Program Highlights
Salmon Recovery and Restoring Ocean-River Connectivity: Partnering to Assess Change in Diadromous Ecosystem Structure and Function

Historically, efforts to restore Atlantic salmon in Maine have focused primarily on supplementing populations though stocking efforts using various life-stages (1800's-1995). Hatchery efforts have resulted in marginal success (living gene banks with static populations) and remain an important fish conservation tool to sustain populations until conditions limiting productivity and recovery can be improved. NOAA recognizes a need to go beyond hatchery efforts and focus on key factors limiting production. In freshwater, these efforts are achieved by NOAA partnerships with the academic community and other organizations and agencies. Working collaboratively with fishery and habitat managers, NEC staff have served on and led numerous working groups, science steering committees, and graduate committees towards a common goal: **restore the overall structure and function of healthy diadromous ecosystems**. This goal has focused NOAA extramural grants and contracts as well as helped partners to leverage funds from other sources. Many smaller two-year NOAA projects have continued and expanded to bring in additional resources and expertise to address knowledge gaps. The first layer of this work focuses primarily on understanding connectivity issues and complements NEC dam impact analysis work. The second layer addresses broader ecosystem level processes. This brief both describes the approach and highlights findings to date.

Direct impacts caused by dams were identified as immediate challenges to Atlantic salmon throughout the Gulf of Maine (GoM), especially in larger river systems. In freshwater, these challenges include degraded, disconnected, or dammed habitats. Quantitative and independent information on fish passage is essential. Research has quantified site-specific mortality patterns and found that emigrating smolts experience critically high mortality through challenges associated with downstream passage at dams (Holbrook et al. 2011, Stich 2014, Stich et al. 2014). In cutting edge follow-up work, researchers also found that legacy effects of fish encounters with upstream dams accounted for as much as 40% of estuarine mortality (Stich et al. In Press-c). Similarly, regarding adult salmon, Sigourney et al. (*In Review*) used passive integrated transponder (PIT) tags to quantify challenges for returning adults during their upstream migration. They found not only delays in passage and site-specific differences but also that larger fish were less successful in reaching headwater spawning and nursery habitat. These challenges are not unique to Atlantic salmon, but affect all diadromous fish throughout the GoM DPS. Besides associated mortality and passage challenges, these dams also limit the movements of river resident fish. Distributions of diadromous fish within impounded watersheds are often defined by dams in the system. Kiraly (2012), Kiraly et al. (2014a, 2014b), and Kleinschmidt Associates (2009a, 2009b), in consultation with the NEC, determined that the majority of diadromous species were encountered below the lowermost mainstem dam in the Penobscot River. Restrictions in other species were noted as well.

With Atlantic salmon return rates continuing to fall short of escapement goals, a more holistic approach to salmon restoration was developed. The underpinnings to this new approach were laid out by Saunders et al. (2006), who highlighted the importance of a **healthy co-evolved diadromous complex**, of which Atlantic salmon are part, in sustaining healthy ecosystem structure and function. Saunders et al. suggest that a diadromous-focused, multi-species approach to Atlantic salmon restoration will enhance their recovery potential and improve the likelihood of restoring other diadromous species. The advantages of a healthy diadromous community are hypothesized to provide four key ecosystem services of benefit to Atlantic salmon: **Habitat Conditioning** is an ecological process that improves gravel permeability and invertebrate production; **Increased Fish Abundance and Diversity** within a system restores river-marine bio connectivity and forms a more complex and resilient native fish community; **Prey Buffering** occurs when a complex community provides a suite of alternative prey species for salmon predators; and **Marine Derived Nutrients** restore natural energy and nutrient flow between the ocean and freshwater rivers and lakes.

Saunders et al. (2006) noted that many of these **ecosystem services** were diminished in large rivers as a result of mainstem dams and countless barriers (remnant dams and culverts). The Greater Atlantic Regional Office (GARFO), Habitat Restoration Center, NEC, and other partners have initiated the identification and assessment of fish passage barriers within these watersheds in order to implement change. Many passage improvement and dam removal projects have occurred in the GoM based on this work. The largest, the Penobscot River Restoration Project (PRRP), which included the removal of two mainstem dams in 2012 and 2013, and the construction of a nature-like fish bypass at the third dam (2015) provided many research opportunities. Through the efforts of science steering committees, many before-after baseline studies have been initiated. The removal of these dams has allowed access for some fish species to habitats that have been unavailable to them for more than 100 years. The following sections highlight some of these research projects and the information mosaic they provide to test the potential impacts to restoration of these four processes to Atlantic salmon recovery.

Habitat Conditioning – Impacts of barriers and legacy effects of forestry, agriculture, and urbanization have altered Maine rivers through increased siltation and embeddedness of streambeds. NEC has supported numerous projects to investigate diadromous restoration dynamics resulting from dam removal upon these factors. Efforts to date have been focused on a small watershed in the lower Penobscot River. NOAA worked with the town of Brewer to facilitate the removal of two low-head dams that existed a short distance upstream of the mouth of Sedgeunkedunk Stream. NEC staff facilitated and supported a variety of student investigations comparing the pre and post dam removal assessments of species distribution and composition in the stream (Gardner 2010; Hogg 2012). Hogg identified several diadromous species that were present, or existed in greater numbers, in response to the removal action, including Atlantic salmon, alewife, sea lamprey, and rainbow smelt. They also witnessed and documented improved habitat conditioning and increased invertebrate and fish production associated with nest building by lampreys.

Increased Fish Abundance and Diversity – Under present conditions, diadromous fish communities comprise a fraction of their historic total abundance. Community survey work by Kleinschmidt Associates (2009a, 2009b), Kiraly (2012), and Kiraly et al. (2014a, 2014b), documented pre and during dam removal conditions. They found that the majority of diadromous species were quite restricted in distribution. Although post-restoration assessment has only just begun in the mainstem Penobscot River, there are early indications that fish are already occupying habitats that were inaccessible for a at least a century. Blackman Stream has experienced its first run of river herring in more than 100 years; counts of river herring have improved from 12,000 at the former Veazie fish trap to more than 300,000 at the new fish-lift at Milford dam-site. Additionally, there have been significant numbers of American shad counted during the first year of the Milford dam lift operation with more than 800 fish passed upstream (Maine DMR 2013). The benefits of increased abundance of diadromous fish are expected to cascade throughout the ecosystem as sub-watersheds continue to be seeded with contributions of spawning adults.

Beyond freshwater studies conducted by partners, NEC is working within the Penobscot estuary to understand changes in the structure and function of Maine's largest estuary. An NEC survey used several fish capture gears (fyke nets, seine nets, and surface trawls) to evaluate best gears and to generate new information about the estuary fish community (Stevens et al. 2010). Besides capturing 10 of the 12 historical diadromous species in the Penobscot River, NEC staff documented estuarine use by multiple year classes of alewives through monthly trawl surveys (Stevens et al. 2011); NEC is currently collaborating with the University of Southern Maine to describe habitat use by alewives and blueback herring using stable isotopes. Beach seining resulted in the capture of young-of-the-year American shad, which confirmed that shad are spawning in the Penobscot River, which was previously not known (Lipsky et al. 2013). Additionally, collaborative studies with the University of Maine that utilize NEC platforms are investigating both the smallest and largest estuarine living marine resources. Lasley-Rasher et al. (2014) are investigating the drivers of mysid distributions and their role in estuarine ecosystems by sampling on NEC estuary survey cruises; since 2006, the University of Maine has been conducting research on shortnose sturgeon and Atlantic sturgeon (Zydlewski et al. 2011). Much of this research is conducted by acoustic telemetry using NEC platforms as primary sources of information for the outer estuary and Penobscot Bay. The documentation and study of the two sturgeon species completes the complement of the 12 diadromous species historically found in the Penobscot River and Estuary.

Prey Buffering – The added benefit of more fish in DPS watersheds, is that prey buffering may occur. There are two assumptions made when defining the prey buffer hypothesis: 1) individual fish should be similar in size to the fish they are affording protection to (e.g. adult river herring for salmon smolts; adult American shad for adult Atlantic salmon); and 2) overall fish abundance limits salmon exposure to predators as part of a larger more diverse forage base. The first step in understanding overlap is to understand relative abundance and migration timing. NEC estuary survey data have provided information on the timing, location, size range, and abundance of alewife, blueback herring, American shad, rainbow smelt, and other species. NEC telemetry data provide information on salmon smolt migration timing, general ecology, and position in the water column. Together these two data sources help to inform the hypothesis of these diadromous fish acting as prey buffers for Atlantic salmon by supporting modeling of predation exposure.

Increase in productivity through marine derived nutrients –The lack of diadromous fishes within most of the DPS watersheds has resulted in nutrient starved environments. Diadromous fish that migrate from marine environments bring nutrients which have been accumulated during their time in the ocean. As numbers of diadromous species increase, so too will the marine derived nutrients to the system. Unlike Pacific salmon species, Atlantic salmon do not die after spawning, so much of the nutrient contributions are from the diadromous fish suite entering the GoM DPS rivers. Nutrients in Atlantic systems are deposited in the form of waste, spawn, or fish carcasses (e.g. lamprey) which provide additional nutrients to upland watersheds. To evaluate the impact of nutrient additions to a system devoid of marine contributions, NOAA funded a study using the addition of salmon carcass analog to portions of watersheds within the Penobscot River basin above several migration barriers. Guyette (2012) and Guyette et al. (2014) documented a response to the influx of nutrients with increases in the composition and abundance of the macroinvertebrate community as well as increases in ichthyofauna. In addition, Guyette et al. (2013), documented positive associations of nutrients to the growth of juvenile salmon found within the sites that were supplemented with these analogs. The benefits of nutrient inputs are not fully known; further investigation is necessary to explore further the benefits of nutrient inputs and what they mean to system health.

Next Steps

The PRRP is ongoing. The two lower most Penobscot mainstem dams have been removed, construction has begun (2015) on a nature-like fishway to bypass a third facility, and modifications to numerous other hydro-electric facilities have been completed as outlined within the PRRP Agreement. A new fish-lift came online at the lowermost mainstem dam in 2014 and efforts are focused to continually improve its performance and efficiency. Considering the scope, magnitude, and resource investment required implement the PRRP, NOAA (NEC, GARFO and Habitat Restoration Center) are committed to monitoring, evaluating and documenting the ecological benefits and consequences of this massive restoration effort.

Prior to the implementation of the PRRP, a suite of nine studies were developed to inform an ecosystem view of the Penobscot River system before and after dam removal. The studies were designed to document changes in the geomorphology, upstream and downstream fish passage, Atlantic and Shortnose sturgeon dynamics, fish community assemblage and riparian zone while also assessing the impacts of increased marine derived nutrients associated with improved connectivity within the system. This monitoring plan was implemented in 2009 and studies have been conducted annually by a variety of federal, First Nation and university partners. The monitoring program has been supported through funding provided by NOAA, a Recovery and Reinvestment Act award, and leveraged funds from a variety of other sources. Although immediate benefits have been realized post-dam removal, it will take decades for the full suite of ecological benefits associated with this massive restoration effort to be realized. NOAA is committed to continuing this monitoring program well into the future. The information collected on the Penobscot River will inform both small and large scale future restoration projects across the country.

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