FISH PASSAGE IN GEORGIA: PLANNING FOR THE FUTURE

S. Kyle McKay[1], Lynnette Batt[2], Robert B. Bringolf[3], Steven Davie[4], Duncan C. Elkins[3], and Kathleen Hoenke[2]

AUTHORS: [1]U.S. Army Corps of Engineers - Environmental Laboratory, 248 Georgia Ave., Athens, GA 30606; [2]American Rivers, Raleigh, NC; [3]University of Georgia - Warnell School of Forestry and Natural Resources, Athens, GA; [4]TetraTech, Atlanta, GA.
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Abstract[1]. In 14 major watersheds and thousands of miles of rivers, Georgia's waterways provide some of the highest levels of aquatic biodiversity in the United States. Hydrologic disconnection by dams, roads, water diversions, and other barriers have led to local declines in both migratory and resident fishes. To counteract these trends, numerous organizations and stakeholders have invested in fish passage structures and dam removal. Techniques for prioritizing barrier improvement, measuring passage efficacy, and designing passage structures are rapidly developing in both research and practice. We review the status of fish passage improvement in the state of Georgia as it relates to two key topics. First, what methods exist (or are being developed) to prioritize barrier improvement? Second, what lessons have been learned from recent fish passage and dam removal projects? We address these questions by way of example projects conducted by a variety of agencies and entities. We conclude by summarizing some emerging challenges and opportunities for future research in fish passage improvement.

HYDROLOGIC DISCONNECTION

Hydrologic connectivity is the "water-mediated transfer of matter, energy, and/or organisms within or between elements of the hydrologic cycle" (Pringle 2001). River connectivity can be measured longitudinally (e.g., tributary and mainstem), laterally (e.g., river and floodplain), and vertically (e.g., pelagic and hyporheic zones), all of which can fluctuate in time (Kondolf et al. 2006).

Unfortunately, Georgia's rivers are severely disconnected. The National Inventory of Dams (USACE 2010) identifies 4,606 dams in Georgia, and this data set has been shown to significantly underestimate the quantity of small dams by as much as 10-fold (Ignatius 2009). Road crossings have also been recognized as key sources of disconnection (Forman and Alexander 1998), and a 2011 estimate identified over 119,000 miles of roads in Georgia (GDOT 2011). Disconnection can also occur due to water withdrawals, thermal and water quality barriers, and behavioral obstacles.

The rate of barrier proliferation within creeks and rivers far outpaces the ability of the conservation community to remove existing barriers. In 2009, for example, $11 million were nationally available through the National Fish Passage Program operated by the US Fish and Wildlife Service to restore fish passage. In the 1999 to 2009 period, 749 barriers were removed through this program (USFWS 2009). However, over 6 million fish passage barriers exist in the United States and the number is increasing due to construction of roads and reservoirs, especially near growing metropolitan areas.

The ecological costs of connectivity can be seen in declines in migratory fauna such as sturgeon and shad, disturbance of algal and detrital processing (Freeman et al. 2003), disruption of sediment transport, and altered flow regimes. Notably, reduced connectivity can also have positive effects such as reduced rates of species invasion (Jackson and Pringle 2010).

The extent of disconnection and associated ecological cost has motivated a variety of techniques for restoring hydrologic connectivity (e.g., dam removal, fish ladders, sediment bypasses). Although lateral and vertical connectivity are also critically important, we focus here on longitudinal connectivity in a river network. We also primarily, but not exclusively, discuss connectivity relative to fish movement and passage. We focus our discussion on connectivity restoration at two scales. First we examine barrier prioritization algorithms for selecting restoration sites. Second, we highlight case studies of site-specific restoration projects to emphasize lessons learned and novel views of passage. In light of these discussions, we identify some emerging challenges associated with planning and implementing connectivity restoration projects.

BARRIER PRIORITIZATION METHODS

Because Georgia's streams are increasingly disconnected and because restoration funding is limited, it is paramount that restoration sites be identified strategically. However, identifying the most effective sites for restoration is challenging due to dependency between sites (e.g., a fish cannot pass a second dam if it did not pass the first) and multiple objectives (e.g., fish passage, dam safety, flow regime).

[1] This document summarizes two sessions of the conference focused on fish passage issues.

Figure 1 provides an example of a hypothetical barrier prioritization problem to contrast a few key elements of these algorithms. This schematic shows two barriers with different amounts of habitat upstream and fish passage rates (i.e., the proportion of fish passing a barrier). Based solely on passage rate, Barrier-B is the preferred location for restoration action. If the quantity of upstream habitat is included, Barrier-A is preferred. If passage rates are considered cumulatively and habitat is included, removal of Barrier-A is significantly preferred over Barrier-B. Furthermore, there may be other objectives associated with bi-directional passage (i.e., upstream and downstream), minimizing project cost, maximizing public safety by removing the most dilapidated dam, maximizing transport of sediment and woody debris, or a variety of other issues (Doyle et al. 2003).

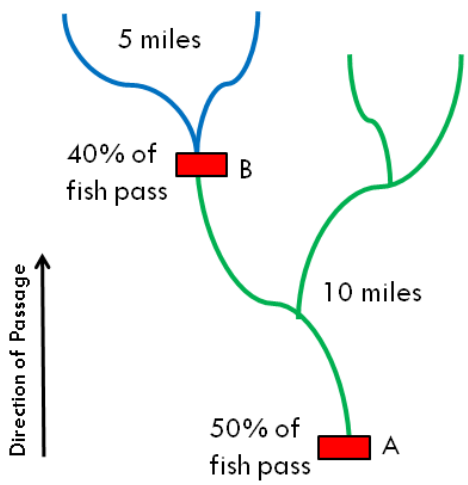

Figure 1: Multiple barriers in a watershed.

Owing to these challenges, there are many algorithms are being developed regionally, nationally, and internationally, both specifically for fish passage (O'Hanley and Tomberlin 2005, Cote et al. 2009, Diebel et al. 2010, O'Hanley et al. 2010, Padgham and Webb 2010, Bourne et al. 2011, O'Hanley 2011) and generally for barrier prioritization (Kuby et al. 2005, Zheng et al. 2009, Martin and Apse 2011). The following sections briefly review five connectivity assessments recently developed or currently being developed in the southeast.

Graph-theory approach to upstream fish passage[2]: A watershed-wide study of fish passage improvement was undertaken for the Truckee River, Nevada (Conyngham et al. 2011). This study proposed a metric for calculating accessible habitat which included cumulative passage rates and the total available upstream habitat. This algorithm was further formalized and extended to address complex dendritic watershed shapes using a graph-theory approach that summarizes watershed topology as a simple matrix of zeros and ones (McKay et al. *In review*). Hypothetical watershed simulations were used to test the behavior of this proposed index and examine general trends in watershed connectivity with changing watershed shape, dam locations, number of dams, and passage rates. The new formulation of the index was re-applied to the Truckee River watershed to examine all permutations of potential actions to develop a suite of cost-effective, watershed-wide fish passage improvement plans. This study demonstrated the utility of a graph-theoretic approach for tracking connectivity in complex watersheds. Currently, this work is being extended to incorporate downstream passage rates into the connectivity index.

Comparing barrier prioritization methods[3]: While large dams are the most obvious barriers to aquatic organism passage, smaller structures, such as milldams, low-water crossings, and culverts, far outnumber large dams on the landscape. Moreover, because they are so numerous and diverse in age and construction, the aggregate effects of these small structures on aquatic connectivity is unquantified. These effects may be particularly significant in the Southeast, given the region's unique biogeography, i.e., high levels of endemism and numerous non-migratory aquatic taxa. Work underway at the University of Georgia, in cooperation with the USFWS, aims to assess the response of three barrier-prioritization algorithms to the inclusion of both field-surveyed and modeled culvert locations and passability estimates in the underlying dataset. We have selected three watersheds encompassing mountain, piedmont, and coastal plain streams to account for variation in barrier density and construction that may be driven by slope or underlying geology. While these watersheds were selected based on the existence of recent surveys for fish passability, we intend to model the presence and passability of barriers at road crossings (e.g., Diebel, et al. 2010) to simulate the application of these prioritizations to the vast majority of watersheds where no such field surveys exist. Finally, we are developing a mitigation algorithm to reprioritize after the imposition of a new barrier to identify barriers for removal in order to maintain or improve overall watershed connectivity.

North Carolina barrier prioritization[4]: Dam removal has proven to be an effective mechanism of quickly restoring in-stream habitat and returning the system to a free flowing state. However, identification of dam-removal

[2] Presenting author is S. Kyle McKay. Contributors include: John R. Schramski (University of Georgia), Jock N. Conyngham, and Craig Fischenich (U.S. Army Corps of Engineers).

[3] Presenting author is Duncan Elkins. Contributors include Nate Nibbelink (University of Georgia, Warnell School of Forestry and Natural Resources), Will Duncan (U.S. Fish and Wildlife Service)

[4] Presenting author is Kathleen Hoenke.

projects is a tedious task that has to account for multiple social, ecological and hydrologic criteria. Here, a GIS tool for prioritizing removal of dams based on eco-hydrologic and social metrics is presented. The tool uses a hierarchical decision-support framework to rank dams-for-removal, based on criteria such as good habitat and water quality connectivity, increased flow volume downstream, improved dam safety and longer stream mile connectivity, while avoiding social conflicts (Hoenke 2012). Application of the tool is demonstrated for three commonly considered prioritization scenarios that rank dams based on their suitability for removal using: social plus ecological criteria, ecological criteria, and enhanced habitability of anadromous fishes. The top 20 ranked dams predicted by the tool includes all dams that are currently identified as potential dam-removal projects, indicating that the tool is performing as intended.

FISH PASSAGE IMPROVEMENT PROJECTS

In addition to site selection, a variety of challenges arise at individual restoration sites. Currently, many connectivity restoration projects are being implemented and planned. This section reviews a wide variety past and current projects to present lessons learned in barrier improvement. These projects were selected to represent a range of objectives (e.g., fish passage v. dam removal), scales (e.g., small streams v. large rivers), entities (e.g., non-profit groups v. federal agencies), and other constraints. Each case study will provide a brief introduction and review notable features of the project such as key objectives or constraints, alternatives considered, the logic behind decision making, or institutional frameworks for effectively implementing barrier improvement.

Cost Effective Dam Removal – Scoping and In-House Work on Four Projects in the Pee Dee River Basin, NC[5]: With diminishing funds for conservation and restoration, identifying ways to save money on projects, while still meeting ecological goals, is key. Dam removal is often seen as a high cost activity. However, two factors can help save substantially and in fact make dam removal a particularly cost effective (and ecologically effective) form of stream restoration: 1) matching the project's scope to its level of complexity, and 2) completing some or all of the work in-house through partner teams. We will cover four dam removal projects in the Pee Dee River basin in North Carolina, near the town of Troy: two completed in 2012, and two now in planning and design. We'll discuss the scope of these projects in terms of planning, design, permitting and construction; and the unique role the partner team, led by the US Fish and Wildlife Service, played by doing the work in-house. We estimate that the two dams removed in 2012 realized up to a 400% cost savings relative to completion by traditional means, while showing ecological success.

Gulf sturgeon as hosts for purple bankclimber mussels: interaction of imperiled species[6]: One of the largest impediments to the conservation of many freshwater mussels is the absence of host fish information. Suitable hosts must be present in sufficient numbers and must co-occur at the appropriate time for successful mussel recruitment. However, habitat degradation and fragmentation caused by dams and other anthropogenic alterations may reduce host availability. Host data were lacking for the federally threatened purple bankclimber mussel (*Elliptoideus sloatianus*), which is endemic to the Apalachicola-Chattahoochee-Flint basin (ACF) in Alabama, Florida, and Georgia, and the Ochlockonee basin in Florida and Georgia. Therefore, we tested 29 species of fish in seven families as potential hosts for purple bankclimbers and observed high (79-89%) metamorphosis success with four species of sturgeons: Gulf (*Acipenser oxyrinchus desotoi*), Atlantic (*A. o. oxyrinchus*), lake (*A. fulvescens*), and shortnoses (*A. brevirostrum*). Blackbanded darters (*Percina nigrofasciata*) and Halloween darters (*P. crypta*) were less successful as hosts (34-36% metamorphosis) and the remainder of the fishes we tested were not suitable hosts. The federally threatened Gulf sturgeon also is endemic to, and is the only sturgeon species present in, the ACF but access of this migratory fish to most of the basin is blocked by Jim Woodruff Dam on the Apalachicola River. In the absence of sturgeon upstream of Jim Woodruff Dam, darters appear to have facilitated persistence of this mussel species, but at abundances far lower than historical conditions. This relationship between the purple bankclimber and Gulf sturgeon is the first description of a federally protected fish serving as a host for a federally protected mussel and represents an archetypal example of the role of habitat fragmentation in the ecology of listed species. Recovery of the purple bankclimber and other mussel species will likely require restoration of habitat connectivity for fish passage.

Fish Passage at the New Savannah Bluff Lock and Dam near Augusta, Georgia[7]: The Augusta Shoals on the Savannah River are considered to be historic spawning grounds for a large suite of species, including Federally Endangered Atlantic and shortnose sturgeon. New Savannah Bluff Lock and Dam largely prevents access to the

[5] Presenting author is Lynnette Batt.

[6] Presenting author is Robert B. Bringolf. Contributors include Andrea K. Fritts, Mark W. Fritts II, Douglas L. Peterson (University of Georgia), and Dewayne A. Fox (Delaware State University)

[7] Presenting author is Steven Davie. Contributors include Robert Nelson, Dennis Barnett (Tetra Tech), Luther Aadland (Consultant), Jonathan "Andy" Ashley, Carol Abercrombie, Beth Williams, Joe Hoke (USACE Savannah District), Hope Moorer (Georgia Ports Authority)

Augusta shoals. Design for a fish bypass structure around New Savannah Bluff Lock and Dam is underway in order to mitigate for salinity and habitat impacts associated with the Savannah Harbor Expansion Project. This structure is intended to pass the sturgeon, but will likely provide passage to increasingly imperiled species such as American shad, robust redhorse, and other anadromous species. The fish passage structure will be constructed adjacent to the dam on existing high ground on the South Carolina bank of the river. Tetra Tech is supporting the USACE Savannah District on engineering the bypass structure. The work includes placement of bedding, armor, and weir stones to construct the fish passage facility. The weir stones will require specific placement locations to provide for successful fish passage. The design is a rock-arched rapid system to simulate natural shoals and provide "flow attraction" for particular fish species. A similar solution was designed and constructed on the Cape Fear River near Wilmington, North Carolina at Lock and Dam No. 1.

Figure 3: Artist's rendering of the fish passage facility at New Savannah Bluff Lock and Dam.

EMERGING CHALLENGES

As demonstrated by the diverse examples presented here, techniques for barrier prioritization and improvement are rapidly evolving. The following list identifies some areas that seem particularly challenging for future projects and particularly fertile for future research.

- Estimates of fish passage rates are often quite variable and uncertain. More accurate techniques are needed for both forecasting (before fish passage improvement) and monitoring passage rates (after improvement).
- Fish passage improvement projects are often justified based on critical movement needs of focal taxa such as fish or mussels. However, there are a host of additional benefits to increased connectivity such as changes in ecosystem processes (Freeman et al. 2003). Additional techniques are generally required to estimate the effects of enhanced connectivity on a suite of ecological variables.
- Multiple objectives are often involved in barrier improvement projects, and additional methods for analyzing multi-objective problems can be challenging to develop and apply (Kuby et al. 2005).
- Numerous connectivity indices are being applied to prioritize barriers, but to date the strengths and weaknesses of these metrics have not be compared and contrasted.
- Fish passage improvement has now been applied as compensatory mitigation at a few locations throughout the southeast. Future opportunities may exist to improve migratory corridors through mitigation actions.
- Effectively designing and implementing fish passage improvement will also prove important when barrier removal is infeasible because of economic or social constraints.
- Research aimed at minimizing fish passage impacts while meeting societal needs requires further exploration, especially with regards to linkages between regulations, actual construction, and resulting fish passage.

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