FISH BARRIERS FOR CONSERVATION: FROM DESIGN TO MONITROING AND LESSIONS LEARNED

Evaluating the influence of barriers to movement and stocking history on the spatial extent of hybridization between westslope cutthroat trout and rainbow trout

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In this study we examine whether the presence of fish movement barriers as well as the spatial extent and intensity of stocking rainbow trout (Oncorhynchus mykiss) influences the probability of introgression with westslope cutthroat trout (O. clarkii lewisi) populations. We measured the level of introgression in 32 populations of cutthroat trout that occurred either above or below fish movement barriers along with the frequency and number of rainbow trout stocked in the watershed over a 43-year period. The occurrence and level of hybridization in cutthroat trout was not related to whether the population was above a fish movement barrier or not. In contrast the level of introgression was related to the distance to nearest stocking location and the intensity of stocking rainbow trout. Our data indicate that cutthroat trout populations at distant locations to stocking have a relatively low risk of introgression with rainbow trout; whereas, populations isolated above movement barriers should not be assumed to be free from introgression until a thorough genetic assessment of the population has been made.

The Graduated-Field Fish Barrier: Lessons learned from the use of an innovative technology for blocking upstream movements of invasive and undesirable species.

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Much attention has been given to developing technologies that limit range extensions of invasive or undesirable fish species. While preventing the upstream movements of species that disrupt native fish assemblages, resource agencies must also manage for ecosystem connectivity among indigenous aquatic species. This presentation highlights the use of the Graduated-Field Fish Barrier (GFFB) as a non-lethal tool to block upstream fish movement. We summarize the key elements of the technology and how it works. General fish-barrier design concepts are mentioned along with innovative concepts for sequenced and “on-demand” types of deterrence fields. Our presentation highlights a case study of the “lessons learned” using data from some of the first GFFBs used for invasive species control. We also highlight fish-barrier efficiency results as reported by independent scientists in peer-reviewed, published accounts and non-published, technical reports. We include results from the world’s largest GFFBs for Asian carp deterrence in Chicago to those used for preventing upstream movements of undesirable species in smaller-scale applications world-wide. Of the over 50 GFFBs deployed around the world for fish guidance and deterrence, published studies suggest a high success rate when non-lethal electric fields are the chosen technology to block upstream fish movements.

Deter and conquer: The quest for an effective non-physical migration barrier for invasive sea lamprey

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Sea lamprey (*Petromyzon marinus*) control is essential to biodiversity and a sustainable fishery in the Laurentian Great Lakes and relies on an integrated approach that uses selective pesticides to kill larval sea lampreys in natal streams, barriers to limit access to spawning habitat, and traps to reduce reproductive potential. Migration barriers were the first sea lamprey control tactic deployed during the 1950s and remain a critical component of the program. Non-physical stimuli to block sea lamprey migration have been investigated because they can deter fish without affecting water flow or navigation and can be seasonally operated to allow some non-target fish passage (in contrast physical structures). Here, we describe non-physical stimuli tested as sea lamprey migration barriers and what lessons have been learned. Sea lamprey migration has been minimally deterred by light, sound, and bubbles in experiments conducted to date. Electrical barriers have been used since the 1950s with limited success, but new pulsator technology and electrode configurations are still being investigated and have shown promise. Recent research into species-specific chemical barriers has also shown promise. Migratory sea lampreys are attracted by the odor of larval sea lampreys (pheromone) and are repelled by the odor of dead sea lampreys (alarm substance). A push-pull approach, where the simultaneous use of repellents (the push) and attractants (the pull), may be effective at guiding sea lampreys away from productive spawning streams and into areas that can be effectively treated with lampricides. Combinations of non-physical stimuli targeting multiple sensory modalities will likely prove most effective for blocking sea lamprey migration.

The history of fish barriers in Wyoming

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The utilization of upstream fish migration barriers has been central to cutthroat trout restoration in the western U.S. and Wyoming. In Wyoming, the human creation of fish barriers dates to early European settlers who inadvertently created fish migration barriers in their efforts to irrigate the high plains. Fish managers struggle to address fish habitat fragmentation and when it is appropriate to construct barriers to protect our cutthroat trout resources. Wyoming’s first barriers constructed for cutthroat trout restoration were built with limited understanding of the swimming and jumping abilities of fishes to be excluded and limited foresight into the functionality of the barrier during extreme hydrologic events. Early efforts generally included a desire to create barriers that resulted in minimal disturbance to the stream and surrounding environments. The barriers were built relatively inexpensively. A common attribute of many early fish migration barriers built in Wyoming was that they failed. Fisheries managers have learned from each of these failures and have developed new barrier designs that while relatively new show great promise. While these new designs generally result in larger initial surface disturbance, they are also built to function through flood and drought for generations.

A Fine-scale Assessment of Using Barriers to Conserve Native Stream Salmonids: A Case Study in Akokala Creek, Glacier National Park

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Biologists must often consider where and when to install barriers to prevent invasion of nonnative fishes when managing native salmonids in stream systems. We employed a spatially-explicit approach evaluating stream habitat conditions, and the abundance and genetic diversity of native westslope cutthroat trout *Oncorhynchus clarkii lewisi* within the Akokala Creek watershed in Glacier National Park, and used this information to assess the potential impacts on long-term population persistence under three barrier placement scenarios. The systematic survey of 24 stream reaches found no natural barriers and showed broad overlap in fish population and habitat characteristics. Analysis of population structure using 16 microsatellite loci showed modest amounts of genetic diversity among reaches, with fish from Long Bow Creek the only genetically distinct group. Two scenarios in headwater areas did not meet population size guidance for supporting long-term genetic diversity (2,500 individuals, Ne = 500). Locating a barrier near the mouth and selectively moving non-hybridized migrants is an alternative that meets multiple
biological objectives and may offer the best option to conserve native trout populations in Akokala Creek. Systematic, fine-scale, habitat, fish distribution, and genetic assessments are needed in conjunction with broader assessments to understand the demographic and genetic impacts of isolation management.

**Blocking Sea Lamprey Spawning Runs into Great Lakes Tributaries: Use of, Research on, and Unintended Consequences of Existing and Purpose-Built Physical Barriers**

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The Great Lakes Fishery Commission deploys a sea lamprey barrier program as an effective alternative to the use of pesticides to control the invasive, parasitic sea lamprey (*Petromyzon marinus*) in the Great Lakes basin. Decades of use and research have demonstrated that pre-existing and purpose-built physical barriers successfully deny sea lamprey access to spawning habitat in Great Lakes tributaries. Nevertheless, these barriers can also reduce the passage of non-target fishes. Newer combinations of barriers and fish passage facilities designed to selectively block sea lamprey have been successful, but require manual sorting of fishes. Seasonally operated barriers have also been explored and are less effective for selective passage because sea lamprey migrate over the same time period as many native fishes. Growing interest in removing dams is presenting new management and policy challenges due to the potential for unintended consequences and for trade-offs between the native lake fishes affected by sea lamprey parasitism and the native and desirable non-native fishes affected by sea lamprey barriers. Better decision support systems for selecting barriers for removal could help reconcile these trade-offs in ways benefitting lake and riverine populations of valued fishes.

**Developing Sea Lamprey Control Tactics Alternative to Barriers**

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In addition to pesticides, physical barriers that deny access to spawning habitat are used to control the invasive, parasitic sea lamprey (*Petromyzon marinus*) in the Laurentian Great Lakes. Nevertheless, physical barriers (like pesticides) can have unintended impacts on aquatic ecosystems, and control tactics are needed for use in situations where negative impacts of a barrier outweigh gains to sea lamprey control. Trapping upstream-migrating adult sea lamprey has been explored as a control tactic independent of barriers, but current techniques rarely capture enough adults to effectively reduce reproduction. Trapping downstream-migrating juveniles has also been explored, but suffers from low trapping efficiency as well. Fortunately, recent developments in understanding sea lamprey behavior have shown promise in enhancing trapping of both adults and juveniles. Particularly, manipulating sea lamprey behaviors through the use of pheromone attractants and repellents is hoped to increase the effectiveness of trapping, thus allowing for its use in place of barriers and the potential for increased aquatic habitat connectivity.

**Reliability Demonstration Testing of Electric Field Parameters for Electric Field-Based Aquatic Nuisance Species Dispersal Barriers on the Chicago Sanitary Ship Canal**

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Electric field-based aquatic nuisance species dispersal barrier (EFBANSDB) systems are employed to create zones on the Chicago Sanitary and Ship Canal (CSSC) that invasive fishes cannot swim through. High probability of successful deterrence of encroaching invasive fish and high levels of confidence are chief considerations in the selection of electric field (EF) parameters applied in these electrified zones. Reliability demonstration testing was conducted, sets of electric field parameters for the electrified zones, under controlled conditions, with a scaled model, using live bighead carp Hypophthalmichthys nobilis. Fish were 73 to 141 (M = 104; SD = 9) mm total length. Fish typically demonstrated graded behavioral responses (i.e., first response, flight, loss of posture, immobility) during the testing. The 95/95 reliability standard was achieved with 14 of the 16 sets of electric field parameters tested, including the set of electric field parameters presently targeted for the electrified zones on the CSSC. Pulse frequency, level of relative duty cycle, and fish length were shown to be influential factors in probability for induction of passage preventing behaviors.

**Engineering Cutthroat Trout Conservation: An Evolution in Fish Barrier Design**

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Many native fishes have been negatively impacted by competition or hybridization with non-native species. For example, most subspecies of cutthroat trout (*Oncorhynchus clarkii*) currently occupy only a fraction of their historic range, predominately due to interactions with non-native salmonids. To protect remaining populations or facilitate restoration, management agencies and conservation organizations have increasingly installed barriers to prevent upstream movement of non-native fishes. Fish barriers are costly and often the linchpin of large conservation efforts, thus barrier integrity and effectiveness is paramount. In our experience, fish barrier design has evolved considerably over the past few decades and this presentation follows the change from height-based barrier design models with on-grade downstream aprons to the elevated downstream apron, uniform flow design model. Relatively little information is available regarding fishes swimming and jumping abilities under varying hydraulic conditions and design modifications were born from hard lessons. Hypotheses on the failure mechanisms of some height based barriers are presented. The elevated downstream apron design model seems to eliminate or greatly minimize the conditions that might allow a fish to breach a barrier. Effectiveness monitoring is critical, but many recently installed barriers have not experienced the range of flow conditions necessary to fully assess barrier performance.

**A Decade of Weirs: Lessons learned from the South Fork Snake River, Idaho**

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Since 2000, the Idaho Department of Fish and Game has operated weirs on four major Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri* spawning tributaries of the South Fork Snake River, Idaho with varying degrees of success. The weirs' purpose is to allow for the removal of non-native rainbow trout *O. mykiss* to reduce hybridization and competition with native cutthroat trout. Trapping resident salmonid spawning runs during run-off conditions has presented numerous complications for traditional weir designs. In effort to maximize trapping efficiencies with minimal operational costs, we have employed picket weirs, floating panel weirs, and Mitsubishi weirs. During low flow conditions trapping efficiencies often exceeded 80% with traditional weirs. However, during normal or above average water years, traditional weirs were not always operational. Thus, alternatives to traditional weirs were installed between 2008 and 2010 including three electric weirs and one combination waterfall/velocity barrier weir. Both designs are effective over a broad range of flows. While modified barriers have yielded improved trapping efficiencies, they are not turn key operations. This presentation provides a summary of what we have learned over 14 years of operating weirs during spring, in snow-melt dominated streams and an investigation of spinal injury rates at our electric weirs.
Non-physical barriers and perspectives for use to avoid fish entrance into hydropower turbines exit tube in Brazil

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Several environmental impacts are due to hydropower plants construction and operation and fish mortality in turbines figures among them. Unlike the most common scenario described in North America for fish mortality after passage through the turbines when migrating downstream, in Brazil the problem is related to fish moving upstream and getting trapped inside the turbine exit tube during maintenance events. Available information showed that mortality ranged from several dozens to tonnes of fish, depending on the abundance and biomass below the dam. Thus, strobe light, bubble curtain and alarm substance were tested to evaluate the behavior of the mandi-amarelo (*Pimelodus maculatus*) exposed to these barriers. The results showed that about 90% of the experimental fish were deterred by strobe light using 92 or 360 flashes/min, mostly during the night. Bubble curtain showed 82% of efficacy to deter mandi. Finally, mandi-amarelo showed strong fright reaction to the solution of macerated skin. Alarm substance may be a new tool to guide fish away from the exit tube. Perhaps, for this approach non-physical barriers could be significantly efficient, since below a dam the flow would help in the process of dragging the fish away from the exit tube.

Risk Based Design for Fish Barriers in Muddy Creek, Wyoming

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Muddy Creek, located south of Rawlins on BLM operated land, is currently part of the Conservation Agreement that helps conserve and protect roundtail chub, bluehead sucker, flannelmouth sucker and the Colorado River cutthroat. Wyoming Game and Fish, BLM’s Rawlins Filed Office, and Trout Unlimited have collaborated to ensure the persistence of the populations of these fish throughout the Muddy Creek Watershed. Muddy Creek is currently the only stream system in Wyoming where all of these native species coexist.

Fish barrier management in east-central Arizona streams for Apache Trout recovery

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Apache Trout *Onchorhynchus apache*, once abundant in the White Mountains of Arizona, was listed under the Endangered Species Act as threatened in 1975. Fish migration barriers play a significant role in recovery efforts for existing pure Apache trout populations by isolating them from upstream encroachment of nonnative salmonids. This presentation will examine: goals for the recovery action, terrain and land access of the region, various types of barriers in use on the Apache-Sitgreaves National Forest, challenges of installation and maintenance, specific barrier successes and failures, and future possibilities.

Hydraulic analysis and risk assessment of a proposed fish barrier for Johnson Creek, Utah

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Historically, Yellowstone cutthroat trout occupied large portions of the Raft River drainage in Utah. Currently however, their range in Utah is restricted to isolated patches of headwater tributary streams in the Raft River drainage, including Johnson Creek. Johnson Creek is a remote, small, ungauged tributary with heavy irrigation diversions. In order to maximize protected area, the barrier is desired in the lower extent of the drainage basin. The proposed site is in cooperation with the landowner and irrigation diverter. The irrigation headworks formerly included a small impoundment, headgate and perched ditch. Some years back the dam failed and the Johnson Creek channel captured the irrigation ditch.

Using Fish Barriers to Conserve Native Trout: A Riverscape Perspective Incorporating Source-Sink Dynamics and Use of Barriers in Montana

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A changing climate, nonnative fish species, and human activities have all impacted native trout populations, particularly in lower-elevation, river-bottom habitats that were historically the most productive habitats. Consequently, native trout distributions are increasingly restricted to tributary streams, often in just headwater reaches. Isolation of some headwater populations of native trout using fish barriers is necessary to protect them from invasion by nonnative trout. This isolation will reduce imminent threats due to hybridization, competition, and predation by nonnative species. We speculate that lower reaches of tributaries and rivers were historically source populations (λ > 1) providing surplus fish to headwater sink reaches, but that now they have become sinks (λ < 1). We suggest that headwater reaches are increasingly become sources due to factors listed above. We believe protection of headwater source populations that have no, or extremely low, levels of genetic introgression could provide a relatively long-term source of genetically unaltered fish to downstream areas and that over time, these source populations might "swamp" genetic introgression from low-elevation populations. A total of 41 projects within the upper Missouri River of Montana are reviewed. We provide a decision framework for determining where to locate fish barriers, costs of barriers, and examples from our experiences.