evening news or a daily newspaper will show that the default tools of Powerpoint are not used by people in the business of communicating. Complex data are presented everyday on the stock tables, weather pages, and sports reports of newspapers, where diverse interested people easily understand them. Graphs and visuals on TV or in newspapers are presented only in support of the narrative. Such examples provide better models for communication than the bullet lists and text boxes of Powerpoint. Clear communication is fundamentally no different for scientific information. Have a point, prepare a narrative that clearly makes the point, show only what needs to be seen to support the narrative, and make sure that what you show can be seen by everyone in your audience. It's easy (and uncommon).

The Science of Science Communication: The Art of Telling Compelling Stories in a New Media Environment (Swanson and Ebert)

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Compelling Visuals for Science Stories

Text is the go-to method for communicating science, and it can be used in diverse, compelling ways. But adding a visual element to a science story can help us tell science stories in new ways, engage new audiences, and have a greater, wider impact with our research. Planet Earth was the most watched show in American cable TV history; there's no denying that visuals, video, and multimedia are a great way to attract viewers. This doesn't mean we have to make compromises on the science. Visual science communication is about thinking through the best way to hook and engage our audience. In the visual science communication session, participants will be guided through a discussion of effective examples of visual science communication, gaining insights into best practices for visual science communication. We will discuss how to start practicing visual science communication in your lab or home with accessible, affordable tools, and how to reach out to skilled visual collaboration partners.

The Science of Science Communication: The Art of Telling Compelling Stories in a New Media Environment (Swanson and Ebert)

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Science Narrative Relies on FACTS

Telling a science story through narrative depends on factors ranging from the intended audience, the medium and the message the teller wants to convey. And it depends on the story itself. Finding the right story structure requires considering the reader. Nearly all stories that attract readers revolve around people. A story about white sturgeon conservation must take into account relevant fish biology and the people who have a stake in the sturgeon's future. The narrative structure must weave together people's wants and fishes' needs. To construct a narrative, story framing can be a useful tool. What is the focus? Is it hydropower flow fluctuations and their affect on spawning success? Who are the people in the story – anglers, biologists, outfitters, utility commissioners, ratepayers? Finding people who illustrate a viewpoint that advances readers' understanding underpins narrative journalism. Consider length: A booklet is more tightly focused than a book; a short television spot tells a more condensed story than an hour documentary. But all forms of narrative typically rely on people interacting with the environment in ways that illustrate a theme and advance public understanding. A good story needs a beginning and end. Keys to developing narrative structure involve framing, action, character, trajectory and the science itself. Framing sets the "angle" of the story; action reflects why the story has impact; character brings the people into focus; trajectory sets the story's arc; and science brings credibility to the story. Good science narrative relies on FACTS: Framing, Action, Character, Trajectory and Science.

The Science of Science Communication: The Art of Telling Compelling Stories in a New Media Environment (Swanson and Ebert)

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Science as a Second Language: Communicating Science to Policy and Decision Makers

For fisheries scientists, the biological resources and aquatic ecosystems that are the focus of our work are usually both intensively managed and threatened by human activities. Many of us recognize a disconnect between risks revealed by our scientific findings and the relatively unresponsive actions of policy and decision makers, and there is growing desire to engage more directly in the management and policy arena. But many scientists are uncertain how to effectively communicate with this audience, and some worry that doing so could impair their scientific credibility and objectivity. This presentation offers suggestions for how to "translate" your work for more effective application to natural resource management, policy development and the public policy discourse. Topics will include recognizing and articulating the context and objectives of your work, understanding what policy and decision makers want to know (as well as what they are not interested in), and strategies for getting your message across. As philosopher Ellen Maccarone said, "scientific knowledge is required for making informed environmental policy." This talk is intended to help you be a more effective partner in this important relationship.

Turning mitigation into beneficial conservation for native fish: challenges, successes, and the attempts to reach a comprehensive approach (Meka Carter)

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David Fast (Yakama Nation)

Using hatchery supplementation to sustain fisheries in a barrier-constrained river system

The Upper Yakima River in south-central Washington State, USA is heavily managed for irrigation with three major storage reservoir dams in the upper watershed and five major irrigation diversion dams in the lower watershed. In addition, salmon from the Yakima River encounter 4 major hydroelectric dams on the Columbia River while migrating to and from the Pacific Ocean. Not surprisingly, salmon populations in the Yakima River were severely depressed with many populations extirpated by the mid-1980s. To reverse salmon declines in the Yakima River Basin, the Yakama Nation and collaborators are using a combination of hatchery supplementation and habitat restoration. The Cle Elum Supplementation Research Facility (CESRF) spring Chinook (*O. tshawytscha*) salmon hatchery program began in 1997. This program was designed to test whether artificial propagation can be used to increase natural production and harvest opportunities while limiting ecological and genetic impacts (RASP 1992). It is an integrated hatchery program (Mobrand et al. 2005) because only natural-origin broodstock are used and returning hatchery-origin adults are allowed to spawn in the wild. The program uses the adjacent, unsupplemented Naches River population as an environmental and wild control system. This talk will present results to date from this innovative project.

Turning mitigation into beneficial conservation for native fish: challenges, successes, and the attempts to reach a comprehensive approach (Meka Carter)

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The Clark Fork Settlement Agreement: A Collaborative Approach to Hydropower Relicensing and Native Fish Conservation

In the mid-1990s, Avista Corporation faced the pending relicensing of their two largest projects. Avista chose to avoid the traditional process which typically resulted in drawn out, expensive, and often contentious relicensing efforts, and failure to result in timely relicensing. Avista chose the Alternative Licensing Process, engaging the full spectrum of stakeholders, with the belief that outcomes could provide for more satisfactory results for all of the parties if a collaborative approach was used. Parties included Idaho and Montana agencies, federal agencies, five Indian tribes, local government, and a variety of NGOs. Meetings at both the technical and policy level were structured to not only be inclusive, but to give participants an opportunity to know and learn about each other. By 1999, after some 14,000 hours of meetings amongst technical and policy members of the various stakeholder groups, Avista had settled with the 27 stakeholders engaged in the process. Total value of the mitigation program will ultimately depend on the cost of fish passage and gas abatement facilities, but commits between $200 and $300 million over the course of the 45 year license. Avista began implementing protection, mitigation, and enhancement measures in the Settlement Agreement (SA) a year prior to the scheduled relicensing date. The FERC license was issued on time in 2000, and fully incorporated the SA as the foundation for the license. A key aspect and primary focus of the SA was the conservation of native fishes, with particular emphasis on recently listed bull trout populations in the basin. Most of the mitigation funding is targeted for fisheries, with an emphasis on native fish. Implementation programs are determined by the Clark Fork Management Committee, which is comprised of the 27 signatories to the SA. Decision making requires continued engagement of the parties, and uses a consensus based approach while maintaining authorities of individual agencies. This approach to settlement and implementation has resulted not only in well funded, scientifically based mitigation efforts, but as importantly engages the larger community of stakeholders in a manner that fosters ownership and buy in to the conservation of native bull and cutthroat trout.

Turning mitigation into beneficial conservation for native fish: challenges, successes, and the attempts to reach a comprehensive approach (Meka Carter)

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A collaborative approach for effective watershed restoration in the Lemhi River sub-basin, Idaho.

Using a collaborative approach among multiple stakeholders is an effective strategy for improving fish habitat and supporting the recovery of salmonids on a watershed scale. This is particularly important when addressing limiting ecological factors that are numerous and complex. In the Lemhi River sub-basin in east central Idaho, salmon recovery efforts were initiated in 1992 by designating this tributary as a Model Watershed, meaning habitat actions would be implemented to support anadromous fish recovery. In 2005, Idaho collaboratively developed a habitat action plan to specifically address limiting factors to ESA listed Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*Oncorhynchus mykiss*), and bull trout (*Salvelinus confluentus*). This plan included conservation measures to reconnect ten tributaries with the Lemhi River to provide previously unavailable high quality fish habitat. Multiple candidate tributaries were identified for reconnection and prioritized based on the intrinsic potential of the watershed to support the life history requirements of targeted fish species. Socioeconomic factors were also considered. Lemhi Little Springs Creek (LSC), a previously disconnected spring fed tributary of the upper Lemhi River was one of the tributaries selected. Using a collaborative process among ranchers, resource managers, agency personnel, and nonprofit conservation organizations, a restoration plan for LSC was developed through a Technical Team operated within the Upper Salmon Basin Watershed Program. The plan identified fish limiting factors and prescribed projects to address flow, structural barriers, and degraded stream and riparian habitats. The plan also assigned project responsibility to select collaborative entities, and developed a systematic approach to implementation. From 2006 - 2012, projects were implemented by first restoring habitat in multiple stream segments and replacing culverts and removing irrigation ditch intercepts prior to restoring stream flow. Restoration of the LSC watershed was completed by fall 2012 that included the removal of all irrigation diversions, restoration of flow, and protection of nearly all of the watershed's floodplain. Success of this approach emphasizes a need for coordinated actions to most effectively address the suite of factors limiting current ecological conditions. Further, a coordinated effectiveness M&E program in the Lemhi is documenting response to the restorative actions while simultaneously guiding adaptive management strategies.

Turning mitigation into beneficial conservation for native fish: challenges, successes, and the attempts to reach a comprehensive approach (Meka Carter)

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Collaborative Implementation of the Clark Fork Settlement Agreement: Where the Rubber Meets the Road

Upon agreement of our stakeholder group and submission to FERC, Avista began Settlement Agreement (SA) implementation in 1999. Listed as threatened under ESA in 1998, bull trout (Salvelinus confluentus) are a primary focus of the Clark Fork projects, and is the subject of a comprehensive Native Salmonid Restoration Plan included within the SA. This systematic approach to reestablishing connectivity addresses stock abundance and genetics, suitability of current and potentially available habitats, distribution of non-native species, and pathogen distribution, using an effective long-term monitoring strategy. Initial genetic investigations clearly determined markers for identifying bull trout stream of origin, and a baseline genetic dataset was developed and used to establish a real-time genotyping protocol to ensure fish are transported to the appropriate river reach. This protocol has helped re-establish connectivity in a fragmented system, providing increased numbers of spawning adults for numerically depressed populations in the basin. Upstream passage facilities are being designed and expected to come on-line prior to 2016. To date, over 400 adult bull trout have been passed above Cabinet Gorge Dam. Large scale and complex habitat restoration and conservation work is also occurring. Over 1,700 acres of habitat within native salmonid drainages have been acquired, as well as habitat enhancement/restoration projects completed in 24 key tributaries, accomplishing both project specific goals and water quality enhancement and protection. Non-native fish reduction efforts are met with both social and political resistance. Although initially highly controversial, suppression efforts in Lake Pend Oreille have removed over 150,000 lake trout and resulted in significantly reduced threats to native westslope cutthroat and bull trout while allowing recovery of the bull trout's primary forage base, kokanee salmon. In addition, several high mountain lake brook trout "seed" populations have been eliminated, as well as non-native reduction efforts within an important bull and westslope cutthroat trout spawning and rearing stream. Finally, the SA also funds a bull trout enforcement and education program administered by Idaho and Montana in cooperation with Trout Unlimited. All of these efforts have been, and will continue to be collaboratively undertaken as part of the ongoing efforts of the Settlement Agreement.

Turning mitigation into beneficial conservation for native fish: challenges, successes, and the attempts to reach a comprehensive approach (Meka Carter)

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Success of a Non-traditional Mitigation Project for Okanagan Sockeye

Public Utility District No. 1 of Douglas County, Washington, (Douglas PUD) owns and operates Wells Dam on the Columbia River. Settlement agreements with fish management agencies and tribes require Douglas PUD to mitigate for losses to fisheries resources associated with passage of Wells Dam, including mitigation for sockeye originating in the Canadian Okanagan River Basin. When hatchery mitigation efforts failed to achieve production goals in the early 1990s, Douglas PUD began working with Canadian collaborators to identify other options for meeting mitigation commitments for Okanagan sockeye. At the same time, escapement for Okanagan sockeye dropped to record lows, prompting concerns over imminent extirpation. After numerous studies in the US and Canada to identify factors limiting the natural production of Okanagan sockeye, and after considering numerous mitigation options ranging from cold-water siphons to spawning channels, Douglas PUD and Canadian partners settled on a novel mitigation option: the Fish-Water Management Tool (FWMT)—a computer model to assist water and fisheries managers with water-management decision for the operation of the Okanagan Lake Regulation System (OLRS). The Okanagan River originates at a dam at the outlet of Okanagan Lake in southeastern British Columbia, and flows through two other lakes with outlet dams before reaching Osoyoos Lake, the nursery lake for Okanagan Sockeye. These dams and associated infrastructure comprise the OLRS. Historically, water management of the OLRS had routinely subjected sockeye to redd desiccation and scour events resulting in density-independent mortality that dramatically reduced smolt production. Implementation of the FWMT in 2004 as an alternative to hatchery mitigation has proven a spectacular success by removing the human-induced impediments that suppressed the productivity of Okanagan sockeye, allowing them to rebound to at or above historic abundance. Annual hydroacoustic-survey estimates of sockeye smolt production from Osoyoos Lake have increased from pre-FWMT numbers of approximately 300,000 smolts to post-FWMT numbers of 3,000,000 to over 8,000,000 smolts, with corresponding increases in adult returns. Other Columbia River sockeye populations have not experienced commensurate increases in adult returns. FWMT implementation has also restored the Okanagan Lake kokanee fishery by preventing desiccation of lakeshore redds.

Turning mitigation into beneficial conservation for native fish: challenges, successes, and the attempts to reach a comprehensive approach (Meka Carter)

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Conservation and Mitigation Program: An Overview and progress update of Arizona's Newest Conservation Program

The Conservation and Mitigation Program (CAMP) was created in 2011 to reduce and offset impacts of the Arizona Game and Fish Department's (AGFD) Sportfish Stocking Program as identified through the ESA and NEPA process as the result of Section 7. The CAMP is responsible for fulfilling conservation and mitigation measures for threatened and endangered (T&E), Candidate, and sensitive species that may be affected by the AGFD sportfish stocking program. There are 45 mandatory measures that CAMP will be responsible for fulfilling within the next ten years. The Tucson Region of the Arizona Game and Fish Department is currently working towards meeting these measures through various projects specifically working with the Chiricahua Leopard frog (*Rana chiricahuensi*) and the Northern Mexican gartersnake (*Thamnophis eques megalops*).

Turning mitigation into beneficial conservation for native fish: challenges, successes, and the attempts to reach a comprehensive approach (Meka Carter)

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The Puget Sound Rockfish Conservation Plan: a blueprint for integrated research, management, and recovery

Rockfishes (genera *Sebastes* and *Sebastolobus*) are some of the longest-lived and latest-maturing fish known in Puget Sound, WA. Twenty-eight species are known from Puget Sound, though several uncommonly occur. Other species are, or were, common and provide(d) valuable ecological functions, in addition to being exploited in commercial and recreational fisheries. The complex nature of multi-species fisheries for rockfish, compounded with identification difficulties, makes fishery management challenging. Adding another layer of complexity, fishery management involves elements of federal, state, tribal, local, and municipal government, in addition to numerous non-governmental organizations. Recognizing increasing pressure for resource managers to balance varied public needs to maintain/restore natural stocks, provide sustainable fishing opportunities, fulfill treaty responsibilities, and conserve a healthy ecosystem, and contemporaneous with publication of a status assessment identifying the majority of Puget Sound stocks as being in Precautionary or Depleted status, in 2009 the Washington Department of Fish and Wildlife (WDFW) convened a panel of stakeholders from diverse sectors to develop a comprehensive plan for rockfish conservation. The Plan was developed to guide the evaluation and evolution of WDFW's harvest, research, habitat, and outreach and education programs and consists of a series of policies, strategies, and actions divided into eight complementary categories: natural production; habitat protection/restoration; fishery management; ecosystem function; evaluation, monitoring, and adaptive management; research; outreach, education, and ecotourism; and artificial enhancement. The specific objectives of the Plan are to: 1) provide a framework for preserving rockfish stocks; 2) maintain rockfish populations to achieve cultural, economic, and ecosystem benefits; 3) meet federal and state laws, including treaty obligations; 4) ensure policies are succinct, relevant, and easily understood by the public; 5) set the stage for productive partnerships; 6) use the best available science and fisheries management methods to effectively steward public resources; and 7) monitor and periodically report on Plan implementation and outcomes. An implementation schedule for the Plan is currently under development and work on several significant elements of the plan has occurred over the last several years. Several such actions will be highlighted to demonstrate the collaborative nature of rockfish conservation in Washington.

Turning mitigation into beneficial conservation for native fish: challenges, successes, and the attempts to reach a comprehensive approach (Meka Carter)

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Turning mitigation into beneficial conservation for native aquatic species in Arizona

Mitigation and conservation programs and projects specifically tied to fisheries resources have been developed for decades to offset impacts of various activities including dam construction and operation, water delivery, extractive industry development, and sport fish stocking. In Arizona, a new conservation and mitigation program was recently developed to offset the impacts of sport fish stocking on native aquatic species. There has been a recent movement to use mitigation dollars to a broader extent by considering it as a tool to aid in the restoration and conservation of native aquatic species in a more holistic and comprehensive manner. The mitigation approach or strategy varies by program, but ultimately follows the "avoid, minimize, compensate" concept. When fisheries conservation projects are tied to a mitigation program, it is generally as a result of the protection of the Endangered Species Act for threatened and endangered fish. Thus there becomes a substantial opportunity for fishery managers to develop meaningful and comprehensive conservation and mitigation programs to benefit certain species. However, some of the challenges therein lie with the ability to implement a long-term beneficial conservation program while working with a multitude of partners, matching mitigation actions with existing species recovery or management plans, variability and constraints with funding, and the ability to show measureable success as a result of the program. This presentation will give an overview of Arizona's conservation and mitigation program and discuss the challenges and successes presented in the first two years of its inception.

Turning mitigation into beneficial conservation for native fish: challenges, successes, and the attempts to reach a comprehensive approach (Meka Carter)

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Conservation, Mitigation, Passion and Frustration in a Desert Oasis Called Fossil Creek Arizona

The Arizona Game and Fish Department has partnered with the US Fish and Wildlife Service to develop a Conservation and Mitigation Program as part of its 10 year statewide sportfish stocking consultation. The program includes the hiring of 6 new positions; 5 aquatic specialists and one overseeing program supervisor. The Arizona Game and Fish has committed to spending on average a minimum of $500,000 a year. Through this program a series of 43 conservation measures have been implemented to offset the potential negative impacts of its sportfish stocking activities over a 10 year period. These measures focus mainly on threat reduction, establishing, and securing populations of selected native species that are potentially impacted by stocking activities. Fossil Creek is one of the important native fisheries in the state of Arizona and is one of the key fisheries in our mitigation efforts. Fossil creek has a decade long history of native fish conservation activities including its original renovation in 2004. Native fish remain threatened by reinvasion of non-native smallmouth bass and other unwanted species into this important native fishery. Management of this heavily utilized resource has been rewarding and frustrating over the recent year.