NOAA Technical Memorandum NMFS-NE-272

Implementing a Monitoring Framework and Data Archive for Dam Removal: Pre-project Ecological Monitoring of the Lower Penobscot River, Maine USA

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts
December 2021

NOAA Technical Memorandum NMFS-NE-272

This series represents a secondary level of scientific publishing. All issues employ thorough internal scientific review; some issues employ external scientific review. Reviews are transparent collegial reviews, not anonymous peer reviews. All issues may be cited in formal scientific communications.

Implementing a Monitoring Framework and Data Archive for Dam Removal: Pre-project Ecological Monitoring of the Lower Penobscot River, Maine USA

Timothy F Sheehan[1], Molly Payne Wynne[2], George Aponte Clarke[3], Steve Coghlan[4], Mathias Collins[5], Alice Kelley[6], Rodney Kelshaw[7], Daniel Kusnierz[8], Joshua Royte[2], Rory Saunders[9], Catherine Schmitt[10], Karen Wilson[11], Gayle Zydlewski[12], Joe Zydlewski[13]

[1]Northeast Fisheries Science Center, National Marine Fisheries Service, 166 Water St, Woods Hole, MA 02543
[2]The Nature Conservancy, 14 Maine Street, Suite 401, Brunswick, ME 04011
[3]Source to Sea Consulting, 29 Munjoy St, Portland, ME 04101
[4]University of Maine, Department of Wildlife Ecology, 5755 Nutting Hall, Orono, ME 04469
[5]NOAA Restoration Center, National Marine Fisheries Service, 55 Great Republic Dr, Gloucester, MA 01930
[6]University of Maine, School of Earth & Climate Sciences, 5790 Bryand Global Sciences Center, Orono ME 04469
[7]Stantec Consulting Services, Inc, 30 Park Dr, Topsham, ME 04086
[8]Penobscot Indian Nation, Department of Natural Resources, 12 Wabanaki Way, Indian Island, ME 04468
[9]Greater Atlantic Regional Fisheries Office, National Marine Fisheries Service, Maine Field Station, 17 Godfrey Drive - Suite 1, Orono, ME 04473
[10]Schoodic Institute, PO Box 277, Winter Harbor, ME 04693
[11]University of Southern Maine, Department of Environmental Science and Policy, 37 College Ave, Gorham, ME 04038
[12]Maine Sea Grant, 5784 York Complex, University of Maine, Orono ME 04469-5784
[13]US Geological Survey, Maine Cooperative Fish and Wildlife Research Unit, 5755 Nutting Hall, University of Maine, Orono, ME 04469

US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Science Center
Woods Hole, Massachusetts
December 2021

Editorial Notes

Information Quality Act Compliance: In accordance with section 515 of Public Law 106-554, the Northeast Fisheries Science Center completed both technical and policy reviews for this report. These predissemination reviews are on file at the NEFSC Editorial Office.

Species Names: The NEFSC Editorial Office's policy on the use of species names in all technical communications is generally to follow the American Fisheries Society's lists of scientific and common names for fishes, mollusks, and decapod crustaceans and to follow the Society for Marine Mammalogy's guidance on scientific and common names for marine mammals. Exceptions to this policy occur when there are subsequent compelling revisions in the classifications of species, resulting in changes in the names of species.

Statistical Terms: The NEFSC Editorial Office's policy on the use of statistical terms in all technical communications is generally to follow the International Standards Organization's handbook of statistical methods.

TABLE OF CONTENTS

ABSTRACT

The Penobscot River Restoration Project (PRRP) sought to restore self-sustaining populations of sea-run fish through strategic dam removal, improved fish passage, and rebalancing hydropower in Maine's largest watershed. The PRRP culminated with the removal of 2 lower river mainstem dams in 2012 (Great Works) and 2013 (Veazie) and the decommissioning and bypassing of a third in 2016 (Howland). The PRRP offered an opportunity to evaluate a suite of ecological effects of dam removal through long-term monitoring. We briefly summarize the development of a restoration monitoring program from its inception in 2004 and implementation in 2009. We provide an overview of the 9 priority studies that constitute the monitoring program and describe the available pre-dam removal data. All pre-dam removal data and summary reports are archived and publically available at https://apps-nefsc.fisheries.noaa.gov/PRRP. The monitoring program has been ongoing since its implementation and is planned to continue through 2027 to collect data on the long-term ecological responses of large-scale dam removal. Post-dam removal data will be documented and archived in a similar manner as the pre-removal data. These data provide restoration planners, scientists, and managers with information for evaluating project outcomes and may assist with identifying realistic expectations for future dam removal opportunities.

INTRODUCTION

The rivers of the northeastern United States once held large and diverse populations of diadromous fish. Most of these species are currently at or near all-time lows in abundance (Limburg and Waldman 2009), resulting in losses of associated ecological functions (Saunders et al. 2006), as well as sustenance, commercial, and recreational fisheries. These declines can be attributed largely to overfishing, pollution, and dams (Moring 2005; Hall et al. 2011). In freshwater, dams remain among the largest challenges to diadromous fish and their associated recovery programs (NRC 2004). Dams impede upstream and downstream passage, directly and indirectly injure or kill fish as they migrate to and from the ocean, block access to otherwise suitable habitat, change hydraulic characteristics of rivers (typically creating slow-moving impoundments in formerly free-flowing reaches), and alter sedimentation and temperature regimes (USOFR 2009a). Dams are ubiquitous across the United States; in the Northeast, thousands of dams, often associated with 18th and 19th-century mills and log driving, remain impediments to fish passage (Magilligan et al. 2016).

The cumulative ecological effects and economic costs of dams combined with the perilous state of many migratory fish species have led to an increasing number of dam removals in recent years (O'Connor et al. 2015). As the frequency of dam removals has increased, so has the recognition that studies of river conditions before and after dam removal are important, but often lacking (Hart et al. 2002; Palmer et al. 2005; Collins et al. 2007; Bellmore et al. 2017). Incomplete knowledge about the ecological effects of dam removal remains an important challenge in developing well-informed strategies to recover diadromous fish and the ecosystems upon which they rely.

The Penobscot River

The Penobscot River drains an approximately 22,000 km2 watershed, the second largest in New England, (Figure 1). Five major tributaries, hundreds of smaller streams, and an estimated 330 km2 of lakes and ponds contribute to habitat diversity, a key factor in the development and maintenance of historically large runs of native sea-run fish populations including alewife (*Alosa pseudoharengus*), American eel (*Anguilla rostrata*), American shad (*Alosa sapidissima*), Atlantic salmon (Salmo salar), Atlantic sturgeon (Acipenser oxyrinchus oxyrinchus), blueback herring (Alosa aestivalis), rainbow smelt (Osmerus mordax), sea lamprey (Petromyzon marinus), sea-run brook trout (Salvelinus fontinalis), shortnose sturgeon (Acipenser brevirostrum), striped bass (Morone saxatilis), and tomcod (Microgadus tomcod; Trinko Lake et al. 2012). For many of these species, historic population estimates (based in part on commercial catch data) range into the millions of individuals per year; alosine fish populations were at least 2 orders of magnitude greater than they are today (Hall et al. 2011). The construction of mainstem dams initiated in the 1800s limited the upstream extent of anadromy (Saunders et al. 2006) and had significant impacts on harvest (Foster and Atkins 1869).

Fisheries restoration efforts in the Penobscot River, which began in the mid-1800s, initially concentrated on Atlantic salmon, a culturally and economically iconic species (Schmitt 2015). More recently, it has been hypothesized that other diadromous species (alosines, sea lamprey, and rainbow smelt in particular) can provide demographic benefits to Atlantic salmon through 4 specific mechanisms: nutrient cycling (i.e., marine-derived nutrient deposition), habitat conditioning, providing alternative prey for predators of salmon (i.e., prey buffer), and serving as prey for juvenile and adult salmon (Saunders et al. 2006). Although refinement and further testing of these hypotheses remain a priority, recovery of remnant stocks of Atlantic salmon in the United States is moving forward with a multispecies approach. For example, the National Marine Fisheries Service specifically identified “freshwater and estuary migration sites with abundant, diverse native fish communities to serve as a protective buffer against predation” as a primary constituent element of critical habitat for the endangered Gulf of Maine Distinct Population Segment of Atlantic Salmon (USOFR 2009a, 2009b).

Despite the precarious status of many diadromous species, the potential productivity in the Penobscot is large relative to other Northeastern rivers. The Penobscot contains the most potential lake and stream habitat for river herring (alewife and blueback herring) in Maine (Hall et al. 2011), has potential for substantial runs of American Shad (MDMR and MDIFW 2009), and for more than a century has been home to the largest remaining population of sea-run Atlantic salmon in the United States (USASAC 2018). Likewise, relative to other large Northeastern rivers, the Penobscot River watershed has less urban development and relatively few dams (Smith et al. 2008). Given these factors, the Penobscot River is a high priority for restoration of diadromous fish and their concomitant ecological processes (Everhart and Cutting 1968; Martin and Apse 2011).

The Penobscot River Restoration Project

Given the Penobscot River’s restoration potential and to resolve longstanding conflict over the licensing of hydropower operations on the river, a multiparty settlement agreement was signed with the Federal Energy Regulatory Commission (FERC) in June 2004 by one of the primary dam owners on the Penobscot River (PPL Corporation, presently Brookfield Renewable Power Partners), 3 federal agencies (the US Department of Interior's Fish and Wildlife Service, the Bureau of Indian Affairs, and the National Park Service), the Penobscot Indian Nation, 4 State of Maine natural resource agencies (the State Planning Office, the Department of Marine Resources, the Department of Inland Fisheries and Wildlife, and the Atlantic Salmon Commission), and 6 non-governmental organizations (American Rivers, Atlantic Salmon Federation, Maine Audubon, Natural Resources Council of Maine, Trout Unlimited, and the Penobscot River Restoration Trust). This agreement, which came to be known as the Penobscot River Restoration Project (PRRP), outlined a plan to restore self-sustaining populations of native sea-run fish on the Penobscot River through the purchase and removal of the 2 most seaward dams; purchase, decommissioning and construction of a nature-like bypass channel around a third dam; maintenance of preexisting energy generation through increased power generation at 6 dams; and improved fish passage at 4 additional dams (Figure 2).

The Penobscot River Restoration Trust (Penobscot Trust) is a Maine nonprofit organization established in May 2004 to implement the core aspects of the Penobscot River Restoration Project (PRRP). The members of the Penobscot Trust are the Penobscot Indian Nation, American Rivers, Atlantic Salmon Federation, Maine Audubon, Natural Resources Council of Maine, and Trout Unlimited. The Nature Conservancy joined the Penobscot Trust in 2006. The Penobscot Trust is currently a nonstaffed organization as the primary obligations outlined within the multiparty settlement agreement have largely been completed; an executive committee of the core organizations still meets annually to oversee lingering commitments and financial matters.

A Restoration Monitoring Framework

Recognizing a lack of monitoring associated with dam removals nationwide, including the removal of the Edwards Dam on the Kennebec River (Maine) in 1999, as well as related calls for more robust science within the restoration community (e.g., Hart et al. 2002), the Penobscot Trust hosted a forum in 2004 to explore science and monitoring needs associated with the proposed project. A few independent research and monitoring projects were initiated shortly thereafter (e.g., Atlantic salmon smolt migration and survival monitoring).

From 2005 to 2008, a diverse group of government agency staff, academic researchers, and nonprofit representatives, working with the Penobscot Trust, helped create and coordinate the Penobscot River Science Steering Committee, an independent forum for multiple partners to collaborate and communicate about science associated with the PRRP. The Maine Department of Environmental Protection, Penobscot Trust, University of Maine's Senator George J. Mitchell Center for Sustainability Solutions, and the Nature Conservancy provided financial support. The primary product of the committee's work was the development of a "Conceptual Monitoring Framework for the Penobscot River Restoration Project" (Appendix A), henceforth referred to as the Monitoring Framework. The Monitoring Framework focused on potential ecological effects of the proposed dam removals that would not be addressed by existing monitoring and research, and it prioritized the data needed to document the ecological effects of restoration.

The work of the Penobscot River Science Steering Committee, as well as stream barrier removal monitoring guidance developed around the same time (Collins et al. 2007), informed the development of NOAA Fisheries' "Penobscot River Long-term Ecological Monitoring: NOAA Priorities" (Appendix B), which was the agency's prioritized list of long-term monitoring parameters for the project, henceforth referred to as the "NOAA Priorities." The NOAA Priorities were developed in recognition that funding for the full Monitoring Framework would be limited, and therefore, key studies and parameters needed to be identified and highlighted.

The Penobscot Trust and the research community were thus well positioned when federal American Recovery and Reinvestment Act (ARRA) funds became available in 2009. The Penobscot Trust competed for these funds to support Great Works Dam removal and initiate long-term monitoring to evaluate the ecological effects of the PRRP. The total awarded was approximately $1.3M USD. In addition, an Open Rivers Initiative award in 2010 (NA10NMF4630217) also supported some of the pre-removal monitoring as well as monitoring during the dam removals. The funding received supported 9 studies consistent with the Monitoring Framework and the NOAA Priorities and focused on fish community, fish passage, physical habitat, and biological habitat (Table 1).

While the 9 studies formed the core PRRP ecological assessment, additional studies were conducted to address federal permitting requirements for the dam removal. In other cases, researchers saw the restoration as an opportunity to address basic and applied questions of broader origin and implication. Further, state and federal fisheries agencies continued ongoing monitoring efforts associated with endangered species and resource management programs. For example, the Maine Department of Marine Resources continued federally-funded monitoring of sea-run fish passage at the lowest Penobscot River dam (https://www.maine.gov/dmr/science-research/searun/programs/trapcounts.html).

Other studies were, and continue to be, leveraged by the 9 PRRP studies for considerable efficiency and effectiveness. For example, telemetry infrastructure consisting of 117 stationary acoustic receivers were deployed by NOAA in 2005 to examine downstream passage of Atlantic salmon smolt migration. This investigation was a collaboration with the US Geological Survey and the University of Maine with funding from the National Fish and Wildlife Foundation (Holbrook et al. 2011). Given the existing infrastructure, the expansion of fish migration and passage monitoring activities in support of the PRRP monitoring was possible with relatively small fiscal investments (Dionne et al. 2013; Stich et al. 2014, 2015a, 2015b, 2015c, 2015d; Altenritter et al. 2018; Johnston et al. 2019). Similarly, a 2008 fish community survey of the watershed was funded by NOAA and The Nature Conservancy (Kleinschmidt Associates 2009a 2009b). The methodology for this study was adopted and modified by subsequent PRRP investigators (Kiraly et al. 2014, 2015; Watson et al. 2018), and these subsequent monitoring efforts served as a platform to collect samples for other PRRP studies (Wilson and Sherwood 2011).

MONITORING STUDIES AND DATA ARCHIVE

Informed by the Monitoring Framework (Appendix A) and NOAA Priorities (Appendix B), we identified these priority parameters for assessing project outcomes:

(1) fish community structure and function, passage at barriers, assembly of diadromous species at the most seaward dam, and importance of marine derived nutrients and organic matter;
(2) monumented cross sections to document vertical and horizontal channel geometry changes;
(3) sediment grain size distribution at the cross sections to document changes in bed material;
(4) visual monumented records of riparian vegetation and channel configuration;
(5) water quality parameters for assessing and understanding changes in fish habitat use, population numbers, and community structure;
(6) benthic macroinvertebrate community structure as an indicator of aquatic ecosystem habitat quality and water quality; and
(7) wetland and riparian plant communities.

From these priority parameters, 9 core studies were developed and initiated:

(1) Geomorphology: Channel Geometry, Bed Sediments, and Photographic Monitoring;
(2) Water Quality: Water Chemistry, Temperature, and Benthic Macroinvertebrate Monitoring;
(3) Fish Passage: Upstream Passage of Salmon and Other Diadromous Species;
(4) Fish Passage: Downstream Migration of Salmon Smolts;
(5) Fish Passage: Sturgeon Habitat Use and Spawning;
(6) Fish Passage: Assembly, Direction, and Passage Systemwide;
(7) Fish Community: Assemblages and Community Changes;
(8) Wetland and Riparian Habitat Mapping; and
(9) Marine-Derived Nutrients and Ecosystem Function.

Each study has between 1-3 years of pre-dam removal data (2009-2011), and some studies collected data during the 2-year dam removal phase. All studies were repeated post-removal, with some studies ongoing and potentially continuing for many years. All pre-dam removal data and summary reports are archived and publically available at the following: https://apps-nefsc.fisheries.noaa.gov/PRRP/. The following sections provide brief overviews of each study and the location of the archived final reports and data. Although we chose the 9 studies for their combined ability to broadly assess ecological response and to be complementary to the extent possible, these were independent studies and we did not prescribe uniform data formats or deliverables.

Geomorphology: Channel Geometry, Bed Sediments, and Photographic Monitoring

An understanding of the geology and geomorphology of the river is important to the interpretation of the landforms and processes at work within a study area. The underlying bedrock, surficial geology, and post-glacial history have influenced the form and characteristics of the Penobscot River. The river channel within the main stem project area is characterized by rapids and falls as the result of glacial derangement of pre-existing drainage patterns. The channel was shaped by discharges higher than present day, which occurred prior to the drainage shift of Maine's largest body of water, Moosehead Lake, to the Kennebec River following the last great Pleistocene ice sheet (Kelley et al. 2011). It is these factors and unique history that give this portion of the river its distinctive characteristics. In more modern times, the construction of large hydroelectric facilities has greatly impacted the geomorphological characteristics of the river, especially impounded reaches. To assess geomorphic impacts of the PRRP, investigators from the University of Maine School of Earth and Climate Sciences and the US Geological Survey implemented repeat surveys of channel geometry and sediment grain-size distribution.

A series of monumented cross sections were established throughout the project area. These were located to represent the range of fluvial geomorphic settings in each of the affected reaches of the project, including impoundments and free-flowing portions of the river, areas immediately upstream and downstream of dams, and within tributary mouths. In 2009 and 2010, cross sections were surveyed, cross-river photos were taken from each bank in each season, sediment grain size of the unwetted bank of each cross section was characterized, channel bed grain size was determined via video images, and sediment thickness and character of the Great Works and Veazie impoundments were surveyed by using seismic reflection profiling and ground-penetrating radar.

A final report entitled "Geomorphology – FINAL REPORT.pdf" provides a complete overview of the project, methods, data processing, and results. All geomorphology data and a ReadMe file describing the folder structure and contents and the final report are available at https://apps-nefsc.fisheries.noaa.gov/PRRP/Data/index.php?b=Geomorphology.

Water Quality: Water Chemistry, Temperature, and Benthic Macroinvertebrate Monitoring

The quality of water in river systems has many implications for fish and other aquatic species. While dams are commonly thought to have negative effects on water quality and benthic invertebrate communities, largely because of the impounded reaches they create, few available studies provide quantitative data before and after dams are removed.

The Penobscot Indian Nation Water Resources Program (PIN WRP) has been conducting water quality monitoring of numerous physical and chemical characteristics throughout the Penobscot River watershed since the early 1990s. While some monitoring has been conducted intermittently downstream of the Milford Dam, most of the regular monitoring has focused on the river and tributaries upstream of this area. In 2009 and 2010 PIN WRP conducted studies of water quality and benthic invertebrate communities at select sites associated with the Veazie and Great Works Dams to characterize conditions prior to the PRRP. This monitoring had 2 primary objectives: (1) document existing benthic macroinvertebrate community composition to determine if it changes with dam removal and (2) document baseline water quality parameters in the Lower Penobscot River to determine if they change with barrier removal.

A Final Report entitled "Water Quality – FINAL REPORT.pdf" provides a complete overview of the project, methods, data processing and results. The final report is archived at https://apps-nefsc.fisheries.noaa.gov/PRRP/Data/index.php?b=WaterQuality. All pre-removal data are archived publicly on the Penobscot Nation Website: https://www.penobscotnation.org/departments/natural-resources/water-resources/water-quality-data. In addition, water temperature data is incorporated into a statewide model and available at http://db.ecosheds.org/. The pre-removal water quality and benthic macroinvertebrate data from this project are also publicly available on the Water Quality Portal (https://www.waterqualitydata.us/ using ID: PENOBSCOTINDIANNATIONDNR and Project ID: 3). Benthic data and aquatic life criteria determination results are available on the Maine Department of Environmental Protection's website (https://www.maine.gov/dep/water/monitoring/biomonitoring/data.html).

Fish Passage: Upstream Passage of Salmon and Other Diadromous Species

A significant impediment to the recovery of Atlantic salmon populations in Maine is barriers to migration such as associated with hydroelectric facilities (NRC 2004). The Penobscot River is impounded by numerous mainstem and tributary dams that impede access to historic spawning grounds. A number of studies have monitored the migration behavior of relative low numbers of telemetry tagged adults and have concluded that dams impose a significant impediment to upstream migration (Power and McCleave 1980). An alternative approach was implemented in 2002 when adult migrating salmon were tagged with Passive Integrated Transponder (PIT) tag technology to study the upstream migration dynamics (Gorsky 2005). This approach allowed for the monitoring of large numbers of migrating salmon with passive tracking technology. This study identified important aspects of salmon migration in the Penobscot River and highlighted the advantages of PIT tag technology over traditional telemetry technology. To monitor the impacts of the scheduled dam removals associated with the PRRP, the US Geological Survey/University of Maine, Maine Cooperative Fish and Wildlife Research Unit implemented a PIT tag study similar in design to that of Gorsky et al. (2009) to collect pre-assessment data prior to the removal of the two lower most dams. Data collected from the study will be used to assess the factors that influence Atlantic salmon migration to spawning grounds in the Penobscot River.

Fish passage was monitored at 9 dams (Veazie, Great Works, Milford, West Enfield, Weldon (also called Mattaceunk), Howland, Brown's Mill, Guilford Industries, and Pumpkin Hill (also known as Lowell Tannery) in the Penobscot watershed between 2010 and 2011. A minimum of 2 antennas connected to a PIT tag reader was installed at each dam (1 at the entrance to an upstream fishway and 1 at the exit of the upstream fishway). All salmon captured and released upstream from the adult trap at Veazie Dam (lowermost dam in the system) were marked with a 12 mm PIT tag inserted into their dorsal musculature. Once released, tagged salmon migrated upriver to spawning grounds. PIT tag readers recorded the date, time, and unique tag number of any salmon detected at the entrance and/or exit of a fishway.

A final report entitled "Fish Passage – Upstream – FINAL REPORT.pdf" provides a complete overview of the project, methods, data processing, and results. All PIT detection data in the form of an Access database and the final report are available at https://apps-nefsc.fisheries.noaa.gov/PRRP/Data/index.php?b=FishPassage-Upstream.

Fish Passage: Downstream Migration of Salmon Smolts

Barriers to migration such as associated with hydroelectric facilities have been identified as a significant impediment to the recovery of Atlantic salmon populations in Maine (NRC 2004). Interruptions during downstream migration through riverine habitats to the marine environment can significantly decrease the likelihood of survival for a migrating smolt. Immediate or delayed mortality may result from predation, direct injury from turbines, or other dam-related structures (Ruggles 1980; NMFS 2000). Migratory delays may further increase predation risk (Nettles and Gloss 1987; Blackwell et al. 1997) or cause poor synchrony of physiological tolerance to salinity (McCormick et al. 1999) which may increase estuarine mortality (Budy et al. 2002; Ferguson et al. 2006). Anthropogenic changes to conditions in rivers such as dams and pollution have also been shown to influence survival (Ruggles and Watt 1975). To monitor the effects of the scheduled dam removals associated with the PRRP, the US Geological Survey University of Maine, Maine Cooperative Fish and Wildlife Research Unit implemented a smolt migration monitoring study using ultrasonic telemetry technology to collect pre-assessment data prior to the removal of the 2 lowest dams. Data collected from the study will be used to characterize mortality and movement rates of wild and hatchery-reared Atlantic salmon in the Penobscot River.

Smolt migration was monitored throughout the Penobscot River in 2010 and 2011 via the NOAA/USGS/UMaine cooperative telemetry array within the Penobscot River and Penobscot Bay providing detection coverage from release sites through the outer Penobscot Bay. A total of 776 Atlantic salmon smolts were acoustically tagged and released in the Penobscot River in 2010 and 2011 as part of a larger smolt monitoring program. A total of 150 of these tags were purchased under this monitoring program, and the remainder was purchased from other funding sources. All acoustic equipment used in this study was purchased from Vemco Ltd. (Halifax, Nova Scotia). Detection data, including date, time, receiver location, and unique smolt ID were compiled and summarized for all detections. Survival was estimated with Cormack-Jolly-Seber (CJS) mark-recapture models in program MARK.

A Final Report entitled "Fish Passage – Downstream – FINAL REPORT.pdf" provides a complete overview of the project, methods, data processing, and results. All detection data in the form of an Access database, and the Final Report are available at: https://apps-nefsc.fisheries.noaa.gov/PRRP/Data/index.php?b=FishPassage-Downstream.

Fish Passage: Sturgeon Habitat Use and Spawning

Shortnose sturgeon (*Acipenser brevirostrum*) was listed as endangered throughout its range in 1967 under the Endangered Species Preservation Act (predecessor to the Endangered Species Act). National Marine Fisheries Service (NMFS) later assumed jurisdiction for shortnose sturgeon under a 1974 government reorganization plan (38 FR 41370). Shortnose sturgeon are long-lived fish that mainly inhabit slower moving riverine waters or nearshore marine waters, migrating periodically into faster moving fresh water areas to spawn. They occur in most major river systems along the US eastern seaboard. Seasonal distribution and movement patterns of adult shortnose sturgeon in the Penobscot River have been studied since 2006 (Fernandes 2010). To aid in the recovery of the species, it is critical to have a solid understanding of the population dynamics and habitat requirements of the species. Considering that in many river systems, shortnose sturgeon typically migrate upstream from their wintering site in the spring to spawn near the head of tide, or at the first barrier to upstream passage such as a waterfall or dam (Kieffer and Kynard 1993; Cooke and Leach 2004), it is important to have a solid understanding of the timing, location, and habitat requirements of shortnose sturgeon spawning in the Penobscot River in light of the significant changes to the lower Penobscot River as a result of the PRRP dam removals. The University of Maine, School of Marine Sciences implemented a shortnose sturgeon spawning and habitat use project in the Penobscot River to quantify the effects of dam removal on both current suitable habitat and habitat that would become suitable post-restoration.

In 2009, acoustic telemetry and egg/juvenile sampling was employed to identify shortnose sturgeon spawning and habitat use. Shortnose sturgeon were also tagged with acoustic transmitters, and their movements were monitored via the NOAA/USGS/UMaine cooperative telemetry array. Data from this tracking in combination with knowledge of previous migration monitoring and river modeling were used to target suspect spawning areas. Sampling for eggs via artificial substrates and juveniles via D-nets were used to document spawning activity. Refinements to earlier habitat suitability modeling efforts were made by incorporating available substrate data, tidal conditions, and refined bathymetry data. A revised model was used to guide egg and juvenile sampling in 2010 and 2011. The model was also applied to the PRRP impact reach to estimate habitat suitability for shortnose sturgeon spawning and other diadromous fish species and life stages pre- and post-dam removal.

A Master's Thesis entitled "Fish Passage – Sturgeon – FINAL REPORT.pdf" provides a complete overview of the project, methods, and results and serves as a Final Report for this project. All relevant data, a ReadMe file describing the folder structure and contents and the Final Report are available at:
https://apps-nefsc.fisheries.noaa.gov/PRRP/Data/index.php?b=FishPassage-Sturgeon.

Fish Passage: Assembly, Direction, and Passage Systemwide

Dam removals and passage improvements by the Penobscot River Restoration Project were anticipated to improve connectivity and access for diadromous fish species. While individual fish can be tagged and tracked to assess implications for fish passage and connectivity, the PRRP provided a unique opportunity to pilot a novel technique aimed at assessing baseline fish abundance, assemblage, and direction of movement below the lowermost barrier to fish passage. University of Maine, School of Marine Sciences, implemented a project to estimate the number of fish passing a designated location below the head of tide on the Penobscot River via fixed location, side-aspect, split-beam hydroacoustics.

Starting in May 2010 (excluding months of ice cover, typically late April to early November), 2 BioSonics DT-X, 200 kHz, split beam transducers were mounted on opposite sides of the river to sample fish passing perpendicular to flow collecting data at a rate of 10 samples per second per side. All data have been archived and processed, and data ancillary to this project are also being used to verify/validate fish counts and identifications. Several techniques were used to attempt to validate acoustic targets (fish species) in the split beam: boat electrofishing, acoustic, and radio tag data of fish moving through the lower river, fish collected in the Veazie fish trap, and mobile DIDSON surveys.

Many challenges resulted from complications of data collection. While there were significant sources of variation in the data related to environmental variables as well as collection settings and methods throughout the multiple years that data was collected, automated data processing was achieved and enabled continuous abundance estimates from fish tracks. The biggest source of variation in the long-term dataset is due to tidal flux at the sampling site that affects the range of fish detection as well as the background noise signature. Modeling the tidal variation in the dataset allowed automated or near-automated data processing to include more range per data file as well as more total data files to the fish abundance index. Variability in fish abundance can be related to tide, discharge, temperature, diurnal cycle, day length, moon phase, and restoration activities (Scherelis et al. 2020).

A Final Report entitled "Fish Passage – System-wide - FINAL REPORT.pdf" provides a complete overview of the project, methods, data processing, and results. All data files, a ReadMe file describing the data structure and the Final Report are available at: https://apps-nefsc.fisheries.noaa.gov/PRRP/Data/index.php?b=FishPassage-System-wide.

Fish Community: Assemblages and Community Changes

The Penobscot River was once home to a vast array of fish species native to the northeastern US river systems. The construction of dams on the mainstem of the Penobscot River and its tributaries altered the abundance and limited the distribution of resident and diadromous species (Quinn and Kwak 2003; Guenther and Spacie 2006; Catalano et al. 2007; Saunders et al. 2006). Prior to dam-removal, it was important to establish the baseline conditions of these fish assemblages for comparison after dam removal.

The University of Maine, Department of Wildlife, Fisheries, and Conservation Biology, implemented a boat electrofishing survey to quantify the fish assemblage of the Penobscot River. A random-stratified sampling design was developed, which was delineated by accessibility, the location of dams, and broad-scale habitat type on the main-stem Penobscot River between Hampden, ME, and West Enfield, ME. Fixed transects were also incorporated into the survey. Efforts were concentrated toward the downstream end of the study area, under the assumption that fish assemblages will change first at these areas upon dam removal. All captured fish were identified to species, measured to the nearest millimeter, and weighed to the nearest tenth of a gram. Coarse habitat variables were recorded after the completion of each transect including weather, water clarity and color, substrate types present, relative composition of substrate types, flow types encountered, and shoreline vegetation types. The time electrofished for each transect was recorded as a measure of effort. The number of seine hauls was also recorded as the measure of effort for beach seine surveys.

All data were standardized by kilometers of shoreline surveyed and fourth-root transformed prior to further summation and analysis. Catch and effort data were reported, a variety of multivariate analyses were conducted including the construction of species-area curves, non-metric multidimensional scaling (NMDS) was conducted to analyze diversity among strata, and Shannon-Wiener Diversity Indices were estimated by using rarefaction methods.

A Master's Thesis entitled "Fish Community – FINAL REPORT.pdf" provides a complete overview of the project, methods, and results and serves as a Final Report for this project. All relevant data, a ReadMe file describing the folder structure, and the Final Report are available at https://apps-nefsc.fisheries.noaa.gov/PRRP/Data/index.php?b=FishCommunity.

Wetland and Riparian Habitat Mapping

Prior to dam removal, it was important to establish the baseline conditions of wetlands and other riparian areas, the river substrate and emergent vegetation, and invasive species associated with the Veazie, Great Works, and Howland Dam impoundments. Boyle Associates, Environmental Consulting of Westbrook, Maine, implemented a project to inventory wetland and riparian habitat data. Methods outlined in the 1987 USACE Wetlands Delineation Manual (Environmental Laboratory 1987) and the most recent edition of the Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Northcentral and Northeast Region

(Environmental Laboratory 2012) were used. These techniques involved collecting and reviewing background information and conducting on-site survey and delineations as required. Select parcels were evaluated with a walk-over inspection of the entire site to identify topographic, drainage, and vegetation features that would indicate the potential for jurisdiction wetland classification. At each sampling location, field data forms were completed to document vegetation, soil, hydrology, and general site characteristics. Boat surveys were also conducted within all 3 impoundments to help identify riparian wetlands, dominant vegetation, dominant substrate, substrate changes, and presence of invasive species. A Trimble Geo XT (2005 Series) Global Positioning System (GPS) unit and a Geographic Information System (GIS) program were used to locate resources, compile the data, and create maps. Wetland Functional Assessments were also performed pursuant to the approach described by the Army Corps Highway Methodology Workbook Supplement: Wetland Functions and Values (US Army Corps of Engineers 1995).

A Final Report entitled "Wetlands – FINAL REPORT.pdf" provides a complete overview of the project, methods and results. All data, a ReadMe file describing the data and the Final Report are available at https://apps-nefsc.fisheries.noaa.gov/PRRP/Data/index.php?b=Wetlands.

Marine-derived Nutrients and Ecosystem Function

Food-web connectivity can describe the ecological functioning of riverine and adjacent nearshore marine habitats (Pringle 2003). In free-flowing rivers, diadromous fish may integrate productivity between freshwater and marine sources. This connection allows for the productivity of riverine and nearshore marine habitats to not be constrained by internal dynamics or local sources of nutrients. The exchange of nutrients from freshwater environments into marine environments or vice versa may increase the productivity of consumers within the 2 connected habitats (Wipfli et al. 2003; Schindler et al. 2005). Further, increasing connectivity effectively increases ecosystem size and may therefore result in increased food-web complexity as larger ecosystems tend to support higher trophic levels (Post et al. 2000). To evaluate the effectiveness of the PRRP at increasing the connectivity of the Penobscot River and nearshore marine ecosystem and thereby increasing the exchange of nutrients and food-web complexity within these 2 systems, it is essential that baseline ecological conditions prior to the PRRP be described. The University of Southern Maine and Gulf of Maine Research Institute implemented a study to collect and analyze data documenting changes in nutrient exchange and food web complexity.

A total of 1166 freshwater and 531 marine fish specimens representing 17 freshwater and 36 marine species were captured. In addition, invertebrates (particularly mussels and snails) were collected to represent primary and lower trophic level consumers. Sampling took place in the Penobscot River drainage and Penobscot Bay in 2009 and 2010 and in the Kennebec River Drainage and nearby bays in 2010 and 2011. The Kennebec System, which has also been the site of 2 mainstem dam removal projects and has experienced significant increases in river herring since 2000, serves as a comparison as to what the Penobscot system might approximate in the future. Fish from freshwater sites were collected by boat or backpack electroshocker, hook and line, or seine, and invertebrates were collected by hand. Marine fish were collected by angling and by trawl, and invertebrates were collected by trap and by hand. Of the total number of samples collected and archived, 578 fish specimens were analyzed for δ 15N (a measure of the ratio of the 2 stable isotopes of nitrogen, ^{15}N:^{14}N) and δ 13C (a measure of the ratio of the 2 stable isotopes of carbon, ^{13}C:^{12}C) isotope signatures. Nitrogen (δ15N) provides information on species' trophic position whereas carbon (δ13C) provides information on species' energy source (i.e., feeding location).

A Final Report entitled "Marine Derived Nutrients - FINAL REPORT.pdf" provides a complete overview of the project, methods, and results. Information about sampling locations and stable isotope measures for all processed samples have been archived along with the Final Report and are available at: https://apps-nefsc.fisheries.noaa.gov/PRRP/Data/index.php?b=MarineDerivedNutrients.

SUMMARY

Restoration of diadromous species to the Penobscot River, and related ecological and socioeconomic benefits was a priority for tribal, state, and federal agencies, and nongovernmental organizations before the 2004 restoration agreement (MDMR and MDIFW 2009). With the PRRP in place, many of these stakeholders focused their attention on developing and implementing a pre- and post-dam removal monitoring framework designed to evaluate physical and biological effects of restoration. To date, the monitoring and research has been implemented through a collaboration between the Penobscot River Restoration Trust, The Nature Conservancy, NOAA's National Marine Fisheries Service, and many other cooperating investigators. Pre-removal and implementation-phase monitoring is complete. These data provide a baseline for comparison with post-removal results.

This collaboration contrasts with the oft-cited lack of communication among river restoration participants (Cockerill and Anderson 2014; Jahnig et al. 2011; Ryder et al. 2008). The monitoring plan, which was based off of the Monitoring Framework and NOAA Priorities (Appendix A; Appendix B), may not meet the criteria of a "guiding image" as defined by Palmer et al. (2005), but it has facilitated federal, state, university, and private-sector entities in their work toward a common goal. For example, species protection and management plans developed contemporaneously were able to benefit from project monitoring, while setting forth management measures that were expected to support the goals of the restoration project (Dubé et al. 2012; NMFS 2012).

Studies began almost immediately after the restoration agreement was announced, and the majority of studies began 4 years prior to removal of the first dam. This level of pre-project monitoring stands in contrast to the majority of dam removals. In a recent review of dam-removal science, Bellmore et al. (2017) reported that only 9% of dam removals are being studied, and those that are being monitored typically have only 1-2 years of pre-project monitoring. The PRRP occurred during the right time and at the right place, and monitoring activities have been maintained for over a decade. Noteworthy investments have resulted in gains in our understanding of the ecological process associated with river restoration (Appendix C). These efforts have involved federal, state, university, and NGO researchers and managers and have benefitted management strategies and efforts within the Penobscot watershed. Similar efforts should be considered in other watersheds challenged with connectivity issues. However, at a minimum, the results from the monitoring program on the Penobscot River can be used to inform restoration decision making in other watersheds across the United States and globally.

Each of the 9 PRRP studies has between 1-3 years of pre-dam removal data, and they were repeated, according to variable schedules, post-removal. Some studies will continue for many years. All pre-dam removal data and summary reports are archived and publically available at the following: https://apps-nefsc.fisheries.noaa.gov/PRRP/. These are valuable monitoring activities and datasets that enable the quantitative description of the ecological benefits realized by the PRRP. These data may also be useful to other researchers asking different questions about

Penobscot River ecological function. The monitoring framework employed, the various methods used for the 9 studies, and the experiences gained throughout its implementation may serve as a useful for researchers and practitioners elsewhere seeking to evaluate similar restoration activities. The results obtained may also help inform expected outcomes from large-scale dam removals elsewhere where monitoring efforts are not able to be undertaken or are ongoing.

ACKNOWLEDGEMENTS

M. Colligan, K. Damon-Randall, D. Hart, T. Trinko Lake, and J. Trial participated in formative conversations that led to the development of this manuscript. We would also like to thank the Senator George J. Mitchell Center at the University of Maine for providing meeting space and coordination for the Penobscot River Science Steering Committee.

REFERENCES CITED

Altenritter ME, Zydlewski GB, Kinnison MT, Zydlewski JD, Wippelhauser GS. 2018. Understanding the basis of shortnose sturgeon (*Acipenser brevirostrum*) partial migration in the Gulf of Maine. Can J Fish Aquat Sci 75:464-473.

Bellmore,JR, Duda JJ, Craig LS, Greene SL, Torgersen CE, Collins MJ, Vittum K. 2017. Status and trends of dam removal research in the United States. WIREs Water, doi: 10.1002/wat2.1164

Blackwell BF, Krohn WB, Dube NR, Godin AJ. 1997. Spring prey use by double-crested cormorants on the Penobscot River, Maine, USA. Colonial Waterbirds 20:77-86.

Budy P, Thiede GP, Bouwes N, Petrosky CE, Schaller H. 2002. Evidence linking delayed mortality of Snake River salmon to their earlier hydrosystem experience. N Am J Fish Manag 22:35-51.

Catalano MJ, Bozek MA, Pellett TD. 2007. Effects of dam removal on fish assemblage structure and spatial distributions in the Baraboo River. N Am J Fish Man 27:519-530.

Cockerill K, Anderson WP Jr. 2014. Creating False Images: Stream Restoration in an Urban Setting. J Am Water Resour Assoc 50(2):468–482.

Collins M, Lucey K, Lambert B, Kachmar J, Turek J, Hutchins E, Purinton T, Neils D. 2007. Stream Barrier Removal Monitoring Guide. Gulf of Maine Council on the Marine Environment. www.gulfofmaine.org /streambarrierremoval.

Cooke DW, Leach SD. 2004. Implications of a migration impediment on shortnose sturgeon spawning. 24:1460- 1468.

Curry RA, Hughes RM, McMaster ME, Zafft DJ. 2009. Coldwater fish in rivers. Pages 139-158 *in* Bonar SA, Hubert WA, editors. Standard Methods for Sampling North American Fishes. American Fisheries Society, Bethesda, MD.

Dionne PE, Zydlewski GB, Kinnison MT, Zydlewski J, Wippelhauser GS. 2013. Reconsidering residency: characterization and conservation implications of complex migratory patterns of shortnose sturgeon (*Acispenser brevirostrum*). Can J Fish Aquat Sci 70:119–127.

Dubé NR, Dill R, Spencer RC, Simpson MN, Ruksznis PJ, Dunham KA, Cox ON, Gallant K. 2012. Penobscot River: 2011 Annual Report. Maine Department of Marine Resources, Bureau of Sea Run Fisheries and Habitat, Bangor, Maine. xiv + 175 pp.

Environmental Laboratory. 1987. Corps of Engineers Wetlands Delineation Manual. Wetlands Research Program Technical Report, Y-87-1. 143 pp. available at: https://www.lrh.usace.army.mil/Portals/38/docs/USACE%2087%20Wetland%20Delineation%20Manual.pdf

Environmental Laboratory. 2012. Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Northcentral and Northeast Region. Wetlands Regulatory Assistance

Program. ERDC/EL TR-12-1. 176 pp. available at: https://www.mvp.usace.army.mil/Portals/57/docs/regulatory/Website%20Organization/Northcentral%20and%20Northeast%20Regional%20Supplement.pdf

Everhart WH, Cutting RE. 1968. The Penobscot River: Atlantic salmon restoration, key to a model river. Bangor, ME: Penobscot County Conservation Association.

Ferguson JW, Absolon RF, Carlson TJ, Sandford BP. 2006. Evidence of delayed mortality on juvenile pacific salmon passing through turbines at Columbia River dams. Trans Am Fish Soc 135:139-150.

Fernandes SJ, Zydlewski GB, Zydlewski JD, Whipplehauser GS, Kinnison MT. 2010. Seasonal distribution and movements of shortnose sturgeon and Atlantic sturgeon in the Penobscot River estuary, Maine. Trans Am Fish Soc 139:1436-1449.

Foster NW, Atkins CG. 1869. Second report of the Commissioners of Fisheries of the state of Maine 1868. Owen and Nash, Augusta, Maine.

Gorsky D. 2005. Site fidelity and the influence of environmental variables on migratory movements of Atlantic salmon (*Salmo salar*) in the Penobscot River basin, Maine, Master's thesis. University of Maine, Orono.

Gorsky D, Trial J, Zydlewski J, McCleave J. 2009. The effects of smolt stocking strategies on migratory path selection of adult Atlantic salmon in the Penobscot River, Maine. N Am J Fish Man 29:949-957.

Guenther CB, Spacie A. 2006. Changes in fish assemblage structure upstream of impoundments within the Upper Wabash River Basin. Trans Am Fish Soc 135:570-583.

Hall C, Jordaan A, Frisk MG. 2011. The historic influence of dams on diadromous fish habitat with a focus on river herring and hydrologic longitudinal connectivity. Lands Ecol 26:95–107.

Hart DD, Johnson TE, Bushaw-Newton KL, Horwitz RJ, Bednarek AT, Charles DF, Kreeger DA, Velinsky DJ. 2002. Dam removal: challenges and opportunities for ecological research and river restoration. Biosci 52:669–681.

Holbrook CM, Kinnison MT, Zydlewski J. 2011. Survival of migrating Atlantic salmon smolts through the Penobscot River, Maine: a prerestoration assessment. Trans Am Fish Soc 140:1255–1268.

Jähnig SC, Lorenz AW, Hering D, Antons C, Sundermann A, Jedicke E, Haase P. 2011. River restoration success: A question of perception. Ecological applications. Ecol Appl 21(6):2007-2015.

Johnston C, Zydlewski GB, Smith S, Zydlewski J, Kinnison M. 2019. River Reach restored by dam removal offers suitable spawning habitat for endangered shortnose sturgeon. Trans Am Fish Soc 148:163-175.

Kelley AR, Kelley JT, Belknap DF, Gontz AM. 2011 Coastal and terrestrial impact of the isostatically forced late-quaternary drainage divide shift, Penobscot and Kennebec Rivers, Maine, USA. J Coast Res 27:1085-1093.

Kieffer MC, Kynard B. 1993. Annual movements of shortnose and Atlantic sturgeons in the Merrimack River, Massachusetts. Trans Am Fish Soc 122:1088-1103.

Kiraly IA, Coghlan SM Jr, Zydlewski J., Hayes D. 2014. A comparison of two sampling designs for fish assemblage assessment in a large. Trans Am Fish Soc 143(2):508–518.

Kiraly IA, Coghlan SM Jr, Zydlewski J, Hayes D. 2015. An assessment of fish assemblage structure in a large river. River Res Applic 31:301–312.

Kleinschmidt Associates. 2009a. Penobscot River fish assemblage survey interim report. Kleinschmidt Associates, Pittsfield, ME.

Kleinschmidt Associates. 2009b. Penobscot River fish assemblage survey second interim report. Kleinschmidt Associates, Pittsfield, ME.

Limburg KE, Waldman JR. 2009. Dramatic declines in North Atlantic diadromous fishes. Biosci 59:955–965.

Magilligan FJ, Graber BE, Nislow KH, Chipman JW, Sneddon CS, Fox CA. 2016. River restoration by dam removal: Enhancing connectivity at watershed scales. Elementa: Science of the Anthropocene 4(1):000108. doi: 10.12952/journal.elementa.000108

Martin EH, Apse CD. 2011. Northeast Aquatic Connectivity: An Assessment of Dams on Northeastern Rivers. The Nature Conservancy, Eastern Freshwater Program. 102 p.McCormick SD, Cunjack RA, Dempson, O'Dea M, Carey JB. 1999. Temperature-related loss of smolt characteristics in Atlantic salmon (*Salmo salar*) in the wild. Can J Fish Aquat Sci 56:1649-1658.

MDMR, MDIFW. 2009. Operational plan for the restoration of diadromous fishes to the Penobscot River. Augusta, ME: Department of Marine Resources and Department of Inland Fisheries & Wildlife.

Moring JR. 2005. Recent trends in anadromous fishes. Pages 25–42 in Buchsbaum R, Pederson J, Robinson WE, (editors). The decline of fisheries resources in New England: evaluating the impact of overfishing, contamination, and habitat degradation. Massachusetts Institute of Technology Sea Grant College Program, Publication 05-5, Cambridge.

Nettles DC, Gloss SP. 1987. Migration of landlocked Atlantic salmon smolts and effectiveness of a fish bypass structure at a small-scale hydroelectric facility. N Am J Fish Man 7:562-568.

[NMFS] National Marine Fisheries Service. 2000. Salmon travel time and survival related to flow in the Columbia River Basin. Northwest Fisheries Science Center, NMFS, Seattle WA.

[NMFS] National Marine Fisheries Service. 2012. Endangered species act biological opinion for FERC projects 2710, 2712, 2354, 2600, and 2666. Washington, DC: United States

Department of Commerce. Available at https://www.fisheries.noaa.gov/new-england-mid-atlantic/consultations/section-7-biological-opinions-greater-atlantic-region

[NRC] National Research Council. 2004. Atlantic salmon in Maine. National Academies Press, Washington DC.

O'Connor JE, Duda JJ, Grant GE. 2015. 1000 dams down and counting. Science 348(6234):496-497.

Palmer MA, Bernhardt ES, Allen JD, Lake PS, Alexander G, Brooks S, Carr J, Clayton S, Dahm CN, Follstad Shah J, Galat JD, Gloss S, Goodwin P, Hart DD, Hassett B, Jenkinson R, Kondolf KM, Lave R, Meyer JL, O'Donnell TK, Pagano L, Sudduth E. 2005. Standards for ecologically successful river restoration. J Appl Ecol 42:208–217.

Post DM, Pace ML, Hairston NG Jr. 2000. Ecosystem size determines food-chain length in lakes. Nature 405:1047-1049.

Power JH, McCleave JD. 1980. Riverine movements of hatchery-reared Atlantic salmon (*Salmo salar*) upon return as adults. Environ Biol Fishes 4:3-13.

Pringle C. 2003. What is hydrologic connectivity and why is it ecologically important? Hydrol Process 17:2685-2689.

Quinn JW, Kwak TJ. 2003. Fish assemblage changes in an Ozark river after impoundment: a long-term perspective. Trans Am Fish Soc 132:110-119.

Ruggles CP. 1980. A review of the downstream migration of Atlantic salmon. Canadian Technical Report of Fisheries and Aquatic Sciences No. 952. Freshwater and Anadromous Division Research Branch, Department of Fisheries and Oceans. Halifax, NS.

Ruggles CP, Watt WD. 1975. Ecological changes due to hydroelectric development in the Saint John River. Journal of the Fisheries Research Board of Canada 32:161-170.

Ryder DS, Brierley G, Hobbs R, Kyle G, Leishman M. 2008. Vision generation: what do we seek to achieve in river rehabilitation? Pages 16-27 in Brierley GJ, Fryirs KA, editors. River Futures: An Integrative Scientific Approach to River Repair. Island Press, Washington, DC, USA.

Saunders R, Hachey M, Fay CW. 2006. Maine's diadromous fish community: past, present, and implications for future recovery. Fisheries 31(11):537-547.

Scherelis C, Zydlewski GB, Brady DC. 2020. Using hydroacoustics to relate fluctuations in fish abundance to river restoration efforts and environmental conditions in the Penobscot River, Maine. River Res Appl 36:234– 246 doi.org/10.1002/rra.3560

Schindler DE, Leavitt PR, Brock CS, Johnson SP, Quay PD. 2005. Marine-derived nutrients, commercial fisheries, and productivity of salmon and lake algae in Alaska. Ecology 86:3225-3231.

Schmitt C. 2015. The President's salmon: Restoring the king of fish and its home waters. Down East Books/Rowman & Littlefield. July 2015.

Smith MP, Schiff R, Olivero A, MacBroom JG. 2008. The active river area: A conservation framework for protecting rivers and streams. The Nature Conservancy, Boston, MA. 64 p.

Stich DS, Bailey MM, Zydlewski JD. 2014. Survival of Atlantic salmon *Salmo salar* smolts through a hydropower complex in the lower Penobscot River, Maine USA. J Fish Biol 85:1074–1096.

Stich DS, Bailey MM, Holbrook CM, Kinnison MT, Zydlewski JD. 2015a. Catchment-wide survival of wild- and hatchery-reared Atlantic salmon smolts in a changing system. Can J Fish Aquat Sci 72(9):1352-1365.

Stich DS, Kinnison MT, Kocik JF, Zydlewski JD. 2015b. Initiation of migration and movement rates of Atlantic salmon smolts in fresh water. Can J Fish Aquat Sci 72(9):1339-1351.

Stich DS, Kocik JF, Zydlewski GB, Zydlewski JD. 2015c. Linking behaviour, physiology, and survival of Atlantic salmon smolts during estuary migration. Mar Coast Fish 7:68–86.

Stich DS, Zydlewski GB, Zydlewski JD. 2015d. Physiological preparedness and performance of Atlantic salmon Salmo salar smolts in relation to behavioural salinity preferences and thresholds. J Fish Biol 88:595–617.

Trinko Lake TR, Ravana KR, Saunders R. 2012. Evaluating changes in diadromous species distributions and habitat accessibility following the Penobscot River Restoration Project. Mar Coast Fish 4:284–293.

[USACE] US Army Corps of Engineers. 1995. The Highway Methodology Workbook Supplement. Wetland Functions and Values: A Descriptive Approach. US Army Corps of Engineers, New England Division. NENEP-360-1-30a. 32 pp.

[USASAC] US Atlantic Salmon Assessment Committee. 2018. Annual Report of the U.S. Atlantic Salmon Assessment Committee. Report No. 30 - 2017 Activities, Portland, ME. 155 pp.

[USOFR] US Office of the Federal Register. 2009a. Endangered and threatened species; determination of endangered status for the Gulf of Maine Distinct Population Segment of Atlantic salmon. Federal Register 74, 117(19 June 2009), 29344–29387. http://www.gpo.gov/fdsys/pkg/FR-2009-06-19/pdf/E9-14269.pdf. 44 pp.

[USOFR] US Office of the Federal Register. 2009b. Endangered and threatened species; designation of critical habitat for Atlantic salmon (*Salmo salar*) Gulf of Maine Distinct Population Segment; final rule. Federal Register 74, 152(10 August 2009), 39903–39907. http://www.gpo.gov/fdsys/pkg/FR-2009-08-10/pdf/E9-19094.pdf. 5 pp.

Watson JM, Coghlan SM Jr, Zydlewski J, Hayes DB, Kiraly IA. 2018. Dam removal and fish passage improvement influence fish assemblages in the Penobscot River, Maine. Trans Am Fish Soc 147(3):525-540.

Wilson K, Sherwood G. 2011. Penobscot River Restoration: Monitoring Marine-Freshwater Food Web Linkages Using Stable Isotopes, Final Report to the Penobscot River Restoration Trust. Gorham, ME: University of Southern Maine.

Wipfli MS, Hudson JP, Caouette JP. 2003. Marine subsidies in freshwater ecosystems: salmon carcasses increase the growth rates of stream-resident salmonids. Trans Am Fish Soc 132:371-381.

Table 1. Nine studies evaluating the ecological effects of the Penobscot River Restoration Project.

#	Name of project	Goals of project	Collaborators
1	Channel Geometry, Bed Sediments, and Photographic Monitoring	Surveys of channel elevation, sediment characterization, and repeat photographic monitoring at permanent cross sections representing important river features.	University of Maine and USGS
2	Water Quality, Water Temperature, and Benthic Macroinvertebrate Monitoring	Water quality/chemistry, water temperature, and benthic macroinvertebrate monitoring at numerous sites throughout the project area to assess water quality and benthic invertebrate community composition changes.	Penobscot Indian Nation
3	Fish Passage: Upstream Passage of Salmon and Other Diadromous Species (PIT tag methods)	Pre-removal and post-removal assessments of fish passage and migration timing/movements through the project area via PIT tags. Focus on salmon, but shad and other species tagged as surrogate as opportunities allow.	University of Maine, USGS, Maine DMR
4	Fish Passage: Seaward Migration of Salmon Smolts (active tag methods)	Downstream movement rates and survival of downstream passage for wild and hatchery-reared juvenile salmon smolts released up river of the project area passively tracked using an array of acoustic receivers cooperatively maintained by USGS, University of Maine, and NOAA.	University of Maine, USGS, Maine DMR
5	Fish Passage: Sturgeon Habitat Use and Spawning (active tag methods and habitat suitability modeling)	Movement patterns of shortnose and Atlantic sturgeon in the river via acoustic tagging methods to identify preferred habitat, to determine whether this population is spawning within the Penobscot River system, and to contribute toward population size estimates for this species. Modeling of potential spawning habitat within the project area.	University of Maine
6	Fish Passage: Diadromous Species Assembling Below Lowest Dam (hydroacoustic methods)	Hydroacoustic technology to detect the presence, abundance, and direction of travel of diadromous fish moving through the lower Penobscot River.	University of Maine
7	Fish Community: Assemblages and Community Changes (electrofishing and seining methods at the reach level)	Quantify and characterize fish assemblages and presence/absence in the lower ~70 kilometers of the Penobscot River system using electrofishing and other methods.	University of Maine
8	Wetland and Riparian Habitat Mapping	Monitoring of wetland and riparian plants and habitat at each of the impacted sites repeated 1 year and 5 years following dam removals.	Boyle Associates, PRRT, The Nature Conservancy, Maine Natural Areas Program
9	Marine-Derived Nutrients and Ecosystem Function: Food web structure via stable isotope methods	Characterization of extent to which marine-derived nutrients and organic matter are incorporated into riverine food webs following restoration of diadromous spawning runs.	University of Southern Maine, Gulf of Maine Research Institute

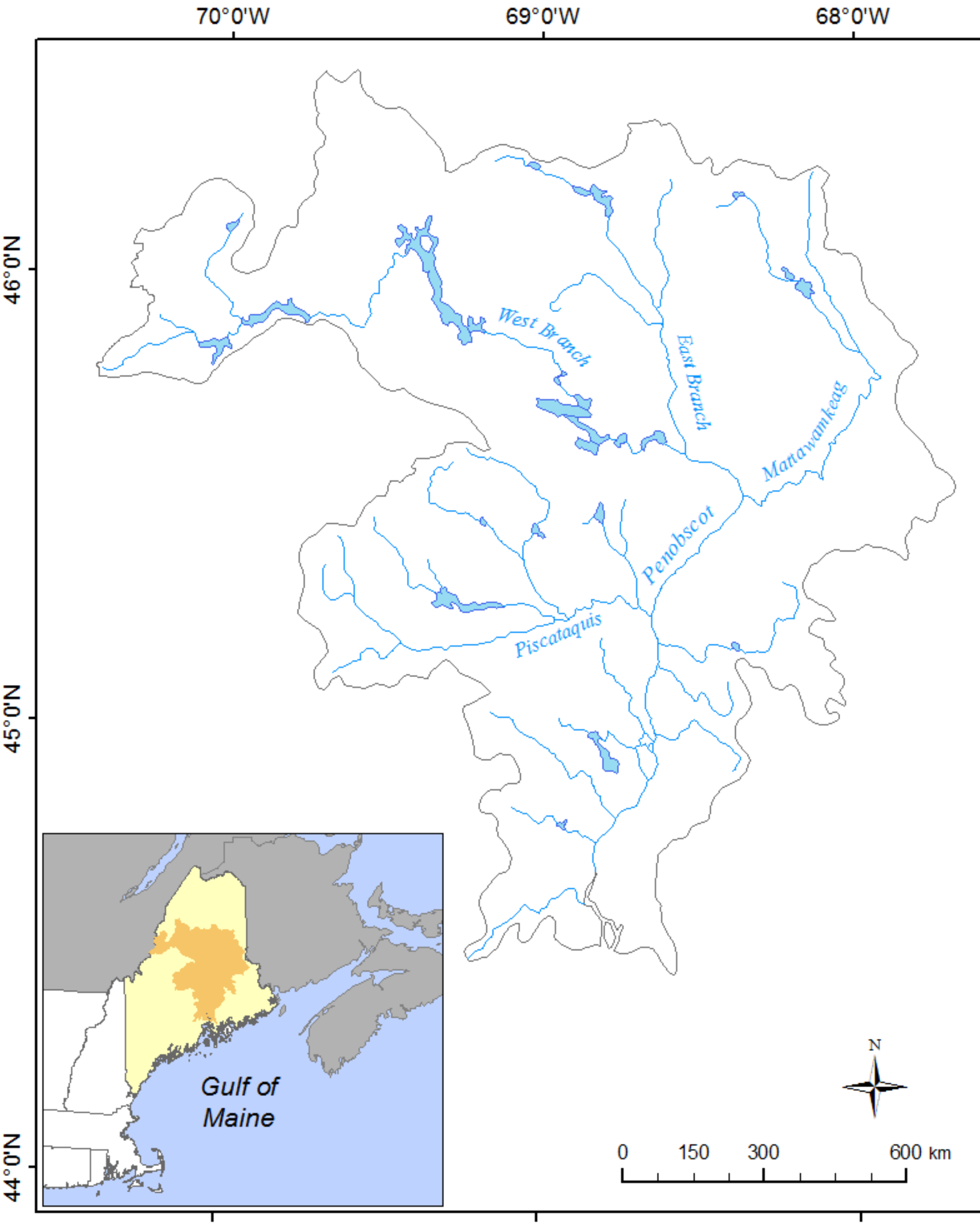


Figure 1. The Penobscot River watershed (orange) located in Maine, USA (yellow).

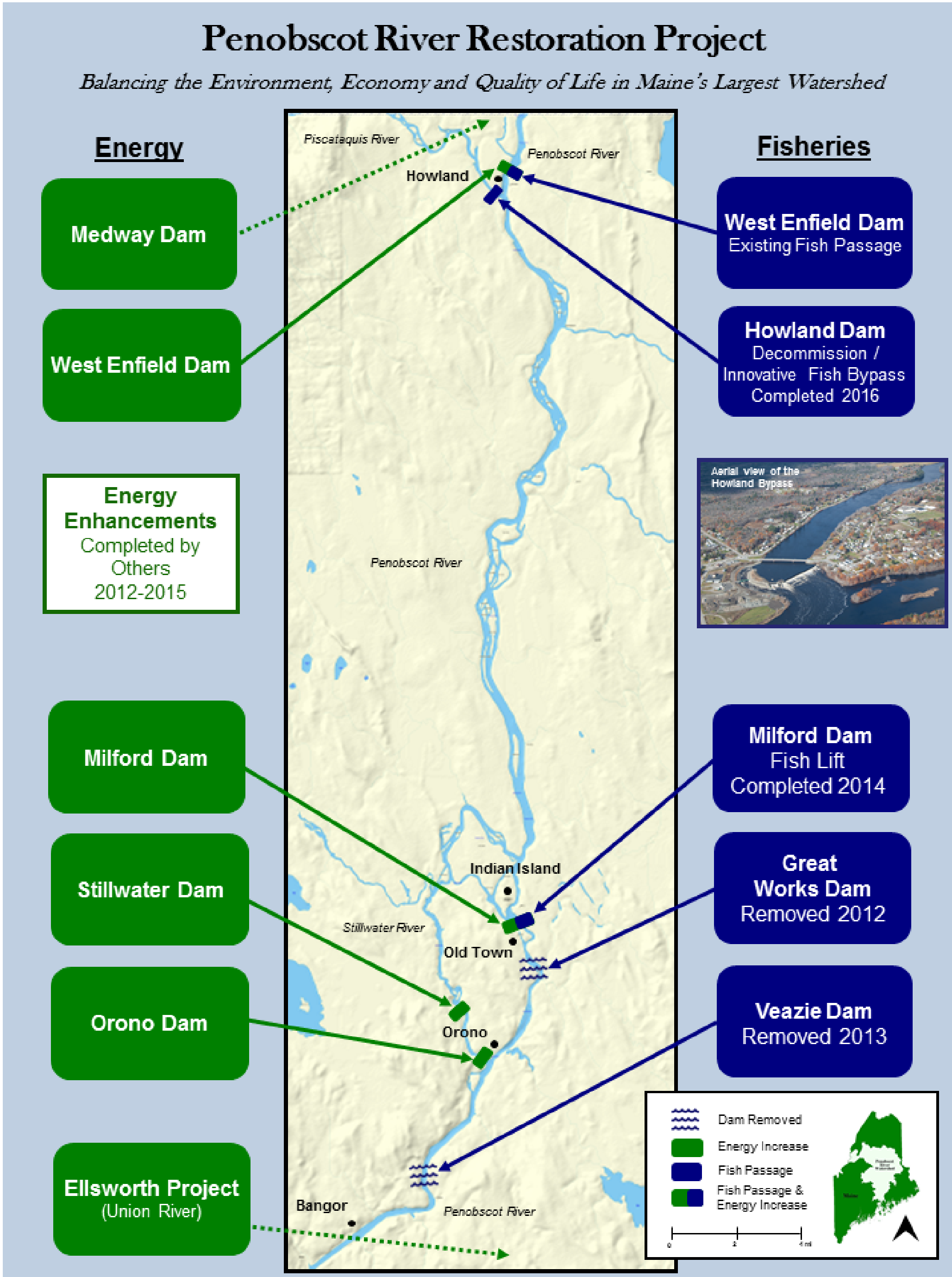


Figure 2. Overview of the Penobscot River Restoration Project (PRRP), which aims to restore diadromous fishes to the Penobscot River via connectivity improvements with 2 foci: Fisheries (blue boxes) and Energy (green boxes). Fisheries improvements will involve the purchase and removal of the 2 lower most seaward dams; the purchase, decommissioning, and construction of a nature-like bypass channel around a third dam; and the improved fish passage at 4 additional dams. Energy improvements will be by the maintenance of current energy generation through increased power generation at 6 existing dams.

APPENDICES

The appendices appear in their original form and have not been edited by NEFSC.

Appendix A: Conceptual Monitoring Framework for the Penobscot River Restoration Project (Monitoring Framework)

PENOBSCOT RIVER MONITORING FRAMEWORK

Prepared by the Penobscot River Science Steering Committee
Edited by J. Royte, C. Schmitt, and K. Wilson
2007

The Penobscot River Science Steering Committee was formed in 2005 to help organize and coordinate scientific research and monitoring related to the Penobscot River Restoration Project (as recommended by the 2004 Penobscot River Science Forum). Today, the committee's mission is to guide and facilitate ecosystem monitoring and research opportunities related to barrier removal in the Penobscot River watershed, estuary, and bay by (1) providing guidance on priority scientific issues for the Penobscot River Restoration Trust, state and federal agencies, and other organizations; (2) exchanging information and sharing data from Penobscot River research and monitoring, and (3) identifying opportunities for collaborative research and education related to ecological restoration. The committee is coordinated by the Senator George J. Mitchell Center for Environmental and Watershed Research at the University of Maine.

Members of this ad hoc advisory committee, who volunteer their expertise, represent the following organizations and interests:

American Rivers

Bates College

Bigelow Laboratory for Ocean Sciences

Boston College

Boreal Songbird Initiative

BSA Environmental Consulting

Eastern Brook Trout Joint Venture

Lower Penobscot River Watershed Coalition

Maine Atlantic Salmon Commission

ME Coop. Fish and Wildlife Research Unit

ME Dept. of Environmental Protection

ME Dept. of Inland Fisheries & Wildlife

ME Department of Marine Resources

Maine Sea Grant

Penobscot Indian Nation

Penobscot River Restoration Trust

Senator George J. Mitchell Center

The Nature Conservancy, Maine Chapter

The Nature Conservancy, Eastern Region Freshwater Program

Trout Unlimited

University of Maine

University of South Florida

University of Southern Maine

Monitoring the Penobscot River restoration, and its effects on riparian, estuarine, and coastal habitat demands extraordinary effort by many scientists from numerous disciplines, including ecology, biology, zoology, chemistry, hydrology, marine science, and socioeconomics.

This framework is intended to aid coordination and collaboration among the various disciplines involved, and serve as a resource for scientist and non-scientists interested in tracking restoration progress now and in the future. This document attempts to highlight opportunities for collaboration on research, field studies, funding opportunities, and data documentation and sharing. On the ground, effective coordination requires continual outreach to scientists working on the river, connecting people and data with restoration projects, and communicating lessons learned to the citizens, policymakers, and scientists concerned with river restoration and monitoring around the world.

Currently, Penobscot River restoration science is coordinated with a part-time position. The Science Coordinator has three critical tools for coordinating activities: 1) the monitoring framework which provides the structure for related river monitoring and research activities; 2) the expertise and extended network of the Science Steering Committee listed above; and 3) the PEARL online portal to store and share information about science as the restoration progresses, including the scientists involved, near real-time results, access to data, and news.

TABLE OF CONTENTS

I. PROJECT BACKGROUND

In June 2004, Pennsylvania Power and Light Maine, LLC (PPL), and federal, state, tribal and conservation interests signed a final agreement to resolve outstanding fish passage, tribal, and other issues associated with the Federal Energy Regulatory Commission (FERC) relicensing of PPL's hydroelectric projects located in the lower reaches of the Penobscot River in central Maine, U.S.A. (Figures 1, 2). PPL agreed to sell three hydroelectric projects (Veazie, Great Works, and Howland dams) to the Penobscot River Restoration Trust (the Trust) for eventual removal or bypassing.[1] The Penobscot River Restoration Trust is a non-profit coalition comprised of representatives from the Penobscot Indian Nation, American Rivers, Atlantic Salmon Federation, Maine Audubon, Natural Resources Council of Maine, The Nature Conservancy, and Trout Unlimited, established for the purpose of increasing fish passage at three lower Penobscot River dams. The settlement agreement also provides for improved fish passage at four other PPL dams on the Penobscot River (Orono, Stillwater, Milford, and West Enfield). Successful implementation of the settlement agreement (referred to as Penobscot River Restoration Project, PRRP) is expected to result in the restoration of various ecological functions in the Penobscot River including connecting animal and plant species with their required habitat, and related effects on watershed food webs.

River restoration projects of the scope of the Penobscot are extremely unusual, perhaps unprecedented. The PRRP presents a significant opportunity to research and document the effects of ecological restoration, both for the Trust and for other communities considering dam removal or restoration activities. Removing two dams on a large river has not been attempted anywhere else in the U.S. to date. The most comparable project in the Northeast was the removal of the Edwards Dam on the Kennebec River in Augusta, Maine, in 1996 (Dudley 1999). The Edwards Dam was the lowermost dam on a large Maine river, providing unimpeded access to an additional 17 miles of mainstem habitat. The results of that removal offer important guidance to the Penobscot project. The PRRP is a more ambitious project on a larger river: two dam removals, natural channel bypass construction at a third dam, and simultaneous fish passage improvement at remaining dams. In practical terms, what can we learn from this project that will help us anticipate and minimize short-term negative effects, and maximize long-term positive effects of river restoration activities?

[1] The Howland Project may be decommissioned and have a natural fishway installed if found feasible.

As with most restoration projects, the PRRP will likely involve a combination of active and passive restoration techniques, each with some level of uncertainty, and a well-designed monitoring plan is critical for documenting positive and negative effects (USGS 2005). Because of the spatial and temporal scale of restoration projects, it is often necessary to re-evaluate restoration efforts at various intervals to make necessary adjustments if monitoring disproves one or more assumptions of the project (USGS 2005).

This conceptual framework presents an approach for monitoring the restoration of environmental resources in the Penobscot River. Together with its online "living" counterpart within the PEARL Web site, we anticipate that this framework will provide an exemplary and growing body of information on large river restoration and ecosystem responses that helps connect people to each other and to revitalized ecosystems.

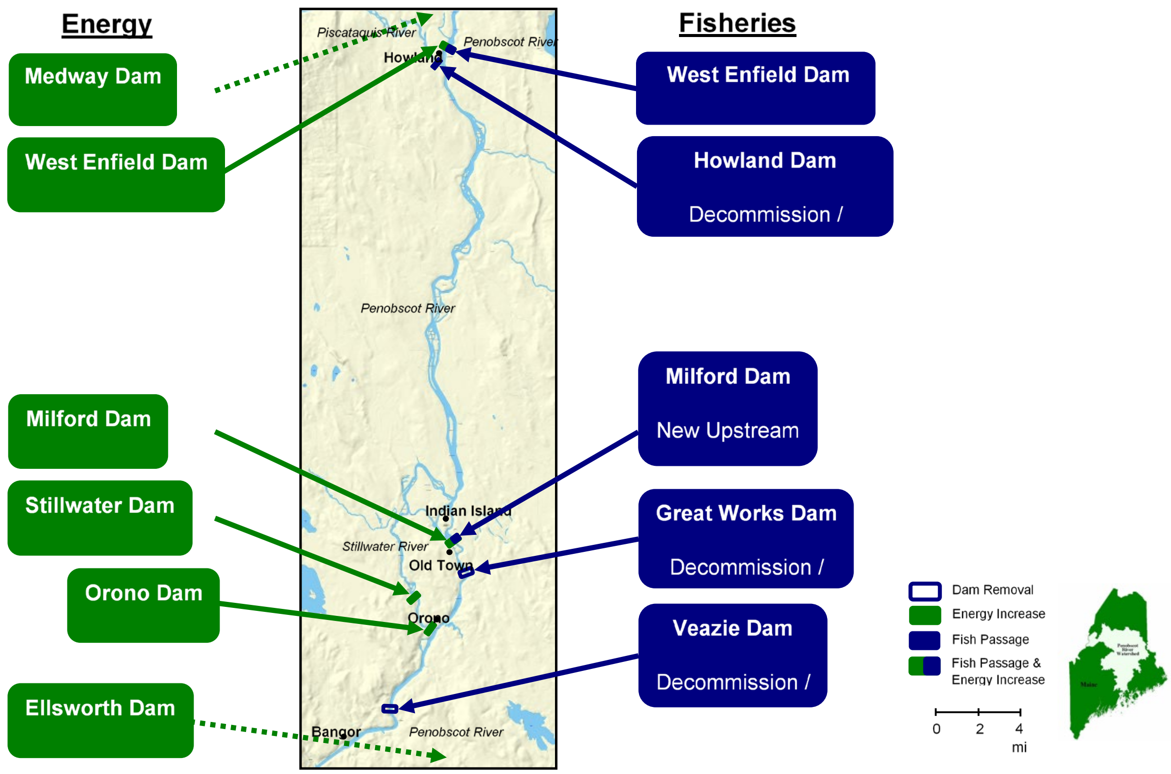
Figure 1. Relative locations of hydroelectric dams in the Lower Penobscot River.

II. RESTORATION PROJECT GOALS AND OBJECTIVES

The broad goal of the Penobscot River Restoration Project is to restore populations of aquatic organisms, particularly diadromous fishes, and the related effects on aquatic, wetland, and riparian ecosystems upstream and downstream of the project focus area, including measurable effects in Penobscot Bay. The restoration is expected to positively affect wildlife, socioeconomic resources, and the Penobscot Indian Nation and other river communities. The Penobscot River Restoration Trust anticipates the following actions:

- Veazie and Great Works dam decommissioning and removal;
- Howland Dam decommission and construction of a natural fishway;
- Orono Dam recommissioned with a new upstream fish trapping facility and upstream American eel fishway(s) with continued operation of existing downstream passage facilities;
- Stillwater Dam outfitted with an upstream fishway(s) for American eels and new downstream passage facilities;
- Milford Dam receives state-of-the-art upstream fishlift and upstream and downstream passage for American eels, to replace the existing Denil fishway;
- River-wide, the project will facilitate interdisciplinary monitoring programs that will (1) generate data before and during removals that will allow for mid-course corrections to the project; (2) provide scientifically sound before-during-after comparison of the effects of dam removal and fish passage improvements and (3) provide context and basic environmental information for additional scientific study.

Figure 2. Fish passage in the Penobscot River watershed before (left) and after (right) the dam removals indicated on the left.



III. MONITORING FRAMEWORK GOALS AND OBJECTIVES

This framework outlines monitoring objectives deemed critical by the members of the Penobscot River Science Steering Committee ("the Committee"), the 2004 Penobscot River Science Forum Workshop, and the 2006 Gulf of Maine Council on the Marine Environment River Barrier Removal Monitoring Workshop. These objectives are organized into seven research areas. These objectives are presented in one document to emphasize the importance of the whole ecosystem and the need for collaboration and interdisciplinary exchange of data and information to create an understanding of changes in the Penobscot River ecosystem as a result of dam removal.

Core parameters[2]

In developing this framework, our goal was to identify a set of "core parameters" for monitoring to ensure a scientifically sound assessment of change in the Penobscot River ecosystem in response to the PRRP. These core parameters are essential to cross-disciplinary research, and often are critical to multiple disciplinary questions. For example, basic water quality data are important for assessing changes in fish habitat as well as ensuring water quality attainment. **Core parameters that are particularly useful for multiple research areas are highlighted in bold throughout the text.** These are "cross-cutting" parameters that need only be shared by two research areas to be defined as such. A secondary goal of this document is to encourage networking among researchers, agency staff, and the Trust, so that the suggested monitoring and research studies will occur in collaboration.

Most monitoring efforts have common data needs and/or can be conducted with shared human power and/or equipment. In many cases, studies within a given research area are dependent upon contextual data collected under the auspices of another research area. For example, water quality data are critical for interpretation of fish population numbers, and morphological/sediment data provide important habitat information for a variety of aquatic organisms. Indeed, concurrent monitoring (in time and space) of all aspects of the river system will greatly strengthen our ability to assess the effects of dam removal and fish passage improvements.

---

[2] Parameter (n) a quantifiable characteristic or feature of the Penobscot

The proposed monitoring falls into one or more of four categories: monitoring required as part of project permitting (see Appendix A), monitoring to inform the restoration process, monitoring to document positive and negative effects of the project, and monitoring to expand scientific knowledge of large river ecology. Where possible, we have indicated which monitoring tasks will be accomplished, all or in part, through project permitting.

Monitoring study design

Restoration monitoring has been classified into at least three overlapping categories including implementation, effectiveness, and validation (Block et al. 2001; USFWS 2000; Federal Interagency Stream Restoration Working Group 1998). Implementation monitoring is used to assess whether or not a directed management action was carried out as designed. Effectiveness monitoring is used to determine whether the restoration action was effective in attaining the desired goals of the project. Validation monitoring is used to verify basic assumptions and scientific understanding concerning the restoration techniques and principles. This plan focuses on the types of monitoring particularly relevant to environmental resources affected by the PRRP, validation and effectiveness monitoring (hereafter referred to collectively as "restoration monitoring").

There are many potential study designs for monitoring single or multiple restoration actions (Roni et al. 2005). The Before-After (BA) study design is the recommended approach for many applications involving stream restoration (Kocher and Harris 2005). The BA study design allows for knowledge of pre-treatment conditions and natural variability (Gerstein 2005; Minns et al. 1996). Good baseline data are required for valid BA study designs (Kondolf 1995; Minns et al. 1996). The main drawback of the BA design is that results can take years to manifest since it relies on the performance of the habitat restoration. BA study designs have been classified into several different types depending upon observation intensity (number of study sites, reaches, watersheds) and existence of controls (Roni et al. 2005). A common approach is the before-and-after control impact design (BACI) where a control site is evaluated over the same time period as the treatment site. The addition of a control site to a BA study design is meant to account for environmental (natural or otherwise) and temporal trends found in both the control and treatment sites (Roni et al. 2005). However, a BACI design with a poorly chosen control site can be less powerful than an uncontrolled before-and-after study design (Roni et al. 2005).

Choosing control sites for the PRRP is not straightforward, because although the project involves the lowermost reaches of the Penobscot River, the project is anticipated to affect some environmental resources throughout the entire 8,570 square-mile watershed. Comparable rivers that might serve as a control site or reference site do not exist, suggesting that a straightforward BA study design may be most appropriate for evaluating the PRRP. However, there is good reason to expect considerable environmental variability in the upcoming decades, suggesting that, for at least some aspects of the project, control or reference sites may be critical. For some monitoring tasks, sub-watersheds of the Penobscot may be suitable reference systems (e.g., Piscataquis River and East Branch). In addition, it may be possible to compare small upstream tributaries that could see an increase in diadromous fish access to other tributaries that will not see increased passage as a result of existing barriers.

We will not make specific recommendations here, because decisions regarding study design should be based on analytical power and may differ depending on the monitoring task. We expect that the Science Steering Committee may coordinate final design decisions.

Temporal extent of monitoring
The effects of dam removal activities on some biotic and abiotic resources in the Penobscot River could take decades to be fully manifested in the ecosystem. Natural variations in fish and wildlife populations, life cycle periods, riparian recolonization, and many other factors will affect the ecosystem response to dam removal as well as our ability to detect a response. Recognizing the levels of funding and staffing needed to perform habitat restoration monitoring studies at a watershed scale, this plan attempts to present an attainable timetable and scale for pre- and post-treatment monitoring. In most cases we have assumed three (3) potential years of pre-data before dam removal, although actual times may vary, and dam removals and passage improvements may be staggered over several years depending upon funding. For most core variables, data would be collected in years 3 and 1 before removal, and 1, 3, and 5 after removal. Additional sampling beyond the 5-year time frame will be required for long-lived organisms such as fish and freshwater mussels. ***In most cases, considerable information may be gained by measuring core parameters at or within the same time frame.***

Spatial extent of monitoring

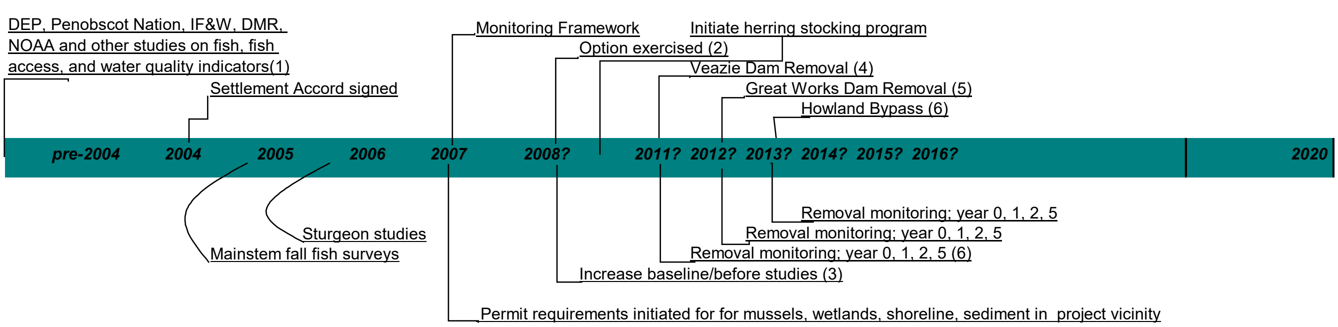
Changes on the Penobscot are predicted to occur both in the immediate area of dam removal (draining of impoundments, sediment movement and redistribution, changes in habitat for resident and migratory organisms, etc.) as well as throughout the Penobscot River watershed (distribution of resident and migratory/spawning diadromous fishes, potential spread of invasive species). To best take advantage of limited resources, the core parameters for each research area should overlap spatially as much as possible. For example, the same river cross-section or bay site could be used for morphology studies, tracking sediment movement, inventory sites for benthic invertebrates and aquatic plants, and transects could extend to the uplands to include wetland and riparian vegetation. Recognizing the value of this approach, the Gulf of Maine Council is adopting cross-sections as the “backbone” of their stream barrier removal monitoring protocols currently in development (M. Collins, pers. comm. 2006). A detailed morphological survey should be used to guide selection of cross-section locations, but additional suggested criteria for locating transects include areas of expected change, such as impoundments, tributary mouths, and above and below the dam sites; upstream and downstream areas where indirect changes in food web structure may occur; locations where minimal effects are expected, e.g., upstream from dams or other barriers that will not be removed. Because change may occur where it is not expected, monitoring should also occur at representative reach “types,” bay and estuary habitats, and at important infrastructure.

IV. DATA SHARING

Data can be shared and made publicly available on PEARL, the source for environmental information in Maine. PEARL, administered by the Mitchell Center, is already serving as the data and information sharing platform for the Committee and will continue to do so, <u>contingent on future funding</u> (http://www.pearl.maine.edu/windows/penobscot/index.htm). Also accessible via PEARL are links to existing online data sources. This links are structured in a spatially-referenced framework, allowing information searches by watershed, town, or waterbody for data on PEARL as well as other data sources. A portal specific to Penobscot data needs to be created, as well as support for a data manager. A mapping interface is currently under development by the Mitchell Center in partnership with College of the Atlantic. This interface will enhance access to Penobscot River research and data.

V. TIMELINE

The Penobscot River Comprehensive Settlement Accord filed with FERC in June,\ 2004 established the timeline for implementing the PRRP. In accordance with the Settlement Accord, the five-year option period to purchase the Veazie, Great Works, and Howland dams expires in June 2009. At this time, the anticipate timeline is as follows:



1) Numerous agencies, organizations, academics, the Penobscot Nation, and other volunteers have monitored the Penobscot River, its fisheries, water quality, and wildlife for decades. For descriptions of studies and monitoring results see the Penbobscot River page on the PEARL: http://www.pearl.maine.edu/windows/penobscot/index.htm

2) Exercizing the option will depend on acquiring funds to purchase the dams; the timing of this occuring is not known at this time.

3) Monitoring to initiate before removal includes spring mainstem fish surveys (IBI), existing up and downstream passage, aquatic invertebrates up and downstream, including

4) While the timing of dam removal is unknown at this time, we hope that operations of dams for acquisition or removal costs won't exceed a few years.

5) It is also uknown whether it makes sense to remove a downstream dam before an upstream, if a year between is enough to mobilize deconstruction of the second dam or if there are economies of scale to doing the removals nearly simultaneously.

6) During and post-removal monitoring

VI. CONCEPTUAL MONITORING FRAMEWORK

A. Hydrodynamics, geomorphology and sediment transport

(Prepared by W. Barnhardt, A. Casper, R. Dudley, A. Kelley, T. Huntington, N. Snyder, J. Reardon)

Core parameters

Detailed river morphology/ bathymetric surveys, sediment chemistry (organic/inorganic contaminants), morphological cross sections**,** velocity surveys and discharge measurements.

Background

Limited work in the Penobscot River (Dudley and Giffen 2001; J. Kelley and Barnhardt, pers. comm.) noted the abundance of coarse-grained sediment in the channel near Old Town, and limited exposures of fine-grained sediment associated with island margins. This observation may be related to the fact that the river developed in response to a steeper than present gradient under higher velocity and flow conditions. However, extensive archaeological work in the Bangor to Old Town reach shows thick (1-2+ m), fine-grained sedimentary sequences associated with tributary mouths upstream from local bedrock-cored base levels in the mainstem of the river. These deposits are the result of hydraulic[3] damming and slackwater deposition during high flow events. Stratigraphic and archaeological analyses of these sediments show that they have been accumulating since the Early Holocene, and continue to receive sediment during floods. Cultural resource investigations on the Piscataquis River related to the relicensing of the Howland Dam revealed the presence of similar deposits at the mouth of the Sebois Stream, as well as thick deposits of sand and finer material along the margins of several islands (Mack et al. 1997; Newsome and Sanger 1998). It is plausible to believe that similar deposits exist in comparable, untested settings in other portions of the Penobscot drainage.

Following European occupation of the region, an extensive network of dams was built on the Penobscot and major tributaries for log driving and hydroelectric power generation. Milford Dam is the site of the first major dam constructed on the mainstem river during the 1820s; the Great

[3] *Hydraulic* refers to water in motion, and describes that which is operated, moved, or affected by moving water, as with sediment carried by a stream. *Hydrologic* is a broader term that describes the properties, distribution, and circulation of water at varying spatial scales.

Works dam followed in 1830 (Cutting 1959). The Veazie Dam was built in 1886 as a pulp mill operation and was converted to a hydroelectric facility in 1891. These dams created higher, artificial base levels that raised water levels and drowned pre-existing rapids (Kelley 2006). The raised water levels have created fluvial and ice erosion of sedimentary sequences previously above annual floods (Kelley 2006). In addition, it is surmised that deposition of fine-grained material is currently taking place farther upstream in the surrounding tributary valleys. It is anticipated that this material will be mobilized at a lower base level. Lowered water levels may also impact older Holocene fine-grained deposits by under cutting and slumping, particularly during the spring freshet. All of these situations have the potential for moving fine-grained sediment into the river in response to dam removal. It is expected that these types of impacts will occur on less than six miles currently impounded by the two dams.

Dam removal projects in general reorganize sediment transport and channel morphology in the affected river system. Sediment previously trapped in impoundments and adjacent tributary mouths is made available for transport because of the lowered river base level. In the Penobscot system, only Meadow Brook, a tributary to the Veazie impoundment, may be affected in this way. Banks that have been modified by impoundments are also susceptible to erosion. Deep water habitats that may have existed in impoundments are modified. Increases in sediment delivery to downstream areas can alter substrate conditions. For these reasons, a key component of a research and monitoring scheme for dam removals should include detailed bathymetric and sediment mapping and sampling (e.g., Dudley 1999; Snyder et al. 2006 and references therein on the Yuba River). The PRRP dams are run-of-the-river hydropower facilities located downstream of other mainstem dams, which likely limits significant post-dam sediment impoundment to localized areas in the mainstem and tributary mouths, which should be identified through detailed mapping. In addition, the Trust will make all attempts to control the decommissioning so that there is not a large load of sediment and debris moving downstream, and permitting requirements will likely address this—see Appendix A (The Trust, pers. comm.). Existing mapping (i.e., by Trust contractors Hydroterra and Kleinschmidt) within the impoundments provides useful information for planning and permitting, but further research and monitoring will require repeatable, high-resolution surveys of morphology and sediment characteristics.

The hydraulic modeling as presented here (see table below) is a high priority, as the results will set the spatial extent for much of the remaining monitoring for parameters that are expected to change with changes in hydrology. While we recognize that some of this work will be accomplished through permitting (and that permitting-related information will be added to the "living" document on the Web when available), we have chosen here to present the best available scientific opinion on effective and efficient restoration monitoring.

Core parameter	Associated questions	Rationale/expectations	Methods
River morphology (riparian topography and bathymetry, stored sediment).	What are the effects of changed hydraulics on the impounded areas and downstream? Will erosion due to lowered base level affect adjacent archeological sites? What is the fate of materials transported downstream? Can we calibrate models for predicting evolution of stream morphology and aquatic habitat after dam removal, applicable to other restoration projects in Maine and elsewhere?	Potential morphologic changes include: erosion and revegetation of channel banks in impounded areas, deposition of sediments stored in impoundments and at tributary mouths, loss of deepwater habitats. These data will provide a baseline for monitoring post-restoration changes to aquatic and terrestrial habitats.	• High-resolution bathymetric survey of impoundments, main channel and upper estuary using a multibeam sonar system. Shallow areas may require a jet ski with single-beam fathometer with closely spaced survey lines. • High-resolution LIDAR topographic survey of river banks and wetlands, covering main stem of the river and major tributaries. • Register both surveys using Differential Global Positioning Systems, combine bathymetric and elevation surveys into one surface (with 1-2 pixels) using mapping software. • Map substrate texture and thickness using modern geophysical techniques (sidescan sonar, seismic reflection). Verify mapping with sediment sampling on a regular grid with archived samples, coring and bottom photography/ video. • Areas should be resurveyed one year after project completion, and then again 3-5 years later.
Sediment chemistry	What is the relationship of sediment and water quality?	Stored sediments have the potential to move	• Analyze sediment samples collected as part of morphological survey for trace metals, organic contaminants (PCBs, dioxin, etc.).

Core parameter	Associated questions	Rationale/expectations	Methods
(organic/inorganic contaminants)		contaminants downstream.	
Morphological cross sections	Do individual flood events affect the post-removal channel morphologic evolution?	Changes in channel, bank and floodplain morphology, sediment texture, vegetation and habitat will result from the dam removal.	• Survey shallow areas with a total station. • Survey mainstem with a jet ski and single-beam fathometer. • Establish photography stations at each cross section. • Resurvey every three months during and after the project period. These surveys would provide greater temporal resolution than is available with high-resolution mapping, allow for monitoring of changes in tributaries.
Velocity surveys and discharge measurements	What are the effects on habitats from changing sediment transport regimes? Where will flow velocity, impoundment extent, flooding frequency and amount change? How are hydrology, sediment transport, channel morphology, and critical habitat linked?	Dam removal will change flow hydraulics and flood hydrology upstream, within, and downstream of impoundments. Changes in dam management also will have important effects on the river system. Some of these changes can be anticipated through development of numerical flow models.	• Acoustic Doppler Current Profiler (ADCP) surveys of water-column flow characteristics. • Discharge monitoring at gauging stations. • Bathymetric and sediment mapping (above). • Develop a **predictive, dynamic spatial model** of post dam removal hydrodynamics from Howland to Bucksport to identify areas in the river, tributaries, and adjacent riparian areas where changes in flow velocity, sediment transport, impoundment extent, and the frequency and amount of riparian inundation, are expected to occur with dam removal. This model should identify anticipated changes compared to present conditions, temporally (by season) and spatially. (Note that this model, at least in part, will likely be part of project permitting. See Appendix A.)

B. Water Quality

(Prepared by D. Courtemanch, T. Huntington)

Core parameters

Basic water chemistry, estuarine dissolved oxygen, water column nitrogen and phosphorus, time-of-[water]travel, PAR, dissolved oxygen time series, benthic invertebrate IBI.

Background

Considerable information exists on the present condition of the lower Penobscot River. Water quality studies were conducted by the Maine DEP and Penobscot Indian Nation in the late 1990s on the Penobscot River below Mattaceunk and the Piscataquis River. These data have been used to construct a preliminary water quality model for dissolved oxygen for the river (QUAL2EU; MDEP 2003). The segment of the river from the confluence with the Piscataquis to the head of tide attains all water quality criteria except for fish consumption (due to the presence of mercury, dioxins, and PCBs). The segment between Bangor and Bucksport does not always attain dissolved oxygen or bacteria criteria (presumed to be effects of wastewater discharges and combined sewer overflows). Because of non-attainment the Penobscot Nation and Maine DEP are working with EPA to develop a total maximum daily load (TMDL) for the lower Penobscot. In recent years, significant algae growth has been observed throughout the river, presumably originating from high nutrient loading conditions in the West Branch. In addition to the PRRP, the Penobscot River has recently, and continues, to go through a number of profound changes that affect water quality. These include changes in hydropower operations on both the West and East Branches; changes of ownership and production at paper making facilities on the West Branch; closure, reopening and expansion of Lincoln Pulp and Paper; closure of the Georgia Pacific plant (Old Town) and reopening as a pulp and biofuel facility; closure of Eastern Paper in Brewer; and upgrades in municipal treatment at Bangor and Brewer. In response, Maine DEP is revising the model to reflect current conditions based on sampling results from the summer of 2007.

The Penobscot Nation conducts regular water quality monitoring including basic water chemistry and macroinvertebrate monitoring in the river and many of the significant tributaries in the area of the restoration. The DEP conducts river-wide monitoring on a rotating basis including basic water chemistry, macroinvertebrates, algae (tributaries), and fish tissue contaminant analysis.

From 1979 to 1994, the USGS maintained a gage and multi-parameter water monitoring station at Eddington. This gage was reactivated in 2007, and additional gages are maintained at Enfield on the mainstem, Medford and Dover-Foxcroft on the Piscataquis, and at Grindstone on the East Branch. The USGS began monitoring water temperature at Eddington on September 6, 2006 (http://waterdata.usgs.gov/me/nwis/uv/?site_no=01034500&PARAmeter_cd=00020,00021).

Additionally, the hydropower station on the West Branch near Medway provides daily discharge data.

Researchers at the University of Maine are investigating mercury in water and sediment south of Orrington related to releases from the former Holtrachem facility (Merritt 2006). A further, more comprehensive study of mercury in the estuary has been initiated as a result of a court settlement (D. Bodaly, pers. comm). There has also been limited study of sediment contamination in the vicinity of Dunnett’s Cove in Bangor (Bangor Gas Works; Elskus 2006). In the estuary, GoMOOS buoy F is located in Penobscot Bay near Rockland. The station monitors chlorophyll, solar radiation, ocean color, and particle scattering. Coordinated with these data, Bigelow Laboratory for Ocean Sciences has placed sensors in the Penobscot River to monitor particulate and dissolved matter entering the bay, accompanied by chemical analyses of samples collected around the watershed (C. Roesler, pers. comm.)

Core parameters	Associated questions/objectives	Rationale/expectations	Methods
Temperature, DO, salinity, conductivity, BOD_5, BOD_u, TSS, phosphorus, chlorophyll-*a*, trace metals, contaminants.	Collect required data for dam relicensing/surrender. Does the river achieve regulatory attainment of water quality? Are there changes in total suspended solids (TSS) load after dam removal?	Basic water quality parameters are required for regulatory purposes, as well as a contextual base for assessing spatial and temporal trends before and after restoration project.	The Maine DEP and the Penobscot Indian Nation have on-going sampling programs in the lower Penobscot River. Secure funding to maintain water quality sampling at the USGS Eddington gage. Additional sampling dates and sites may be needed, especially further upriver and downstream in the estuary.
Dissolved oxygen in Penobscot Bay/River interface	Does the estuary achieve water quality attainment?	Characterize relative inputs of DO to the estuary	Grab samples and/or data loggers (perhaps as a cross-cutting parameter in coordination with hydroacoustic array).
Water column nitrogen and phosphorus (by nutrient species)	Are there changes in flux & origin of nutrients in the river?	Incoming (or outgoing) diadromous fish will add (or remove) nutrients	Water column nutrients should be measured in conjunction with diadromous fish runs marine-derived nutrient study (stable isotopes).
Time-of-[water]travel	Recalibrate DEP river model QUAL2EU.	Recalibration and reanalysis of the model may result in revision of wastewater licenses	Construct/calibrate final river model (QUAL2EU) for use in wasteload modeling to establish new interim wastewater licenses for each mill on the river (2007-08).

Core parameters	Associated questions/objectives	Rationale/expectations	Methods
PAR, dissolved oxygen time series, **stream morphology** [see section A] and **hydrologic data** [see section A]	How does primary productivity and metabolism change?	Increases in dissolved oxygen, coupled with changes in morphology and hydraulics may increase or decrease metabolism.	Collect time series of dissolved oxygen and temperature and a time series of photosynthetic active radiation (PAR). Construct and calibrate Whole Stream Metabolism program (WSMP) for use in assessing gross primary productivity, net metabolism, and daily respiration.

Water Quality abbreviations:

BOD – biological oxygen demand

TSS – total suspended sediments

PAR – Photosynthetically Active Radiation

C. Biological components: Non-fisheries aquatic fauna

1. Invertebrates (benthic macroinvertebrates and freshwater mussels)

(prepared by C. Loftin and B. Swartz)

Core parameters

Benthic macroinvertebrate community structure, mussel distribution, relative abundance, microhabitat use, population age/size distributions, presence and condition of marked individuals, **fish host identification, distribution, and abundance,** mussel condition (glycogen levels) and **contaminant loads**

Background

The Maine Department of Inland Fisheries and Wildlife has identified sites in the Penobscot River and several tributaries between Howland and Bangor with two state-threatened freshwater mussel species (tidewater mucket, *Leptodea ochracea*; yellow lampmussel, *Lampsilis cariosa*), two freshwater mussel species of special concern (creeper, *Strophitus undulatus*; triangle floater, *Alasmidonta undulata*) and one candidate for state-threatened status (brook floater, *Alasmidonta varicosa)*; Nedeau et al. 2000). Surveys conducted in the mid 1990s broadly mapped mussel distributions across the state; hence, the surveys were not comprehensive within a site. Although presence of these species was documented, there is no comprehensive information about mussel distributions, density or population estimations, and population age/size distributions of these species in this region of the river and its tributaries. Given that current distributions and abundances of freshwater mussels in the river are not well-known, effects of these dam removals on the freshwater mussel populations also are not clear.

Most freshwater mussels are dependent on specific fish species to host and disperse their larvae. Fish communities in the river and tributaries are expected to change following dam removal, as increasing numbers and different species of fish move into previously inaccessible or unoccupied habitat and habitat changes occur. Although greater access to suitable host fish is likely with dam removal, displacement and redistribution of host fishes is also possible. Changes in nutrients may alter food availability for mussels, especially if high quality phytoplankton are displaced by a lower quality assemblage. It is difficult to anticipate changes in mussel populations that might occur, given the current lack of knowledge about the existing mussel community composition and distribution, fish host identification, habitat and food resource needs, and mussel tolerance to habitat change.

Removal of dams presents a situation for freshwater mussels that has been experienced in only a few locations in North America and never at this scale. Although dam removals are increasing throughout the country, few cases have affected listed mussel species. Another pending dam removal in Maine (the Fort Halifax Dam on the Sebasticook River) and several other petitions to remove dams in Maine are expected in the future. A recent study of mussel translocation methods and mussel distributions in the Fort Halifax Dam impoundment (Kurth 2007) will provide insight into determining the current and potential distributions of freshwater mussels and their fish hosts in the Penobscot River and tributaries, as well as provide information on the potential success of using mussel relocation as a tool to minimize effects of dam removal.

Macroinvertebrates have been collected along the river on a regular basis by MEDEP and PIN since the early 1980s, but not recently in the Veazie (1994) or Great Works (1999) impoundments. Most recent work has been focused on the West and East Branches with less intensive sampling on the mainstem.

Core parameters	Associated questions	Rationale/expectations	Methods
Mussel distribution, relative abundance, microhabitat use (concentrating on species of conservation concern)	Where are rare species currently located in the river and tributaries? What microhabitats are currently used by mussels in the river and tributaries? What suitable but unoccupied habitat exists?	Improved mussel habitat may be created downstream from the project area, and there may be loss of habitat in the dewatered area, and/or no change in upstream areas. Mussels could be harmed by increased sediment.	Qualitative snorkel and dive mussel surveys based on MDIFW surveys and available bathymetric maps. Surveys should cover areas expected to experience altered hydrology following dam removal, as well as areas that are not expected to experience hydrologic change (e.g., control areas). **Habitat surveys (including benthic environment and hydrological conditions) conducted over several years (June-September) prior to dam removal.** Surveys should note species identifications and relative abundances. Because mussels remain burrowed for most of their life cycle, repeated surveys over the same areas are necessary to account for seasonal dynamics in the above-ground portion of the population. Post-drawdown monitoring should continue annually for more than 5 years after dam removal. Tissues from individuals sampled for identification purposes should be properly preserved for stable isotope analyses and contaminant analyses.
Population age/size distributions	What are current mussel population sizes, densities and age structures? Is there evidence of population growth?	The presence of all age classes indicates that conditions are suitable for population persistence, which can be confirmed with monitoring over several years to document reproduction and survival of young age classes.	Using qualitative information from above, surveys of density estimates and variances among plots and valve measurements, following methods outlined by Strayer and Smith (2003). Surveys repeated over several years before and after dam removal. Sieving to determine buried component of population Mark-recapture studies to determine proportion of population observed at any one time, population change over time, and survival estimates of age classes

Core parameters	Associated questions	Rationale/expectations	Methods
Presence and condition of marked individuals.	What proportion of mussels are recaptured after dam removal, and what is their condition at recapture?	The fate of translocated mussels will be unknown without long term monitoring of marked individuals.	Mark-recapture studies of individuals translocated to sites outside the project area and individuals retained within the project area, to determine proportion of population observed at any one time, population change over time, survival estimates of age classes, and physiological condition. Areas currently unoccupied also should be surveyed to determine if these areas are colonized after dam removal.
Fish host identification, distribution, and abundance	Which fish species are suitable hosts for mussels, and where are they found?	Freshwater mussels require a host fish to nurture and transport mussel larvae upon release from the brooding female mussel.	Based on methods established by Kneeland (2006), identify fish host populations and evidence of infestation by mussel glochidia of species found in the qualitative and quantitative mussel surveys, concurrent with fish surveys in proximity to existing mussel beds during breeding season.
Mussel condition (glycogen levels) and **contaminant loads**	What is the current physiological condition of mussels in the river and tributaries before and after dam removal?	Physiological stress may indicate declining condition. Variations in tissue contaminant loads may reflect changes in river contaminant loads.	Tissue samples collected from mussels tagged in mark-recapture studies; tissue can also be analyzed for stable isotope ratios to determine role of mussel in the river food web, and changes that occur with dam removal, as well as contaminants.
Benthic macroinvertebrates	How do invertebrate communities respond to changes in water quality?	Expect shift from lentic to lotic communities.	Sampling to document benthic invertebrate communities should occur at Veazie, Great Works, Milford, Howland and Enfield impoundments, transects, and bay locations.

2. Biological Component: Avian life

(prepared by Jeff Wells)

Core parameters

Avian species diversity, abundance, habitat use, reproductive success, behavior, changes in food sources, contaminant accumulation

Background

Bird life in, over, on, and around the Penobscot is expected to respond to restoration activities including increases in new riparian zone vegetation, and from changes in aquatic food availability associated with the addition of millions of fish and their impacts on both up and downstream including marine ecosystem productivity. Increased fish access is expected to boost numbers and diversity of potential prey species as well as enhance riverine and riparian ecosystems through increased nutrients (dead fish, spawn, and waste products). The addition of migratory fish may dilute in-stream toxins and pollutants that may currently impair birds and their dependent food web. For purposes of before-and-after monitoring of bird community response to watershed restoration, the various bird species that use the river and adjacent habitats can be partitioned into several ecological or indicator groups based on foraging ecology in relation especially to other animal and plant communities in or adjacent to the river. These indicator groups could include:

a. fish-eating species (common merganser, double-crested cormorant, great cormorant, great blue heron, green heron, osprey, bald eagle, various gulls, belted kingfisher);
b. aquatic invertebrate specialists feeders (bufflehead, common goldeneye, Barrow's goldeneye, some gulls, various shorebird/sandpipers);
c. aerial insectivores (swallows, cedar waxwings, sometimes gulls);
d. terrestrial insectivores (various migrant and breeding landbirds);
e. aquatic herbivores (mallard, American black duck, green-winged teal) and;
f. marsh inhabiting species (rails, herons)

Ongoing monitoring by MDIFW of bald eagles includes nest location, eagle residency, and eaglet production, as well as historic and anecdotal locations of osprey nests. The agency also has historic data (1976-1981) on eagle food habits from prey debris collection at nests from over 150 sites in Maine. U.S. Fish and Wildlife Service has six years of monitoring data on organochlorines, dioxins, furans, and heavy metals in eagle eggs. The BioDiversity Research Institute has surveyed mercury residues in eaglet blood and feathers from sites in the Penobscot River; this work is continuing in the Penobscot estuary in 2007. These programs could be amended or expanded to document pre- and post-restoration mercury and other contaminant loads in a range of bird species from individuals that are known to nest and forage in and adjacent to the river (Evers and Clair 2005).

Core parameter	Objective question	Rationale/expectations	Methods
Species abundance and diversity and changes in use (timing, frequency eating, perching, etc.)	Do indicator species numbers and behavior change due to restoration activities? What is the spatial and temporal variation of bird species?	Increased numbers of birds could be expected to spend more time foraging in, on, and near the river, including new riparian zones and have higher reproductive success due to both increased forage and forage nutrient quality. Changes in abundance or diversity may indicate changes in the ecosystem components upon which birds depend.	Before, during, and after dam removal, document avian diversity and abundance on and adjacent to the river from below former Bangor Dam to above Howland dam throughout the year. Breeding bird, migration and winter bird counts during high activity times that will include nest surveys and spatially focused surveys in areas with new riparian vegetation, and in areas where increases in fish are expected. Timing (pre- and post dam removal): • One-two fields seasons of pre- removal monitoring to collect enough data to map communities and survey key transition zones. • Field season one year after drawdown (document initial response) • Five years from dam removal to help describe the longer term trends • Ten years from dam removal when fish populations will have begun to respond to new habitat.
Marine-derived nitrogen	Are marine-derived nutrients supporting avian food sources?	Marine-derived nitrogen is expected to become more prevalent in birds as sea-run fish import more marine-derived nitrogen into riverine and associated ecosystems.	Tissue or blood samples from birds (including their eggs) that spend a majority of their time on and around the river are sampled for marine derived nutrients using isotopic analysis to document foraging ecology and the trophic levels at which different bird species are using within the river ecosystem (Hobson et al. 1994, Paszkowski et al. 2004, Romanek et al. 2000)
Contaminants	Will contaminant loads decrease or increase with	With increased flow in impoundments and increased fish in and out	Tissue and/or blood sampling for contaminants. Annual surveys documenting the numbers and location of nesting bald eagles, osprey, kingfisher, and perhaps great blue herons, and riparian breeders, are carried out within the

Core parameter	Objective question	Rationale/expectations	Methods
	changes in hydrology and sediment loads?	migration historic toxins in the system should decrease.	watershed region likely to be impacted by the restoration activities. Ideally this would include (at least for some species) a measure of annual reproductive success.

3. Biological Component: Marine and freshwater mammals

(prepared by J. Royte with input from Erin Summers)

Core parameters

Abundance and composition of piscivorous mammals (seals, otter) utilizing the river, estuary, and the riparian zone in areas subject to increased fish access. **Contaminants** and **marine-derived nutrients** in mammalian predators.

Background

Increased fish access and associated food web enrichment, particularly upstream of dam locations but potentially downstream as well, is expected to attract mammalian predators such as grey seals and harbor seals, river otters, raccoon, and fisher. Seals have been observed beyond the former Edwards Dam site in the Kennebec River (Sherwood 2006). Maine Department of Inland Fisheries and Wildlife maintains harvest data on river otter, which are trapped in November and December. Statewide, 1,112 otters were harvested in Maine in 2005. Their overall population status is unknown. A study in the *Journal of Mammalogy* (Docktor et al. 1987) found that otters in Maine seem to have a stable reproductive rate, but mercury pollution may be a problem. Studies by the BioDiversity Research Institute have looked at mercury levels in otters near the mercury-polluted Holtrachem site in Orrington. Mercury levels in brains were below the concentrations that cause acute death, but levels in their fur were high, indicating chronic exposure (Yates et al. 2005).

In addition, more sea-run fish, which tend to be lower in contaminants than freshwater residents, may change the nutrient and toxics loads in predators and their offspring. Indirectly, mammals may have increased nutrient uptake of food web components such as aquatic vegetation (moose), aquatic insects (shrews, mink), and mussels (otter, mink, fisher).

Core parameters	**Associated questions**	**Rationale/expectations**	**Methods**
Mammal species use, timing, abundance and diversity along and in the river	Do indicator species numbers and behavior change due to restoration activities? Are seals making single, brief feeding runs into the river, or are they resident in the system for days or longer?	Increased numbers of mammals could be expected to spend more time foraging in, and near the river and have higher reproductive success due to both increased forage and fitness due to increased nutrient quality.	Observation, scent and camera stations, aerial surveys, winter tracking surveys, IFW harvest records, 2 years before dam removal and years 2 and 4 post, downstream of Veazie, Bangor, Winterport, Bucksport. For seals, observations at mouth of river and estuary. Habitat assessment of use areas (depth, fish species, salinity, temperature, etc.)
Nitrogen signatures in freshwater otters	Does the contribution of sea-run fish to otter diets change?	Sea nutrients expected to become more prevalent in mammals as sea-run fish become a more important part of their diet.	Tissue or blood samples from mammals that spend a majority of their time on and around the river (determined from above) sampled for marine derived nutrients (federal permit required)
Contaminants	Will contaminant loads decrease or increase with changes in hydrology and sediment loads?	With increased flow in impoundments and increased fish in and out migration historic toxins in the system should decrease.	Tissue sampling for and contaminants) can be from individuals sampled to ID

D. Biological component: (wetland and terrestrial) Plant Communities

(prepared by A. Calhoun and C. Loftin)

Core parameters

Changes in the extent (size), distribution, and vegetation composition (species types and dominance including invasive species dominance) of aquatic and riparian plant communities.

Background

Submersed and emergent wetlands associated with the impoundments and nearby tributaries may be affected by potential changes in water levels, flow rate, and sediment dynamics that result from the dam removals. These natural communities may experience changes in water quality from the increased oxygen and nutrient dynamics due to both dam removal and subsequent changes in fish abundance. Other dam removal and fish access case studies suggest that there will be an influx of sea-derived nutrients that are quickly absorbed into in-stream and potentially nearshore habitats through the food web and direct deposition (e.g., Walters and Post 2007). Plants also play a role in stabilizing newly formed banks.

The drawdown zone and disturbed soil at the construction site and downstream may provide opportunities for invasion by non-native plant species. The Maine Natural Areas Program has not completed an aquatic plant survey either for rare species or invasive species along the Penobscot River, although several exotic/invasive wetland plant species, purple loosestrife (*Lythrum salicaria*), and common reed (*Phragmites australis*) are known to occur throughout the watershed and may be expected to colonize newly dewatered areas along the river as a result of the restoration project. Flowering rush (*Butomus umbellatus*) is known to occur in the Kenduskeag drainage but does not appear to be expanding its range at this time. At this time, there are no reported invasive aquatic plant species.

Several sites along the mainstem Penobscot and many of its tributaries harbor rare plants such as Steinmetz's bulrush and exemplary natural communities such as silver maple floodplain forests. It is not clear what effects the project would have on these habitats.

The Nature Conservancy has begun an assessment of existing wetland extent in the project area and wetlands within the 100 year floodplain and associated with tributaries. Recent student efforts to assess wetland extent and species composition of fringing marshes in the tidal portion of the lower river have found that some areas are misclassified or omitted on NWI maps (Kropp et al. 2007, S. Yost pers. comm.).

The Department of Environmental Protection wetland biomonitoring program sampled the Penobscot Basin in 2006. Biological sampling includes aquatic macroinvertebrates, epiphytic algae, and phytoplankton. Water samples are analyzed for nutrients, chlorophyll-a, etc. DEP also collected data on algal communities from streams in the Penobscot Basin.

Core parameters	Associated questions	Rationale/expectations	Methods
Size, extent, and species composition of wetlands in the drawdown area and downstream.	How do riparian habitats respond to drawdown? Do rare plants and exemplary natural community sites change in response to food web nutrient changes?	Drop in water level above dams may result in a loss of wetlands in some areas, while other areas will develop new riparian zones and wetlands. Floodplain communities if exposed to increased levels of sea-derived nutrients could see increased productivity of some species.	One year prior to removal and one year after drawdown (to document initial response), map stream-associated wetlands in the entire area expected to be impacted by drawdown and potential sedimentation or erosion downstream. Using bathymetry, hydraulic model, NWI maps and aerial photographs, as well as field verification, identify areas of the river and surrounding drainages where wetlands will potentially be affected by changes in sediment distribution, water depth, flow velocities, and hydroperiod. Establish transects (co-located with morphometry and mussel cross-sections) to document wetland vegetation change pre- and post dam removal. Transact data should include vegetation-dependent fauna (i.e., dependent on structure or species composition) and seed bank composition. One year prior, one nd five years from dam removal re-do transects to describe longer term trends. Survey rare plant and natural communities with plots. If increased production noted then nutrient studies to track potential link to fish.
Invasive species	Do invasive plant species expand in range as a result of the dam removals?	Increased connectivity and newly exposed banks may provide an opportunity for invasive species to colonize new areas.	Streamside surveys for invasive plant species in areas likely to experience habitat changes, especially newly exposed sediments.

Core parameters	Associated questions	Rationale/expectations	Methods
Wetland function	Are wetland functions altered as a result of dam removal?	Changes in flora, fauna, and ecosystem processes may alter or enhance the function of riparian wetlands.	Perform functional assessments on existing wetlands (flora, fauna, ecosystem processes) to provide comprehensive baseline pre-dam removal data and for post-dam removal comparison.

E. Biological Component: Fish Communities

(prepared by J. Trial, J. Murphy, et al.)

Core parameters

Changes to: 1) total fish biomass and production, 2) temporal and spatial fish community structure (i.e., species richness, distribution of biomass, and production, including non-native fish expanding into new areas), and 3) biomass, production, and animal nutrient and toxicity content.

Background

Dam removal will affect the fish communities in the impoundment areas that will become free flowing, from habitat changes as well as increased access to more and additional species of diadromous fish. The addition of new and more abundant diadromous fish species could potentially affect the entire ecosystem through changes in competition for resources, additional nutrients, new nutrients, potential dilution of in-stream toxins, and changes in fish prey and predator structure, as well as pest and pathogen access.

Introduced fish species may expand in range as barrier removal provides access to new areas of the watershed, and as a result of habitat modifications that allow colonization in areas previously unsuitable to introduced species. Of the 20 fish species identified in the mainstem, and 18 in the tributaries, upwards of half of all species at any site were introduced, and even greater percentages of total fish population at some sites were made up of introduced species, notably centrarchid species (Yoder, 2004) while the majority are already widespread throughout the project area and would not be affected by the restoration project, at least two species, northern pike (*Esox lucius*) and central mudminnow (*Umbra limi*), are recent introductions only known to occur in a limited area and any removal of barriers could enhance their movement into new portions of the watershed.

Studies of fishes can occur at the individual, population, and community levels (Minns et al. 1996). Restoration monitoring in the Penobscot River based on indices at each of these levels of organization will address the range of ecosystem functions potentially affected by the PRRP. The Maine Atlantic Salmon Commission along with other state and federal resource agencies released a draft multi-species fisheries management plan for the Penobscot River in December 2007. The multi-species management plan develops species-specific restoration goals for the Penobscot River based upon habitat, water quality, species life history, etc. To assess the results of the PRRP, a whole-life history model could be developed using data collected during monitoring studies. Estimates of age/size specific survival, growth, fecundity, etc. could be weighted by production goals to identify where bottlenecks exist in meeting restoration goals. Also, data collected during restoration monitoring studies could be used to periodically calibrate species-specific restoration goals of the management plan within a whole-life history model.

A recent review of historical populations of diadromous fish and how those populations may have interacted with salmon populations in the Penobscot, using board of agriculture and fisheries commissioner reports from the last 200 years, provides a baseline for pre-dam conditions and restoration potential (Saunders et al. 2006). In addition, historical fish passage information is contained in FERC and NEPA relicensing documents and applications. The Maine Atlantic Salmon Commission coordinates trap counts at Veazie and Weldon dams in addition to routine monitoring of juvenile salmon populations, available habitat, and redd counts. A current research project to assess sturgeon populations and habitat in the Penobscot provides Before-dam removal information for both Atlantic and shortnose sturgeon (M. Kinnison, G. Zydlewski, S. Fernandes, University of Maine).

A team from the Maine Cooperative Fish & Wildlife Research Unit, University of Maine, and NOAA-NMFS tracks migration of stocked Penobscot River salmon smolts using ultrasonic telemetry to study movement patterns, mortality, and migration delays. NOAA also deploys rotary screw traps below the Veazie dam from April to November. Further out in the estuary, the National Marine Fisheries Service began a post-smolt trawl survey and smolt mark-recapture studies in 2001. Their array of hydroacoustic receiver buoys in Penobscot Bay could be utilized for tracking other species.

Core parameters	Questions	Rationale/expectations	Methods
Fish growth, abundance, biomass, production.	Have diadromous or resident fish populations changed with dam removal & passage improvements?	Dam removal and passage improvements will increase populations of diadromous fishes; resident fishes may be displaced by diadromous fishes.	Continue using Index of Biotic Integrity (IBI) protocols already in use on the river (Yoder and Kulik 2003; Yoder 2005).
Fish movement, **species richness.**	Has the extent and rate of diadromous fish (and resident fish) movement changed in response to dam removal and passage improvements? Have survival rates increased with improvements in fish passage?	Dam removal and passage improvements should increase migration success (and speed?). Fewer dams and improved fish passage should improve survival rates.	PIT tag and ultrasonic telemetry studies of fish movement. Counts of all fish species at dam passage facilities. Studies should focus on EXTENT of movements, as well as the efficacy of fish passage before and after improvements . Note that presently Atlantic salmon are the only diadromous fish to occur above the Veazie Dam in large enough numbers for pre-dam removal tracking.
Juvenile diadromous fish migration.	Do survival rates and passage rates of juvenile Atlantic salmon smolts and	Removal of dams should reduce fatalities associated	Rotary screw traps deployed below site of Veazie dam from April to November, continuing work by NOAA Fisheries Maine Field Station.

Core parameters	Questions	Rationale/expectations	Methods
	other diadromous fishes increase?	with downstream fish passage.	
Returning diadromous fish counts.	Do returns of diadromous fish increase? Has freshwater residency time of diadromous fish changed in the river?	Dam removal and passage improvements should increase the returns of diadromous fish to the river.	Continued counts at existing dam passage structure. Many of these counts must be conducted as part of FERC licensing agreements. Based on life-history constraints, returns may take some time to increase (i.e., years at sea before adults return)
Occurrence of “invading” fish species (pike, mudminnow).	Are invasive species spreading into new habitats?	Barrier removal may provide opportunity for colonization by invasive fish species.	Monitor upstream and downstream of Milford and Howland through trap data at these two facilities.
Estuarine fish population parameters (abundance, distribution).	Do estuarine fish populations respond to increases in diadromous fish runs?	Increases in diadromous fish runs may be accompanied by increases in (1) juvenile and adult diadromous fishes in the estuaries and (2) increases in their predators.	Hydroacoustic survey of Penobscot estuary for fish abundance (presence) and distribution. Additional information on Penobscot Estuary phytoplankton and zooplankton distributions and abundance could be collected at the same time. Rotary screw traps could be used to calibrate hydroacoustics.

F. Biological Component: Food web structure and marine-derived nutrients

(prepared by K. Wilson)

Core parameters

Stable isotope signatures (N & C) of focal organisms and annual lake sediments.

Background

An increase in diadromous fishes in the Penobscot, as well as changes in distribution of resident fishes, would result in changes in food web structure and nutrient sources over time. In Pacific river systems, anadromous fishes import marine-derived nutrients to freshwater ecosystems through excretion, gametes, and carcasses, contributing to periphyton, invertebrate, and juvenile salmon production (Bilby et al. 1996, Cederholm et al. 1999, Schindler et al. 2003). These nutrients may be subsumed into freshwater food webs through a top-down pathway, i.e., direct consumption of fish prey, or a bottom-up pathway, i.e., marine nutrients and tissues are made available through the decomposition action of bacteria, fungi, or invertebrate scavengers. Similar pathways have not been well elucidated for Atlantic salmon and other co-evolved East Coast diadromous fishes (e.g., clupeids, sea lamprey, eel), but existing research does suggest the potential for marine-derived nutrients to be incorporated into freshwater ecosystems (Garman and Macko 1998; MacAvoy et al. 2000, Nislow et al. 2004).

Analysis of naturally occurring stable isotopes is commonly used to quantify food web structure, e.g., assign 'trophic position,' and track additions of nitrogen and carbon from remote sources. Marine consumers are more enriched in the heavier ^{15}N isotope relative to freshwater consumers because nitrogen is not limiting in freshwater systems and primary producers can and do preferentially take up the lighter ^{14}N. Under limiting N conditions (i.e., in the ocean), primary producers often do not have this luxury and take up the more energetically sluggish ^{15}N as well. Thus marine organisms are generally enriched in the ^{15}N isotope. In addition, ^{15}N is less likely to be excreted and thus bioaccumulates. For example, the muscle tissues of a shark will have a higher ^{15}N signature than those of an alewife, just as the muscle tissues of a bass will have a higher ^{15}N signature than those of a minnow. When a bass eats sea-run alewives, however, one would expect that bass to have an N^{15} signature elevated above that of a bass from the same lake eating only minnows. It is this signal, in particular, the comparison of freshwater organisms with and without access to marine-derived nitrogen, that has been used with success in detecting marine inputs to freshwater food webs.

Carbon's stable isotopes can be used to assess the ultimate photosynthetic pathway through which carbon enters a food web, either through terrestrial leaf litter (allochthonous) pathways as is often found in streams and rivers or through atmospheric deposition and internal cycling (autochthonous) as is often found in lakes and reservoirs. Lake food webs have lower ^{13}C ratios than river food webs. Because of this difference one might expect tissues samples from organisms in a food web in impounded stretches of a river to have lower ^{13}C signatures. At the same time, marine-derived carbon is enriched in ^{13}C relative to freshwater or terrestrially carbon.

Carbon and nitrogen isotopic ratios are often presented together to show carbon source as well as trophic level. Generally, the ratio of ^{15}N increases ~ 3.4 units per trophic level while ^{13}C remains generally the same. The stable isotope signature of many tissues changes on the order of weeks to months, and in some cases years. Stable isotope analyses are versatile and can present an integrated long-term picture of food web structure or a seasonal picture. Stable isotope analysis complements other food web techniques, in particular diet studies that alone requires considerable replication to adequately characterize food web links.

Core parameters	**Related questions**	**Rationale/expectations**	**Methods**
Stable isotope signatures (N & C) of target species **	Does trophic structure shift with the addition of diadromous fishes? What is the contribution of marine-derived nitrogen to the riverine food web ? Quantify the contribution of terrestrial, marsh and phytoplankton primary production to the food web	Increased availability of small fish prey may increase the trophic position of predator fishes ^{15}N ratios should increase as diadromous fish runs increase. Increases in ^{15}N may be most pronounced in benthic invertebrates, fast-growing YOY fish, or fast-turnover tissues such as liver (e.g., MacAvoy et al. 2001) Loss of phytoplankton productivity associated with impounded areas may shift carbon sources to benthic algae or more terrestrial sources.	Measure stable isotope signatures (C & N) for at least 10 individuals of a given species and ontogeny (based on size or assumed major prey) in mid- summer, after major spawning runs are complete To monitor contributions of marine derived N to avian predators of anadromous fishes, take blood samples at monthly intervals during spawning runs and analyze for stable isotopes. Isotopic composition of down & feathers of juveniles may also indicate marine derived nutrients.
Stable isotope signatures of annual lake sediments	What is the contribution of marine derived nutrients to annual lake production/primary production?	Increases in diadromous fishes (primarily alewife) will increase	In lakes, monitor stable isotope signature of annual sediments caught using sediment traps.

Core parameters	Related questions	Rationale/expectations	Methods
		the ratio of ^{15}N in lake sediments.	

**Target species: benthic baseline consumers (snails), POM baseline consumers (mussels), benthic invertebrates (multiple functional feeding groups), fishes (resident, non-resident, minnows to apex predators), avian predators, riparian predators (spiders)

G. Human Dimensions

(prepared by L. Lewis and J. Banks)

NOTE: Recognizing the importance of this subject matter, members of the Trust, Lynn Lewis, and John. Banks are continuing to refine and expand this section. Some parameters such as recreational uses of the river,, socioeconomic impacts, and cultural and archaeological resources are being addressed through Trust permitting activities.

Background

The human dimensions surrounding the Penobscot River Restoration Project are numerous and enormously complex. The river has immense historical and cultural significance to the Penobscot Indian Nation as well as to more recent residents of the area and the State of Maine. The historical development along the river, including the industrial development of the hydropower dams has both created and destroyed *value*. Economic, psychological, cultural, spiritual and ecological values have all been affected.

The economic value of hydropower and the mills has in turn caused the destruction of important economic, aesthetic and cultural values.

The human values associated with a restoration of this river system are difficult to measure. For example, the intrinsic economic value known as *existence value* is a monetary measure of the willingness to pay to preserve something simply so that it will continue to exist. There is no associated *use* per se. On the other hand, recreational fishery values are somewhat easier to measure using indirect measures such as recreational angler expenditures. The value of water quality can be teased out of property values using hedonic analysis. Commercial values are even easier to measure using market prices. None of these tell the whole story even when simply focusing on the economics. The value of the salmon to the Penobscot Indian Nation, for example, is not measurable in these terms at all. The values are immeasurable. It will be difficult to set up a monitoring plan to assess tribal members "recovery" of cultural/spiritual integrity resulting from a restored Penobscot River ecosystem, nevertheless, this aspect of the human dimension should not be overlooked.

Some of the human dimensions can be captured by observing human behavior, but others are more difficult to measure or observe. The geographical, historical, cultural, aesthetics, economic and emotional features of this system are broad in scope and scale. Intrinsic values are extremely important when looking *ex-post* at a restoration project.

Since the focus of this plan is to monitor the environment surrounding the project at the outset, we simply acknowledge here the scope and magnitude of the human component and suggest that these areas be considered for future research.

Awareness of Place

A 1994 Penobscot River Recreation Study (Tynon and Fusselman) found that the strongest preference among those residents surveyed was for relaxing, walking, or picknicking, followed by motorboating or fishing from a boat, but that boating opportunities were limited due to a lack of access. This study could provide a useful reference document if the survey was repeated prior to dam removal and again in 5 or 10 years. As part of project permitting, Kleinschmidt is conducting a public access study, including review of existing information in FERC and state records. The study includes potential effects of water level changes on recreational infrastructure, as well as potential use changes, for example from flatwater to whitewater boating.

Appendix A. Dam Removal Permitting

Anticipated Penobscot River Hydroelectric Dam Removal Permitting Procedures

Federal

1. Once the option is exercised, Penobscot River Restoration Trust must file (a) an application for transfer of the FERC license from PPL to the Trust; and (b) a License Surrender Application to FERC. The license surrender application will include information compiled by the applicant documenting the "existing environment," and provide information on any changes or impacts to resources, including geology, water resources, fisheries resources, wildlife, botanical/wetland resources, cultural and historic resources, land management and aesthetics, recreation resources.

The most recent dam removal projects at FERC licensed dams in Maine are the Fort Halifax Dam and the Sandy River Dam,[4] which provide the best indication for expected permitting requirements of the Penobscot dam removals.

After receiving the applications, FERC will prepare a draft Environmental Assessment or Environmental Impact Statement to satisfy requirements of the National Environmental Policy Act (NEPA). It will address each of the areas outlined above. There will be several opportunities for public input, and considerable review by state and federal agencies. A final EA or EIS will be prepared after public comment and agency review.

2. A Clean Water Act Section 404 dredge and fill permit and a Rivers and Harbors Act Section 10 permit are required from the Army Corps of Engineers.

[4] Both projects involved a single dam. The analysis for the Penobscot River Restoration Project will include changes at 3 dams on the state's largest river.

Both of the Federal permits discussed above will trigger consultation under other federal statutes, including the Clean Water Act, the Endangered Species Act, and the National Historic Preservation Act.

State

Removal of hydropower generating or storage dams needs a permit under the Maine Waterway Development and Conservation Act, "the state's one-stop hydropower permitting statute." Approval criteria include (a) making adequate provisions for financial capability and technical capability, public safety and traffic movement, and for mitigating adverse environmental impacts, (b) assuring that water quality standards will be met, and (c) weighing the positive and negative impacts to wetlands, soil stability, fish and wildlife resources, historic and archaeological resources, public rights of access and use of surface waters, flooding, and power generation.

Dam removal is also subject to state water quality certification under Section 401 of the Clean Water Act. The Trust will have to demonstrate that the project "will not result in significant harm to water quality or will not violate applicable water quality standards."[5]

At the local level, dam removal may be subject to local shoreland zoning ordinances and other town development/demolition standards and planning board approval, depending on local ordinances.

---

[5] 38 M.R.S.A. Sec. 635-B.

Appendix B. FUNDING

The following table provides **preliminary cost estimates** for conducting monitoring studies in the Penobscot River. Cost estimates include sampling, data analysis, and reporting. There is considerable overlap between these efforts and we anticipate that, with appropriate coordination, total costs could be reduced considerably . In some cases funding already exists for this work or potential sources have been identified.

Resource	Study	Estimated No. of Years	Annual Cost Estimate ($1,000)
Fisheries	Fish Population Studies	5	50-90
	Smolt Movement (ultrasonic telemetry)	4	125-150
	Adult Salmon Movement (PIT tagging)	4	25--50
	Howland Nature-Like Fishway Effectiveness	2	50-75
	Fishway Monitoring	5	75-100
	Milford, Orono, and Stillwater Fishway Effectiveness	2-3	150-200
	Juvenile Migrant Sampling (rotary screw traps)	5	50-75
	Estuarine Hydroacoustics Sampling	5	150
	Water Quality	3	50
	Habitat Mapping	2	50-75
	Marine Derived Nutrients	2-3	50-75
Geomorphic/ Sediments	Mapping and sampling program		
	-ship-based operations	3	200
	-LIDAR surveys	3	100-150
	Sediment chemistry	1-3	?
	Cross-section surveys	5	10-50
	Hydraulic modeling	1-3	25-250
Wetlands/ Riparian			
Human Dimensions			
Water Quality			

LITERATURE CITED

Bilby, R.E., B.R. Fransen, and P.A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: Evidence from stable isotopes. *Canadian Journal of Fisheries and Aquatic Sciences* 53:164-173.

Block, W.M., A.B. Franklin, J.P. Ward, Jr., J.L. Ganey, and G.C. White. 2001. Design and implementation of monitoring studies to evaluate the success of ecological restoration on wildlife. *Restoration Ecology* 9:293-303.

Cederholm, C.J., M.D. Kunze, T. Murota, and A. Sibatani. 1999. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrrestrial systems. *Fisheries* 24:6-15.

Cutting, R.E. 1959. Penobscot River Salmon Restoration. Augusta, ME: Maine Atlantic Sea-Run Salmon Commission.

Docktor, C.M., R.T. Bowyer, and A.G. Clark. Number of corpora lutea as related to age and distribution of river otter in Maine. *Journal of Mammalogy* 68: 182-185

Dudley, R.W. 1999. Riverbed-sediment mapping in the Edwards Dam impoundment on the Kennebec River, Maine, by use of geophysical techniques. Open-File Report 99-200. Augusta, ME: U.S. Geological Survey http://me.water.usgs.gov/reportsxsub.html.

Dudley, R.W. and S.E. Giffen. 2001. Composition and Distribution of Streambed Sediments in the Penobscot River, Maine. Water Resources Investigations Report 01-4223. Augusta, ME: U.S. Geological Survey.

Elskus, A. 2006. Studying Toxicity. *International Water Power and Dam Construction* March 2006:30-32.

Evers, D.C., and T.A. Clair (eds.). 2005. Biogeographical Patterns of Environmental Mercury in Northeastern North America. *Ecotoxicology* 14.

Federal Interagency Stream Restoration Working Group. 1998. Stream Corridor Restoration: Principles, Processes, and Practices. GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.

Garman, G.C. and S.A. Macko. 1998. Contribution of marine-derived organic matter to an Atlantic coast, freshwater, tidal stream by anadromous clupeid fishes. *Journal of the North American Benthological Society* 17: 277-285.

Gerstein, J.M. 2005. Monitoring the effectiveness of instream habitat restoration. Berkeley, CA: University of California Center for Forestry, 45 pp.

Hobson, K.A., J.F. Piatt, J. Pitocchelli. 1994. Using stable isotopes to determine seabird trophic relationships. *Journal of Animal Ecology* 63: 786-798.

Kelley, A.R. 2006. Archaeological Geology and Postglacial Development of the Central Penobscot River Valley, Maine, USA. Ph.D. Dissertation. Orono, ME: University of Maine.

Kneeland. S.C. 2006. Identification of Fish Hosts for Wild Populations of Rare Freshwater Mussels (*Lampsilis cariosa* and *Leptodea ochracea*) Using a Molecular DNA Key. Electronic Theses and Dissertations. 1184. https://digitalcommons.library.umaine.edu/etd/1184

Kondolf, G.M. 1995. Five elements for effective evaluation of stream restoration. *Restoration Ecology* 3:133-136.

Kropp, C.A. 2007. A survey of riparian and estuarine wetlands on the lower Penobscot River, Penobscot County, Maine, USA. Report prepared for School of Forest Resources. Orono, ME: University of Maine.

Kurth, J., C.S. Loftin, J. Zydlewski, and J.Rhymer. 2007. PIT Tags Increase Effectiveness of Freshwater Mussel Recaptures. *The Journal of the North American Benthological Society* 26:253-260.

MacAvoy, S.E., S.A. Macko, and S.P. McIninch. 2000. Marine nutrient contributions to freshwater apex predators. *Oecologia* 122: 568-573.

MacAvoy, S.E., S.A. Macko, and G.C. Garman. 2001. Isotopic turnover in aquatic predators: quantifying the exploitation of migratory prey. *Canadian Journal of Fisheries and Aquatic Sciences* 58:923-932.

Mack, K.E., B. Newsom, and A.R. Kelley. 1996. *An Assessment of the Cultural Resources in the Howland Reservoir: Results of Phase 1 Investigations*. Report submitted to Bangor Hydro-Electric Company. Orono, ME: University of Maine.

Maine Department of Environmental Protection. 2003. Penobscot River Modeling Report. Augusta, ME: Bureau of Land and Water Quality.

Merritt, K. and A. Amirbahman. 2006. Mercury cycling in sulfide-rich sediments: Contaminant storage in the Penobscot river estuary, Maine. Presented at the Eighth International Conference on Mercury as a Global Pollutant, Madison, WI, August 2006.

Minns, C.K., J.R. Kelso, and R.G. Randall. 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. *Canadian Journal of Fisheries and Aquatic Science* 53:403-414.

Nedeau, E.J., M.A. McCollough, and B.I. Swartz. 2000. The freshwater mussels of Maine. Augusta, ME: Maine Department of Inland Fisheries and Wildlife.

Newsom, B. and D. Sanger. 1998. *Results of the Phase 2 Archaeological Survey, Howland Reservoir, Central Maine*. Report submitted to Bangor Hydro-Electric Company. Orono, ME: University of Maine.

Nislow, K.H., J.D. Armstrong, and S. McKelvey. 2004. Phosphorus flux due to Atlantic salmon (Salmo salar L.) in an oligotrophic upland stream: effects of management and demography. C*anadian Journal of Fisheries and Aquatic Sciences* 61:2401-2410.

Paszkowski, C.A, B.A. Gingras, K. Wilcox, P.H. Klatt, and W.M. Tonn. 2004. Trophic relations of the red-necked grebe on lakes in the western boreal forest: a stable-isotope analysis. *Condor* 106: 638–651.

Romanek, C.S., K.F. Gaines, A.L. Bryan, Jr., and I.L. Brisbin, Jr. 2000. Foraging ecology of the endangered wood stork recorded in the stable isotope signature of feathers. *Oecologia* 125:584-594.

Roni, P., M.C. Liermann, C. Jordan, and E.A. Steel. 2005. Steps for designing a monitoring and evaluation program for aquatic restoration, pages 13-34 in *Monitoring Stream and Watershed Restoration*. Bethesda, MD: American Fisheries Society.

Saunders, R., M.A. Hachey, and C.W. Fay. 2006. Maine's Diadromous Fish Community: Past, Present, and Implications for
Atlantic Salmon Recovery. *Fisheries* 31:537-547.

Schindler, D.E., M.D. Scheuerell, J.W. Moore, S.M. Gende, T.B. Francis, and W.J. Palen. 2003. Pacific salmon and the ecology of coastal ecosystems. *Frontiers in Ecology and the Environment* 1:31-37.

Snyder, N.P., S.A. Wright, C.N. Alpers, L.E. Flint, C.W. Holmes, and D.M. Rubin. 2006. Reconstructing depositional processes and history from reservoir stratigraphy: Englebright Lake, Yuba River, northern California. *Journal of Geophysical Research* 111:F04003 1-16.

Strayer, D.L., and D.R. Smith. 2003. A guide to sampling freshwater mussel populations. American Fisheries Society Monograph 8. Bethesda, MD: American Fisheries Society.

Tynon, J.F., and M.J. Fusselman. 1994. Penobscot River Recreation Study. Miscellaneous Report 381. Orono, ME: Maine Agricultural and Forest Experiment Station.

USFWS. 2000. Stream Corridor Restoration. Course Materials. Shepherdstown, WV: National Conservation Training Center. .

USGS. 2005. Draft Elwha River Restoration Monitoring Plan.

Walters, A.W. and D.M. Post. 2007. The impacts of marine-derived nutrients in anadromous alewife streams. Presented at ASLO 2007 Aquatic Sciences Meeting, February 2007, Santa Fe, NM.

https://www.sgmeet.com/aslo/santafe2007/viewabstract2.asp?AbstractID=617&SessionID=SS16

Yates, D.E., D.T. Mayack, K. Munney, D.C. Evers, A. Major, T. Kaur, and R.J. Taylor. 2005. Mercury Levels in Mink (Mustela Vison) and River Otter (Lontra Canadensis) From Northeastern North America. **Ecotoxicology 14:263-274.**

Yoder, C.O. and B.H. Kulik. 2003. The development and application of multimetric indices for the assessment of impacts to fish assemblages in large rivers: A review of current science and application. *Canadian Water Resources Journal* 28:301-328.

Yoder, C.O., B.H. Kulik, J.M. Audet, and J.D. Bagley. 2006. The Spatial and Relative Abundance Characteristics of the Fish Assemblages in Three Maine Rivers: Kennebec River: Bingham, ME to Merrymeeting Bay (2002-3) Androscoggin River: Errol, NH to Merrymeeting Bay (2003) Sebasticook River: Pittsfield, ME to Winslow, ME (2003).September 1, 2006. Columbus, OH: Cntr for Appl. Bioassessment & Biocriteria, Midwest Biodiversity Institute.

APPENDIX B: PENOBSCOT RIVER LONG-TERM ECOLOGICAL MONITORING (NOAA PRIORITIES)

Penobscot River Long-term Ecological Monitoring: NOAA Priorities

This report is a work in progress and should not be considered an official policy paper issued by NMFS. Any comments and questions regarding any of the information in this draft are welcomed and should be directed to Rory Saunders at (207) 866-4049 or Rory.Saunders@noaa.gov.

1.0 Introduction

Dams may create impassable barriers for migrating fish, degrade water quality, and negatively alter ecosystem conditions. The socioeconomic costs and ecological impacts posed by dams have led private entities, natural resource professionals, non-profit organizations, and municipalities to seek dam removal as a viable option for diadromous fish and stream restoration (Collins *et al.*, 2007). Common goals for stream barrier removal projects include:

- restoring instream habitat for migratory and resident fishes;
- reconnecting artificially fragmented stream and riparian systems;
- restoring natural flow regimes and stream processes; and
- improving water quality.

In 2004, a coalition of federal, state, and tribal governments and conservation groups signed a settlement agreement with the owner of the two lowermost dams on Maine's Penobscot River that will result in their removal and the construction of a bypass channel around a third dam further upstream. This agreement was pursued primarily to restore diadromous fish runs to the lower Penobscot River basin and accrue the ecosystem benefits associated with dam removals.

Understanding the effectiveness of dam removal requires systematic project monitoring and data reporting. Toward that end, the Penobscot River Science Steering Committee (PRSSC), a diverse group of government agency staff, academic researchers, and non-profit representatives that was initiated by the Penobscot River Restoration Trust in 2005 to organize and oversee scientific research and monitoring related to the Penobscot River Restoration Project (PRRP), has developed a draft Penobscot River Monitoring Framework (PRSSC, 2007). This framework identifies monitoring studies important for understanding long-term ecological response to the dam removals in the lower river. NOAA Fisheries Service and NOAA Restoration Center (collectively referred to as NOAA) are both represented on the PRSSC.

Concurrent to the PRSSC process, but unrelated to it, the NOAA Restoration Center, through the Gulf of Maine Council (GOMC) and in collaboration with state and provincial resource management agencies and non-profit organizations, developed stream barrier removal monitoring guidance for the region (hereafter referred to as the "GOMC guidance"; Collins *et al.*, 2007). The monitoring guidance enables evaluating restoration success in these important contexts: hydrology, hydraulics, and sediment; in-stream, wetland, and riparian habitats; and diadromous fish (Collins *et al.*, 2007). To develop the guidance, over 70 experts in these topics were convened in June 2006 for a series of workshops. The group sought to converge on parameters that are integrative—i.e., useful for answering a broad range of questions across disciplines. Participants represented many perspectives including those of resource managers, academics, consultants, and non-governmental organizations (NGOs) in the United States and Canada. Many of the individuals participating in the workshops are also affiliated with the PRSSC.

NOAA recognizes the value of the GOMC guidance in the context of planning long-term ecological monitoring for the PRRP. It is NOAA's view that the critical parameters identified through that multidisciplinary, international effort likely represent the fundamental ecological monitoring needs of the Penobscot project and can form the nucleus of a monitoring program that may include additional parameters. This document describes how NOAA compared the GOMC guidance with the PRSSC draft Penobscot River Monitoring Framework and extracted from it a short list of <u>NOAA Priority Long-term Ecological Monitoring Parameters</u> (or, in some cases, categories of parameters). Also described is the rationale for including each priority parameter on this short list, how to integrate long-term ecological monitoring with permitting and/or feasibility studies, and estimated costs for each parameter.

2.0 DRAFT NOAA Priority Long-term Ecological Monitoring Parameters

To identify priority long-term ecological monitoring parameters, NOAA compared the GOMC guidance with the PRSSC draft Penobscot River Monitoring Framework. Table 1 shows all eight of the monitoring parameters that are identified as "critical" in the GOMC guidance (in some instances these are parameter categories). Also shown are the PRSSC draft Penobscot River Monitoring Framework groups for which there is a "core" parameter that is closely matched to a GOMC guidance critical parameter. It is evident that all of the GOMC guidance critical parameters were also identified as core parameters by the PRSSC. Parameters prioritized by both efforts are clearly valued by the experts involved in these vetting processes and thus are appealing as NOAA priority parameters. The parameters in the shaded rows are the DRAFT NOAA priority monitoring parameters.

Table 1: Long-term monitoring parameters identified by Collins *et al.* (2007) and the PRSSC.

Long-term Monitoring Parameter	GOMC guidance	PRSSC
Monumented cross-sections	critical	Group A
Longitudinal profile	critical	Group A
Grain size distribution	critical	Group A
Photo stations	critical	Group A
Water quality	critical	Group B
Wetland and riparian plant communities	critical	Group D
Benthic macroinvertebrates	critical	Group B
Fish community structure and function	critical	Group E

The only GOMC guidance critical parameter not recommended for further consideration as a NOAA priority parameter is longitudinal profile. Although valuable, repeatedly resurveying the longitudinal profile of the project reach on this large river would be costly and a rough approximation of the longitudinal profile can be obtained from the monumented cross-sections.

There are many other PRSSC core parameters not recommended here as NOAA priority parameters, however the intention is not to diminish their importance or exclude them altogether. These parameters may be considered again for NOAA funding at a later date as the project progresses, but for planning purposes at this juncture, NOAA is prioritizing the parameters listed above because they are most likely to cost-effectively provide the essential information necessary to understand ecosystem response.

3.0 Rationale

3.1 Monumented Cross-Sections

In a long-term ecological monitoring context, cross-section re-surveys will document vertical and horizontal channel adjustments (i.e., degradation, aggradation, widening, narrowing) in response to the new flow and sediment transport regimes following barrier removal. Having the cross-sections monumented also makes them useful as multi-parameter transects at which numerous long-term monitoring parameters can be evaluated. For example, the monumented cross-sections can be the locations where the repeat photo stations are established, grain size distribution evaluated, water quality measurements taken, and wetland and riparian plant communities investigated. They may also be suitable locations for macroinvertebrate and fisheries studies. As multi-parameter transects, the monumented cross-sections are the “skeleton” of the monitoring framework, forming its spatial framework. They can also augment the geometry data in the permitting/design hydraulic model.

3.2 Grain-Size Distribution

Resampling grain size distribution during cross-section re-surveys will document how the composition of the bed material is changing at the cross section over time, and with that information much can be inferred about local changes in the stream’s hydraulic characteristics such as roughness and flow competence. These surveys will also provide valuable information about habitat condition for various biota including fish and benthic macroinvertebrates.

3.3 Photo Stations

Repeat photos taken at established, georeferenced locations along the multi-parameter transects can provide a visual record of ecosystem conditions such as riparian vegetation and channel configuration. These conditions may be captured by other parameters, for example vegetation monitoring or channel cross-section elevation surveys, but the photo record provides visual documentation that may be more easily understood by non-specialists. Also, photos capture and integrate in one image a variety of site conditions and in so doing aid the interpretation of other data sets.

3.4 Water Quality

Basic water quality data are critical inputs necessary for assessing and understanding changes in fish habitat use, fish population numbers, and fish community structure and function. Concurrent monitoring (in time and space) of numerous water quality parameters will greatly strengthen our ability to assess the effects of barrier removal/alteration of the Penobscot River fish community. This information will be invaluable for assessing the success or failure of the PRRP towards restoring the Penobscot ecosystem and for the assessment and prioritization of future barrier removal projects.

3.5 Wetland and Riparian Plant Communities

Wetlands and other plant communities in the riparian zone provide a wide array of functions within a riverine ecosystem including: canopy cover to instream and riparian areas; fluvial and slope wash erosion protection; detritus contribution which provides both cover and a food source to instream and terrestrial biota; and transformation or uptake of suspended or dissolved constituents transported to the stream by overland flow or ground water discharge. Since wetlands and other riparian plant communities are strongly influenced, and indeed defined, by local hydrology, characterizing their structure, composition, and function both pre- and post-project is important for understanding the Penobscot River ecosystem's response to the dam removals.

3.6 Benthic Macroinvertebrates

Benthic macroinvertebrate community structure is widely regarded as an important indicator of aquatic ecosystem habitat quality and function. Surveys of the benthic macroinvertebrate community integrate a wide array of chemical and biological parameters because benthic macroinvertebrates have limited mobility, have highly varying tolerances for environmental perturbations, and can be sampled with relative ease. Various metrics of benthic macroinvertebrate community structure have been used to quantify biotic integrity. As an example, the Maine Department of Environmental Protection has used benthic macroinvertebrate communities to assess attainment of water quality standards since 1983.

3.7 Fish Community Structure and Function

The PRRP offers some unique opportunities to reconnect the native suite of diadromous fish with historically accessible freshwater habitats. Current scientific information suggests that a number of ecological linkages (e.g., prey buffers) will also be restored concurrently. However, most of these ecological linkages largely remain untested hypotheses for northeast riverine ecosystems. Large-scale research and monitoring efforts in the Pacific Northwest and Mid-Atlantic states have provided some broad areas that require further testing. Of particular relevance to the Penobscot are the following general areas: 1) marine-derived nutrients can provide important nutrient subsidies to freshwater and riparian environments; 2) interspecific relations may drive demographic trends of both predators (striped bass) and prey (Atlantic salmon smolts); 3) thorough understanding of abundance levels of diadromous fish populations is requisite to understanding any interactive effects of dam removal. A major hurdle to testing these linkages in a scientifically rigorous way has been the absence of commitments to monitor long-term ecological changes in a restored system. Thus, the Penobscot offers unique opportunities to collect baseline data before, during, and after treatment (i.e., diadromous fish restoration) to truly understand the ecological effects of a large scale dam removal and fish restoration effort.

4.0 Monitoring Methods, Durations, and Estimated Costs

Table 2 summarizes NOAA's priority long-term ecological monitoring parameters including tentative estimates for monitoring methods, durations, and annual costs, among other information. NOAA will continue to refine this information.

Table 2: NOAA priority long-term ecological monitoring parameter summaries

Long-term Monitoring Parameter	**Core Objective**	**Key Questions**	**Methods (proposed avenue)**	**Parameters to monitor (Sampling scheme)**	**Min # of years to monitor/ # of sites**	*tentative* **Monitoring schedule**	**Approx annual costs**	**Comments**
Hydrodyn., geomorph., and sediment transport	Determine how the PRRP affects hydrodyn., geomorph, and sediment transport in the lower PRB	<u>Has the stream channel geometry changed?</u> Cross-section re-surveys will document vertical and horizontal channel adjustments (i.e., degradation, aggradation, widening, narrowing) in response to the new flow and sediment transport regimes following barrier removal. Results will provide insights regarding the dominant hydraulic and geomorphic processes operating in the reach post-dam removal and indicate the existing, or developing, physical habitat conditions	survey shallow areas with a total station; survey mainstem with a fathometer mounted on shallow water craft;	monum. cross-sections	10/TBD	2 - years of pre-treatment, 4 years of post treatment;	25-50K	
Hydrodyn., geomorph., and sediment transport	Determine how the PRRP affects hydrodyn., geomorph, and sediment transport in the lower PRB	<u>Has the grain size distribution at the monumented cross-sections changed?</u> Resampling grain size distribution during cross-section re-surveys will document how the composition of the bed material is changing at the cross section over time, and with that information much can be inferred about local changes in the stream's hydraulic characteristics such as roughness and flow competence. These surveys will also provide valuable information about habitat condition for various biota including fish and benthic macroinvertebrates.	survey shallow areas manually (pebble counts or bulk samples; survey mainstem with geophysical instrument mounted on shallow water craft;	grain size distribution (at cross-sections)	10/TBD	2 - years of pre-treatment, 4 years of post treatment;	Covered in above cost	

Long-term Monitoring Parameter	Core Objective	Key Questions	Methods (proposed avenue)	Parameters to monitor (Sampling scheme)	Min # of years to monitor/ # of sites	*tentative* Monitoring schedule	Approx annual costs	Comments
Hydrodyn., geomorph., and sediment transport	Determine how the PRRP affects hydrodyn., geomorph, and sediment transport in the lower PRB	<u>What can repeat photos at prescribed stations and bearings tell us about physical processes occurring at the monumented cross-sections?</u> Repeat photos taken at established, georeferenced locations along the multi-parameter transects can provide a visual record of ecosystem conditions such as riparian vegetation and channel configuration. These conditions may be captured by other parameters, for example vegetation monitoring or channel cross-section elevation surveys, but the photo record provides visual documentation that may be more easily understood by non-specialists. Also, photos capture and integrate in one image a variety of site conditions and in so doing aid the interpretation of other data sets.	establish photo stations at each cross section.	photo stations	10/TBD	2 - years of pre-treatment, 4 years of post treatment;	5-10K	Preferred camera specs: >3 MP resolution; optical zoom; video function;
Water Quality	Determine how the PRRP affects Water Quality in the lower PRB	<u>Has water quality in the lower PN changed?</u> Basic water quality data are critical inputs necessary for assessing and understanding changes in fish habitat, fish population numbers and fish community structure and function. Concurrent monitoring (in time and space) of numerous water quality parameters will greatly strengthen our ability to assess the effects of barrier removal/alteration of the Penobscot River fish community. This information will be invaluable for evaluating the success or failure of the PRRP towards restoring the Penobscot ecosystem and for the assessment and prioritization of future barrier removal projects.	continuous water quality sampling (grab samples when necessary) (contract)	temp, DO, salinity, BOD, TTS, phosphorus, nitrogen (?), chlorophyll-a, trace metals and contaminants (set stations)	6/TBD	2 - year of pre-treatment, 4 years of post treatment (seasonally);	40K	

Long-term Monitoring Parameter	Core Objective	Key Questions	Methods (proposed avenue)	Parameters to monitor (Sampling scheme)	Min # of years to monitor/ # of sites	*tentative* Monitoring schedule	Approx annual costs	Comments
Wetland and riparian plant communities	Determine how the PRRP affects wetland and riparian plant community in the lower PRB	<u>How do riparian habitats respond to drawdown?</u> Wetlands and other plant communities in the riparian zone provide a wide array of functions within a riverine ecosystem including: canopy cover to instream and riparian areas; fluvial and slope wash erosion protection; detritus contribution which provides both cover and a food source to instream and terrestrial biota; and transformation or uptake of suspended or dissolved constituents transported to the stream by overland flow or ground water discharge. Since wetlands and other riparian plant communities are strongly influenced, and indeed defined, by local hydrology, characterizing their structure, composition, and function both pre- and post-project is important for understanding the Penobscot River ecosystem's response to the dam removals.	Establish transects (co-located with morph.) to document wetland vegetation change pre- and post dam removal.	size, extent, and species composition of wetlands in the drawdown area and downstream	5/TBD	One year pre-treatment, one and five years post treatment;	20K	
Water Quality		<u>Has the benthic invertebrate community structure changed?</u> Similar to basic water quality data, understanding changes to the benthic community structure due to the PRRP is a critical input necessary for assessing and understanding changes in aquatic community structure and function. Monitoring the Penobscot River benthic community before, during and after the PRRP will allow for the determination if barrier removal leads to changes in terms of abundance, species richness and spatial distribution of the benthic community. This information will be invaluable for interpreting documented changes to the Penobscot River fish community, for evaluating the success or failure of the PRRP towards restoring the Penobscot ecosystem and for the assessment and prioritization of future barrier removal projects.	survey (contract)	IBI-type metrics (Stratified random)	9/TBD	1 year of pre-treatment, then every 5 years per DEP protocols.	30K	These efforts are ongoing. by DEP on a 5 year cycle year. Only one additional year of pre-treatment data should be collected.

Long-term Monitoring Parameter	Core Objective	Key Questions	Methods (proposed avenue)	Parameters to monitor (Sampling scheme)	Min # of years to monitor/ # of sites	*tentative* Monitoring schedule	Approx annual costs	Comments
Fish Communities	Determine how the PRRP affects fish community structure and function	Has fish community structure changed? The PRRP provides and opportunity to understand how riverine fish communities may respond to dam removal/alteration. Monitoring the Penobscot River fish community before, during and after the PRRP will aid in evaluating if barrier removal leads to changes in resident or diadromous fish communities in terms of abundance, species richness and spatial distribution. This information will be invaluable for evaluating the success or failure of the PRRP towards restoring the Penobscot ecosystem and for the assessment and prioritization of future barrier removal projects.	Electro-fishing/hydro-acoustics (contract)	IBI-type metrics: species composition, length, guild, etc (Stratified random)	18/TBD	2 years of pre-treatment, then post-removal and then every 4 years (4 years = one generation, for salmon and alewives)	50K	
Fish Communities		Has adult abundance of alewives, salmon, shad, eels, and sea lamprey changed? The PRRP offers the unique opportunity to reconnect the native diadromous species complex to their historic habitats in the Penobscot system. Annual monitoring activities are critical to understanding the progress made towards this goal prior to and post barrier removal/alteration.	Trapping facilities (NOAA Fisheries Service Grant to DMR SRFH)	adult escapement of each species (Census)	20/1 (Milford fish lift)	indefinitely	40K (+75K one time cost to develop automated counting windows)	

Long-term Monitoring Parameter	Core Objective	Key Questions	Methods (proposed avenue)	Parameters to monitor (Sampling scheme)	Min # of years to monitor/ # of sites	*tentative* Monitoring schedule	Approx annual costs	Comments
Fish Communities		Has production of juvenile alosines changed? Restoring the native diadromous species complex to their historic habitats is a major step towards restoring the health of the Penobscot River ecosystem. Establishing self sustaining diadromous populations are required before the full ecological benefits to the system can be realized. Monitoring juvenile alosine production is critical to understanding how quickly and to what extent these populations establish post barrier removal/alteration.	Hydro-acoustic survey (contract)	juvenile production (or index of production) (sonar transect)	18/TBD	2 years of pre-treatment, then post-removal and then every 4 years (4 years = one generation, for salmon and alewives)	35K	
Fish Communities		Has survival of emigrating salmon smolts changed? The National Academy of Sciences stated that the highest priority for restoring the endangered Atlantic salmon in Maine is dam removal. Monitoring emigrating salmon smolt survival prior to and post dam removal/alteration projects is absolutely critical to understanding the benefits afforded by barrier removal/alteration projects towards Atlantic salmon restoration efforts.	Telemetry (NOAA Fisheries Service)	emigration survival (random)	8/TBD	4 - year of pre-treatment, 4 years of post treatment	50K	

Long-term Monitoring Parameter	Core Objective	Key Questions	Methods (proposed avenue)	Parameters to monitor (Sampling scheme)	Min # of years to monitor/ # of sites	*tentative* Monitoring schedule	Approx annual costs	Comments
Fish Communities		<u>Has survival of adult salmon changed?</u> The National Academy of Sciences stated that the highest priority for restoring the endangered Atlantic salmon in Maine is dam removal. Monitoring migrating spawning adult survival from the ocean to their spawning grounds prior to and post dam removal/alteration is absolutely critical to understanding the benefits afforded by barrier removal/alteration projects towards Atlantic salmon restoration efforts.	telemetry/PIT tags (NOAA Fisheries Service Grant to DMR SRFH)	survival during spawning migration	7/ *TBD*	3 - year of pre-treatment, 4 years of post treatment	50K	
Fish Communities		<u>Has the distribution of invasive species (e.g. pike) increased?</u> An important concern is potential for increased and accelerated spread of previously established invasive species within the Penobscot River due to the PRRP. Invasive species can have negative effects on the native species complex and could hinder restoration efforts towards re-establishing the native diadromous species complex to their historic habitats. Monitoring the distribution of invasive species will provide critical information on the effects of barrier removal/alteration to their spread and provide information necessary to managed against the potential for negative impacts.	Trapping facilities, telemetry, creel surveys (NOAA Fisheries Service Grant to DMR SRFH)	distribution of targeted invasive species (Census)	18/TBD	2 - year of pre-treatment, 4 years of post treatment (staggered)	50K	

Long-term Monitoring Parameter	Core Objective	Key Questions	Methods (proposed avenue)	Parameters to monitor (Sampling scheme)	Min # of years to monitor/ # of sites	*tentative* Monitoring schedule	Approx annual costs	Comments
Fish Communities		<u>Have the competitive and predatory impacts of invasive species on native diadromous species changed?</u> Invasive and native species interact in a number of ways, including competition. However, the PRRP could create an environment where the competitive and predatory impacts imparted by the established invasive species prevent the establishment of self sustaining native diadromous populations. If diadromous populations failed to become established, it could be falsely assumed to be a failure of the PRRP. Monitoring the competitive and predatory interaction between invasive and native species is essential to understanding the effects the PRRP has on the fish community of the Penobscot River	competition/ predation studies (contract)	distribution/census data, diet data of invasive species	12/TBD	2 - year of pre-treatment, 4 years of post treatment (staggered)	75K	

Long-term Monitoring Parameter	Core Objective	Key Questions	Methods (proposed avenue)	Parameters to monitor (Sampling scheme)	Min # of years to monitor/ # of sites	*tentative* Monitoring schedule	Approx annual costs	Comments
Fish Communities		Have the competitive and predatory impacts of native estuarine species on native diadromous species changed? Native estuarine and diadromous species do naturally compete and interact within the Penobscot River estuary. However, the PRRP could create an environment where the balance of the competitive and predatory impacts of these two specie complexes hinders the establishment of self sustaining native diadromous populations within newly accessible habitats in the watershed. If diadromous populations failed to become established, it could be falsely assumed to be a failure of the PRRP. Monitoring the competitive and predatory interactions between these two species complexes within the estuary is essential to understanding the effects the PRRP has on the Penobscot fish community.	predation studies (NOAA Fisheries Service Grant to DMR SRFH)	distribution/census data, diet data of estuarine species	12/TBD	2 - year of pre-treatment, 4 years of post treatment (staggered)	75K	

Long-term Monitoring Parameter	Core Objective	Key Questions	Methods (proposed avenue)	Parameters to monitor (Sampling scheme)	Min # of years to monitor/ # of sites	*tentative* Monitoring schedule	Approx annual costs	Comments
Fish Communities		What are the competitive and predatory impacts of native diadromous species co-existing? Historically, the native diadromous species complex within the Penobscot River co-evolved over time to minimize niche overlap and maximize energy gain per individual. These relations may have provided ecological benefits to some species (e.g. marine-derived nutrients deposition and prey buffering). Attempting to restore this complex to the Penobscot River on a human time scale versus an evolutionary time scale may create an environment where negative competitive interactions out weight the positive benefits obtained from co-existing. Monitoring these interactions will improve our understanding of these processes and will aid in the future management of barrier removal/alteration projects.	competition studies (contract)		12/TBD	2 - year of pre-treatment, 4 years of post treatment (staggered)	50K	
Fish Communities		What are the effects on sturgeon dynamics (abundance, survival, distribution, life history…)? Shortnose sturgeon has been listed as endangered since the inception of the ESA in 1973. Little has been known about their status in the Penobscot until recently. Even with new data, abundance levels are still far from clear. Minimally, the upstream distribution for both shortnose and Atlantic sturgeon should be understood. If possible, investigations on the dynamics of these species in these newly accessible habitats should be conducted to understand of the effects of these barrier removal/alteration projects on the species.	Telemetry/active sampling (NOAA Fisheries Service)	survival (random)	20/TBD	4 - year of pre-treatment, 4 years of post treatment (staggered)	50K	

Long-term Monitoring Parameter	**Core Objective**	**Key Questions**	**Methods (proposed avenue)**	**Parameters to monitor (Sampling scheme)**	**Min # of years to monitor/ # of sites**	*tentative* **Monitoring schedule**	**Approx annual costs**	**Comments**
Fish Communities		Has the availability and utilization of marine derived nutrients changed? With one goal of the PRRP being to restore the native diadromous fish populations within the Penobscot River, there is an expectation of marine-derived nutrients being imported into the freshwater ecosystem through both top-down and bottom-up pathways. These nutrients may contribute to periphyton, invertebrate and fish communities through increased production and survival. Documenting the addition of nutrients from marine sources and correlating these additions with increases in invertebrate and fish production and survival is critical to understanding the putative benefits of barrier removal/alteration.	Stable isotope analysis of focal organisms and lake sediment samples (contract)	Stable isotopes; stratified random	18/TBD	2 - year of pre-treatment, 4 years of post treatment (staggered)	75K	

5.0 Integration with Permitting and/or Feasibility Studies

As project proponents, NOAA is well positioned to assure that studies necessary for project implementation are integrated with long-term ecological monitoring efforts, where such integration is logical and mutually beneficial. For example, three field studies completed during summer/fall 2007 have direct bearing on the recommended NOAA priorities: detailed bathymetry and sediment characterization studies; freshwater mussel inventories; and a shoreline natural resource and infrastructure assessment.

The detailed bathymetry and sediment characterization studies are a good example of how NOAA is facilitating such integration. The bathymetry and sediment investigations are not only necessary to construct hydraulic models and conduct sediment transport studies required by project regulators, but they are also a prerequisite to identifying the monumented cross-sections that will serve as multi-parameters transects for the long-term ecological monitoring. To make this work useful in the long-term monitoring realm, NOAA will lead an effort to review the ongoing bathymetry and sediment investigations with an aim of identifying these long-term monitoring transects.

NOAA envisions that similar integration is possible for other permitting/feasibility studies, especially the freshwater mussel and shoreline surveys. NOAA intends to continue serving as an important link between the project proponents and the research community.

6.0 Socioeconomic Studies

Socioeconomic factors are critical to consider for river restoration projects generally, and dam removals specifically. Much like the potential ecological benefits of dam removal, little data exists to appropriately evaluate the socioeconomic effects of dam removals. Although not specifically described here, NOAA envisions a variety of socioeconomic studies as part of the monitoring efforts on the Penobscot. We are currently seeking input on core variables of interest and potential partners both internal and external to NOAA.

7.0 Summary and Conclusions

NOAA is committed to evaluating the long-term ecological response of the Lower Penobscot River basin to the dam removals planned as a major component of the PRRP. The response will be physical, chemical, biological, and socioeconomic. The NOAA Priority Long-term Ecological Monitoring Parameters presented in this document, identified by comparing the GOMC guidance with the PRSSC draft Penobscot River Monitoring Framework, cost-effectively provide the essential information necessary to understand ecosystem response. Additional parameters can be added to this core group as needed to support critical research needs, and as funding permits. Proposed monitoring will also take advantage of existing, complementary research underway in the Penobscot basin and adjacent basins.

Annual costs for the full suite of NOAA Priority Long-term Ecological Monitoring Parameters are estimated to be approximately $600,000 to $900,000. Table 2 shows that some parameters require 3-4 years of pre-removal baseline data collection, which suggests that monitoring for those should begin during the 2008 season (assuming dam removal begins in the fall of 2010 at the earliest). Doing so will require monitoring plans and any necessary requests for proposals (RFPs) be developed in the late winter and early spring of 2008.

8.0 References

Collins, M., K. Lucey, B. Lambert, J. Kachmar, J. Turek, E. Hutchins, T. Purinton, and D. Neils, 2007. Stream Barrier Removal Monitoring Guide. Gulf of Maine Council on the Marine Environment. Available from http://www.gulfofmaine.org/streambarrierremoval/

Penobscot River Science Steering Committee, 2007. Penobscot River Monitoring Framework. DRAFT.

Appendix C: Reference list of published scientific articles resulting from data collected prior to dam removal by one of the nine studies within the comprehensive monitoring program

Altenritter ME, Zydlewski GB, Kinnison MT, Zydlewski JD, Wippelhauser GS. 2018. Understanding the basis of shortnose sturgeon (*Acipenser brevirostrum*) partial migration in the Gulf of Maine. Canadian Journal of Fisheries and Aquatic Sciences 75:464-473.

Altenritter ME Zydlewski GB, Kinnison MT and Wippelhauser GS. 2017. Atlantic sturgeon use of the Penobscot River and marine movements within and beyond the Gulf of Maine. Marine and Coastal Fisheries 9:216-230.

Altenritter ME, Kinnison MT, Zydlewski GB, Secor DH and Zydlewski JD. 2015. Assessing dorsal scute microchemistry for reconstruction of Shortnose sturgeon life histories. Environmental Biology of Fishes 98:2321-2335.

Collins MJ, Kelley AR, and Lombard PJ. 2020. River channel response to dam removals on the lower Penobscot River, Maine, United States. River Research and Applications. 36: 1778-1789.

Dionne PE, Zydlewski GB, Kinnison MT, Zydlewski JD and Wippelhauser GS. 2013. Reconsidering residency: Characterization and conservation implications of complex migratory patterns of shortnose sturgeon (*Acispenser brevirostrum*). Canadian Journal of Fisheries and Aquatic Sciences 70:119-127.

Izzo LK, Maynard GA and Zydlewski J. 2016. Upstream movements of Atlantic salmon in the lower Penobscot River, Maine following two dam removals and fish passage modifications. Marine and coastal fisheries, 8(1), 448-461.

Johnston, C., Zydlewski, G.B., Smith, S., Zydlewski, J. and Kinnison, M. 2018. River Reach Restored by Dam Removal Offers Suitable Spawning Habitat for Endangered Shortnose Sturgeon. Transactions of the American Fisheries Society 148: 163-175.

Kiraly IA, Coghlan Jr SM, Zydlewski JD and Hayes D. 2014. An Assessment of Fish Assemblage Structure in a Large River. River Research and Applications 31:301-312.

Kiraly IA, Coghlan Jr SM, Zydlewski JD and Hayes D. 2014. Comparison of Two Sampling Designs for Fish Assemblage Assessment in a Large River. Transactions of the American Fisheries Society 143:508-518.

Maynard GA, Kinnison MT and Zydlewski JD. 2017. Size selection from fish ways and potential evolutionary responses in a threatened Atlantic salmon population. River Research and Applications 33:1004-1015.

Maynard GA, Izzo LK and Zydlewski JD. 2018. Movement and mortality of Atlantic salmon kelts (Salmo salar) released into the Penobscot River, Maine. Fishery Bulletin, 116(3-4), 281-291.

Scherelis, C., Zydlewski, G.B., Brady, D.C. 2019. Using hydroacoustics to relate fluctuations in fish abundance to river restoration efforts and environmental conditions in the Penobscot River, Maine. River Research Applications. 1–13. https://doi.org/10.1002/rra.3560.

Stich DS, Bailey MM and Zydlewski JD. 2014. Survival of Atlantic salmon (*Salmo salar*) smolts through a hydropower complex. Journal of Fish Biology 85:1074-96.

Stich DS, Zydlewski GB, Kocik JF and Zydlewski JD. 2015. Linking behavior, physiology, and survival of Atlantic salmon smolts during estuary migration. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 7:68-86.

Stich DS, Bailey MM, Holbrook CM, Kinnison MT and Zydlewski JD. 2015. Catchment-wide survival of wild- and hatchery-reared Atlantic salmon smolts in a changing system. Canadian Journal of Fisheries and Aquatic Sciences 72:1352-1365.

Stich DS, Kinnison MT, Kocik JF and Zydlewski JD. 2015. Initiation of migration and movement rates of Atlantic salmon smolts in fresh water. Canadian Journal of Fisheries and Aquatic Sciences 72:1-13.

Stich DS, Zydlewski GB and Zydlewski JD. 2016. Physiological preparedness and performance of Atlantic salmon (*Salmo salar*) smolts in relation to behavioral salinity preferences and thresholds. Journal of Fish Biology 88:595-617.

Watson JM, Coghlan Jr SM, Zydlewski JD, Hayes DB and Kiraly IA. 2018. Dam removal and fish passage improvement influence fish assemblages in the Penobscot River, Maine. Transactions of the American Fisheries Society 147:525-540.

Wippelhauser GS, Sulikowski J, Zydlewski GB, Altenritter MA, Kieffer M and Kinnison MT. 2017. Movements of Atlantic sturgeon of the Gulf of Maine inside and outside of the geographically defined Distinct Population Segment. Marine and Coastal Fisheries 9:93-107.

Zydlewski GB, Kinnison MT, Dionne PE, Zydlewski JD and Wippelhauser GS. 2011. Shortnose sturgeon use small coastal rivers: The importance of habitat connectivity. Journal of Applied Ichthyology 27:41-44.

Procedures for Issuing Manuscripts in the Northeast Fisheries Science Center Reference Document (CRD) and the Technical Memorandum (TM) Series

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of the nation's ocean resources and their habitat." As the research arm of the NMFS's Greater Atlantic Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "conducting ecosystem-based research and assessments of living marine resources, with a focus on tsshe Northeast Shelf, to promote the recovery and long-term sustainability of these resources and to generate social and economic opportunities and benefits from their use." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously peer reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own series.

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series typically includes: data reports of long-term field or lab studies of important species or habitats; synthesis reports for important species or habitats; annual reports of overall assessment or monitoring programs; manuals describing program-wide surveying or experimental techniques; literature surveys of important species or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab studies; progress reports on experiments, monitoring, and assessments; background papers for, collected abstracts of, and/or summary reports of scientific meetings; and simple bibliographies. Issues receive internal scientific review and most issues receive copy editing.

CLEARANCE

All manuscripts submitted for issuance as CRDs must have cleared the NEFSC's manuscript/abstract/webpage review process. If your manuscript includes material from another work which has been copyrighted, then you will need to work with the NEFSC's Editorial Office to arrange for permission to use that material by securing release signatures on the "NEFSC Use-of-Copyrighted-Work Permission Form."

For more information, NEFSC authors should see the NEFSC's online publication policy manual, "Manuscript/abstract/webpage preparation, review, and dissemination: NEFSC author's guide to policy, process, and procedure."

STYLE

The CRD series is obligated to conform with the style contained in the current edition of the United States Government Printing Office Style Manual. That style manual is silent on many aspects of scientific manuscripts. The CRD series relies more on the CSE Style Manual. Manuscripts should be prepared to conform with these style manuals.

The CRD series uses the Integrated Taxonomic Information System, American Fisheries Society's guides, and the Society for Marine Mammalogy's guide for verifying scientific species'names.

For in-text citation, use the name-date system. A special effort should be made to ensure that all necessary bibliographic information is included in the list of references cited. Personal communications must include date, full name, and full mailing address of the contact.

PREPARATION

Once your document has cleared the review process, the Editorial Office will contact you with publication needs – for example, revised text (if necessary) and separate digital figures and tables if they are embedded in the document. Materials may be submitted to the Editorial Office as email attachments or intranet downloads. Text files should be in Microsoft Word, tables may be in Word or Excel, and graphics files may be in a variety of formats (JPG, GIF, Excel, PowerPoint, etc.).

PRODUCTION AND DISTRIBUTION

The Editorial Office will perform a copyedit of the document and may request further revisions. The Editorial Office will develop the inside and outside front covers, the inside and outside back covers, and the title and bibliographic control pages of the document.

Once the CRD is ready, the Editorial Office will contact you to review it and submit corrections or changes before the document is posted online. A number of organizations and individuals in the Northeast Region will be notified by e-mail of the availability of the document online.