Not to be cited without prior reference to the author

ICES CM 2008/N:07

The use of GIS based modeling to establish basin specific fisheries goals and prioritize restoration efforts in the Penobscot River Basin (Maine, USA).

Tara Trinko, Chad Keith, Rory Saunders, and Tim Sheehan

ABSTRACT

The Penobscot River Restoration Project (PRRP) is a multimillion dollar endeavor that aims to restore self-sustaining populations of native sea-run fish through the removal of two mainstem dams and improved fish passage at numerous other dams on the Penobscot River. While many diadromous species will benefit from the PRRP directly, other species such as endangered Atlantic salmon (*Salmo salar)*, alewife (*Alosa pseudoharengus*), and American shad (*Alosa sapidissima*) may require additional habitat improvements (barrier removal, fishways, etc.) or stocking. Thus, additional active restoration measures may be required to realize the full potential of the PRRP. Due to the high profile and high cost of the project (as well as the number of State, Federal and non-governmental organizations involved), there is a need to prioritize restoration efforts in the basin to increase the probability of project success. To help facilitate this goal, we created an ecologically-based GIS tool to help establish restoration goals and to identify and prioritize restoration opportunities (stocking options, barrier removal, and fishway improvements). Initial data inputs for the model include spawning habitat for a number of focal species, a habitat weighting variable, and passage barriers (location and passage state). The outputs of the model are ecologically-based targets for the focal species and prioritized lists of restoration projects based on their biological merits. These outputs will help ensure that achievable goals are established, and that funding and restoration efforts are applied in the most appropriate manner.

Keywords: GIS, modeling, diadromous, restoration

Contact author Timothy Sheehan: NOAA Fisheries Service, Atlantic Salmon Research and Conservation Task, 166 Water St. Woods Hole, MA 02543 USA [tel: +1 508 495 2215, fax: +1 508 495 2393, email: Tim.Sheehan@noaa.gov].

INTRODUCTION

The Penobscot River is the second largest river in New England, draining most of central Maine. Historically the Penobscot held significant numbers of diadromous fish species, such as alewife (*Alosa psuedoharengus*), American eel (*Anguilla rostrata*), American shad (*Alosa sapidissima*), Atlantic salmon (*Salmo salar*), Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus)*, Atlantic tomcod (*Microgadus tomcod*), blueback herring (*Alosa aestivalis*), rainbow smelt (*Osmerus mordax*), sea lamprey (*Petromyzon marinus*), shortnose sturgeon (*Acipenser brevirostrum*), and striped bass (*Morone saxatillis*).

Historical abundance estimates (i.e., prior to European colonization) of most diadromous fish in the Penobscot Basin are quite elusive. However, annual commercial catch estimates from the 1800s range in the millions of individuals for alosines (Foster and Atkins 1869) and up to 100,000 Atlantic salmon (Foster and Atkins 1869).

Since the 1800s, the Penobscot River, like most rivers in Maine, has been adversely affected by dams, overharvesting of fish communities, and the introduction of non-native invasive fish species (Moring 2005). Many species of diadromous fish are presently at all-time lows. For example, alewife populations are well below historical estimates; American shad no longer have a commercial fishery and have been extirpated from many rivers in Maine; and Atlantic salmon are listed as endangered under the U.S. Endangered Species Act (Saunders et al. 2006).

Despite well over a century of single-species management efforts to restore Atlantic salmon in the Penobscot River, returning adult numbers have continued to remain at a fraction of historic numbers. New research suggests that a more holistic approach to fisheries management focusing on multiple species interactions and ecosystem benefits may be more successful (Pauly et al. 2002) and has been accepted as a paradigm in Pacific salmon management (e.g. Schindler et al 2003). The complex relationships between other diadromous fish populations and Atlantic salmon is not well understood, but is recognized that these species represent potentially important food sources and may also act as prey buffers for Atlantic salmon (Goode 2006; Saunders et al 2006).

The Penobscot River Restoration Project is multimillion dollar endeavor that aims to restore self-sustaining populations of native sea-run fish through the removal of two mainstem dams and improved fish passage at numerous other dams on the Penobscot River (Figure 1). The PRRP is the result of unprecedented collaboration among a hydropower company (PPL Corporation), the Penobscot Indian Nation, six conservation groups (collectively referred to as the Penobscot River Restoration Trust, PRRT), and state and federal agencies. Successful implementation of the project has the potential to revive not only native fisheries but social, cultural and economic traditions of New England's second largest river - the Penobscot.

While dam removals have clearly shown to have a positive effect on diadromous fish species in terms of historical habitat gains (Burdick and Hightower 2006), it is important to note that the goals outlined by the PRRT rely heavily upon the migrating fish successfully passing other existing dams. Although many of these dams will have new and/or updated fishways, Oldani et al.(2007) has shown in South American rivers that a low percentage of migrating fish successfully pass obstructed waterways, even with engineered passage provided. Furthermore, downstream passage and migration back-to-sea is often not taken into consideration when designing a fishway. Because of this there is often a high mortality rate when the fish attempt to return to the sea post-spawning period (Oldani 2007). Thus, both upstream and downstream passage efficiencies at remaining dams must be taken into account when developing restoration goals.

Following the dam removals and alterations many fish species in the Penobscot River will see significant gains in terms of their historically accessible habitats, while other species will see little to no appreciable gains in accessible habitat. This is due to the continued presence of dams, even with the removals and improvements in fish passage. For example, the removal of the dams will allow both shortnose and Atlantic sturgeon to regain full access to historical spawning habitats. Other species such as alewives, which spawn in lakes and ponds above head of tide (Munroe 2002), and Atlantic salmon will regain little of their historical spawning grounds due to the presence of many smaller dams and obstructions (see Figures 2 and 3). Thus, additional active restoration measures may be required to realize the full potential of the PRRP.

Because of the high profile and high cost of the project (as well as the number of State, Federal and non-governmental organizations involved), there is a need to define specific objectives and optimize restoration efforts in the basin to increase the probability of project success. Currently, a group of state and federal biologists forming the Penobscot Interagency Committee (PIC) has been tasked with developing management objectives for the suite of diadromous species that historically inhabited the Penobscot River. Some examples of management goals for diadromous species could be to increase commercial fishing opportunities, increase species abundance, or to increase ecological benefits to other species within the river. While these goals are not necessarily mutually exclusive, each has a slightly different strategy with regard to restoration activities. For instance, alewives are used as lobster bait in Maine when available. Thus, any potential commercial use would be near the coast due to time and transport cost. A management goal of maximizing alewife production would target the largest lakes, regardless of location. And finally, a management objective of conveying ecological benefits would focus on marine nutrient deposition, prey buffering, and direct consumption as food for salmon, which would focus activities in the headwaters.

The objective of this paper is to outline an ecologically-based geographic information system (GIS) tool that could help to spatially display management objectives and identify and prioritize restoration opportunities (stocking options, barrier removal, and fishway improvements) to aid in multispecies management within the Penobscot Basin.

METHODS

PITS Tool

The Penobscot Interagency Teleost Strategy (PITS) is a GIS-based tool that uses readily available digital data such as lake surface area, Atlantic salmon habitat survey data, dam and other passage barrier locations. The initial version of PITS includes a subset of diadromous species (Atlantic salmon and alewives) in the Penobscot River. Initial data inputs for the model include spawning habitat for salmon and alewives, a habitat weighting variable, and passage barriers (location and passage state). Initially, outputs are limited to stocking options, barrier removals, and fishway improvements.

As new data becomes available, the complexity of the analyses can increase. For example, adding additional focal species will require more specific habitat data (e.g., habitat suitability data for American shad). Further, as fish passage efficiency data and cost estimates for additional restoration projects becomes available, model outputs will expand to include prioritized lists of restoration projects and detailed cost estimates for a variety of restoration scenarios.

Inputs

Assessing the historical extent of diadromous fish populations in the Penobscot basin is limited almost entirely to historical accounts, as little current data exists. Information about historic and current distributions of diadromous species in the Penobscot has been previously compiled by Saunders et al. (2006) and Houston et al. (2007). From previously available information and best professional judgment, distributions for a shortened group of focal species, alewives and salmon, were digitized using GIS (ArcGIS 9.2) and linked to the stream reaches from the National Hydrography Dataset (NHD).

Because of the federally endangered listing of Atlantic salmon in the lower Penobscot and the potential expansion of the Atlantic salmon Gulf of Maine distinct population segment throughout the Penobscot Basin, a weighting variable was developed to favor restoration projects that occur closest to watersheds that contain the largest quantities of predicted Atlantic salmon spawning and rearing habitat as determined by the Atlantic Salmon Habitat Model (J. Wright unpublished data). As restoration priorities are developed, this weighting variable can be used to increase the likelihood of enhancing endangered Atlantic salmon populations.

Distributions of diadromous fish post-PRRP were estimated using current extent and the National Inventory of Dams (NID) database along with current fishway locations and passage information (Bureau of Sea Run Fisheries, unpublished data). Surveyed road crossing data from the lower Penobscot Basin (Abbot 2008) were also used to further refine distributions.

Model Simulations

The flexibility of the PITS tool allows it to be used with a variety of restoration goals ranging from maximizing commercial fishing opportunities to prioritizing ecosystem benefits. To demonstrate possible outcomes from the model, we have run the following three simulations using alewife stocking as our restoration activity: 1) commercial fishing scenario; 2) maximum alewife production scenario; and 3) proximity to salmon habitat scenario.

In the commercial fishing scenario, alewives are valued for their economic benefit as a bait fish for the commercial fishing industry. Potential stocking lakes were chosen based on historic alewife access and proximity to the coast (≤30 kilometers). In the maximum production scenario, the end goal is to maximize alewife production potential in the basin through lake stocking. Potential stocking lakes were chosen based on historic alewife distribution. No distinction was given based on the number of fishways to pass or the presence of an outlet dam. In the third scenario, proximity to salmon habitat, the goal is to convey ecosystem benefits to salmon through alewife stocking following the PRRP. Potential stocking lakes were selected based on historic alewife distributions, the absence of outlet dams, and proximity to predicted salmon spawning and rearing habitat.

RESULTS

The primary output of a PITS simulation is a visual representation of the watershed with the top five stocking lakes highlighted. Maps for the three management scenarios are shown in Figures 4-6. Spatial locations of priority stocking lakes varied from coastal (commercial fishing scenario), to mid-drainage (maximum production scenario) to headwaters (proximity to salmon habitat) with distances to coast ranging from 5km to 168km (Table 1). Total alewife production potential for the top five lakes was greatest in the maximum production scenario (6.9 million alewives), followed by the salmon habitat scenario (1.6 million alewives) and the commercial fishing scenario (1.3 million alewives).

DISCUSSION

The restoration scenarios that we present in this paper only represent three hypothetical management objectives. We chose the three scenarios because they represent reasonable management objectives and the diversity of applications for the PITS tool. If the main objectives are to increase commercial value, activities should focus on coastal areas. In order to produce maximum alewife abundance, stocking activities and passage barrier remediation should focus on areas downstream of large lakes. If enhancing salmon populations is a top management priority, then restoration activities post-PRRP should be focused in headwater areas. Each of these are rational strategies; the appropriate choice depends on the set objectives.

The outputs of the PITS model are ecologically-based targets for the focal species and prioritized lists of restoration projects based on their biological merits. Within the basin, habitat restoration needs are greater than capacity to complete projects, thus prioritzation will require development of well-designed management plans based on scientific knowledge (Wohl et al 2005). Results from other river restoration projects show that the likelihood of project success increases when clearly stated goals guide the project (Bernhardt et al 2007). These outputs will help ensure that achievable goals are established, and that funding and restoration efforts are applied in the most appropriate manner. These products will allow the PIC to prioritize restoration projects based on their biological merits, rather than being selected as opportunities arise.

We hope that the PITS will be recognized as a sound tool to help in the development of a multi-species management plan for the Penobscot River and as a novel management tool for the recovery endangered and threatened species using a multispecies approach. In the future, the PITS could also be used to optimize restoration activities in any river basin in which the basic data are available and single species management has been ineffective.

Table 1. Top five lakes and attributes from the three model scenarios. Alewife production potential in Maine is based on a production potential of 94 adult returns per surface hectare of spawning habitat (see Flagg 2007).

Model Scenario	Top Lakes	Area (ha)	Alewife Production Potential	Distance from Coast (km)
Commercial Fishing				
	Alamoosook Lake	403.4	234,060	6.3
	Brewer Lake	387.7	224,895	17.3
	Eddington Pond	203.7	118,205	29.3
	Toddy Pond	974.7	565,880	4.8
	Silver Lake	275.8	160,035	8.6
Maximum Production Potential				
	Baskahegan Lake	2757.9	1,601,478	126.6
	Pushaw Lake	1893.8	1,099,706	38.7
	Schoodic Lake	2841.7	1,649,700	87.0
	Sebec Lake	2574.7	1,495,117	84.6
	Seboies Lake	1948.7	1,131,596	94.5
Proximity to Salmon Habitat				
	Endless Lake	582.4	338,165	100.0
	Mattawamkeag Lake	1029.2	597,628	164.1
	Saponac Pond	361.6	209,996	75.6
	Upper Mattawamkeag Lake	307.2	178,388	167.6
	Wytopitlock Lake	440.9	256,056	145.9

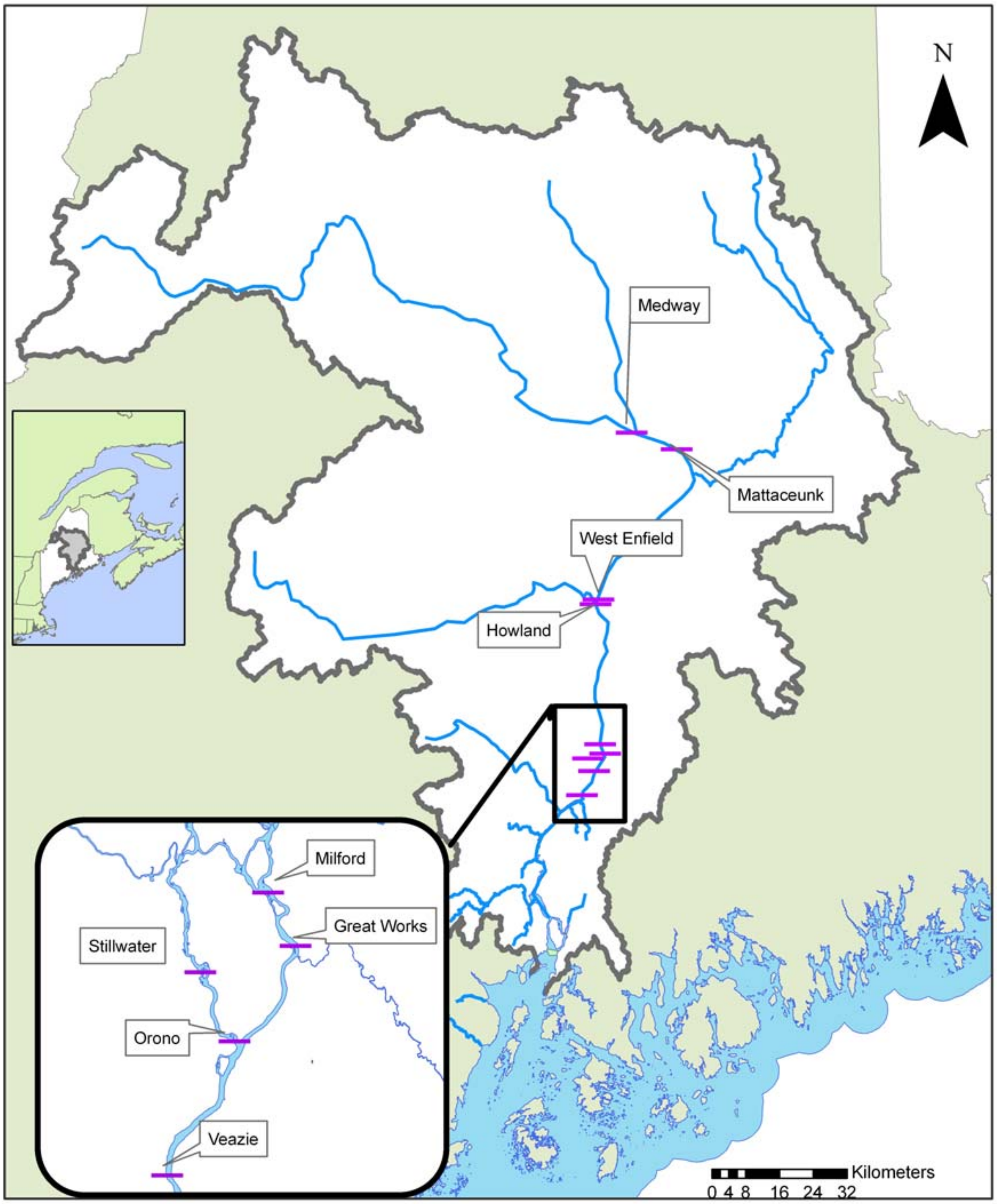

Figure 1. Penobscot River watershed and major hydropower dams in Maine, USA. The Penobscot River Restoration Project seeks to remove the two lowest mainstem dams, Veazie and Great Works. Other passage improvements include a fishlift at the Milford dam and a naturelike fishway at the Howland dam.

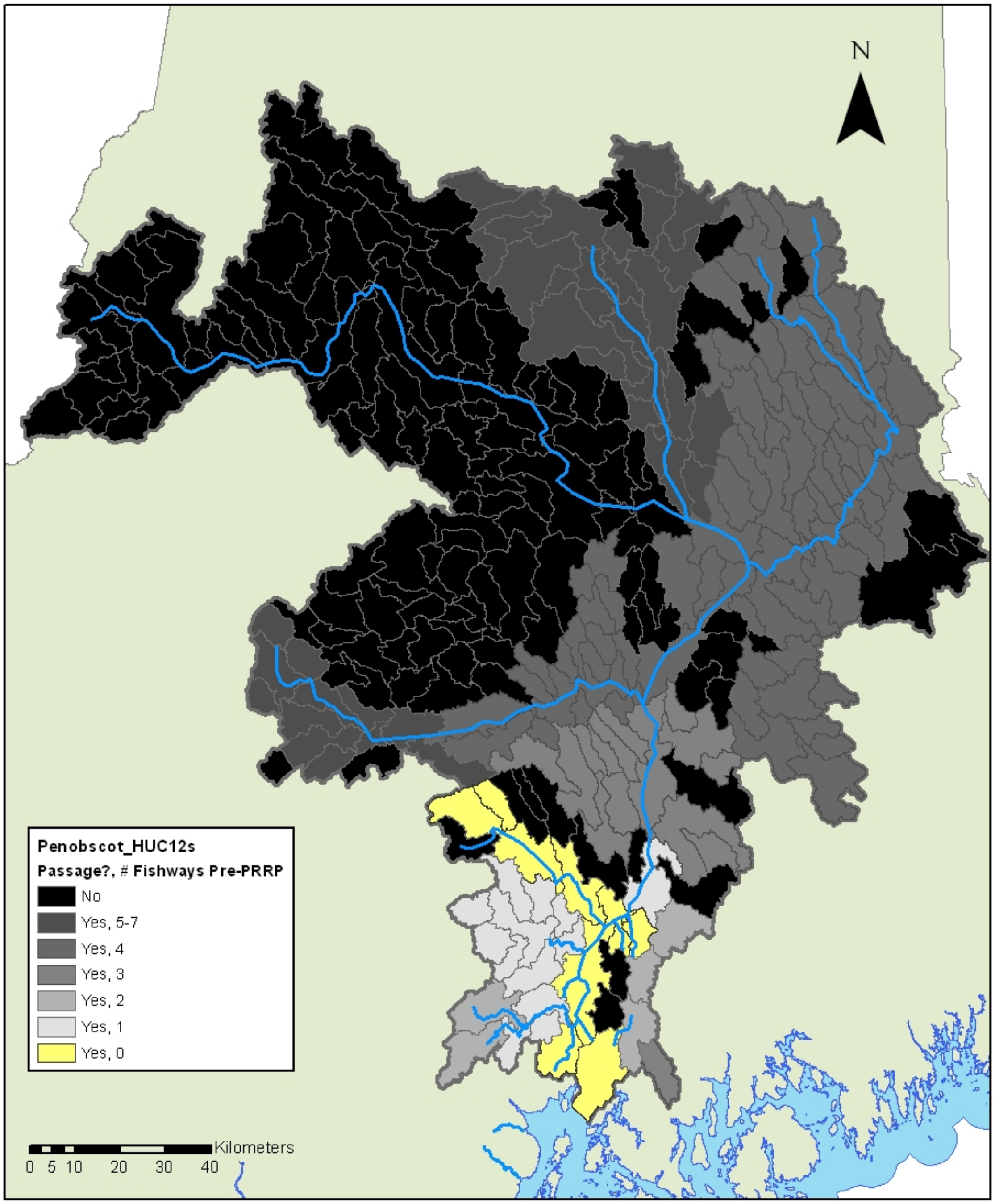

Figure 2. Penobscot River HUC12 (twelve digit hydrologic unit code) subbasins pre-Penobscot River Restoration Project. Subbasins in yellow are currently accessible for diadromous without the aid of fishways. All other HUC12s require the passage of one to seven fishways (grayscale) or are currently inaccessible due to dams (black).

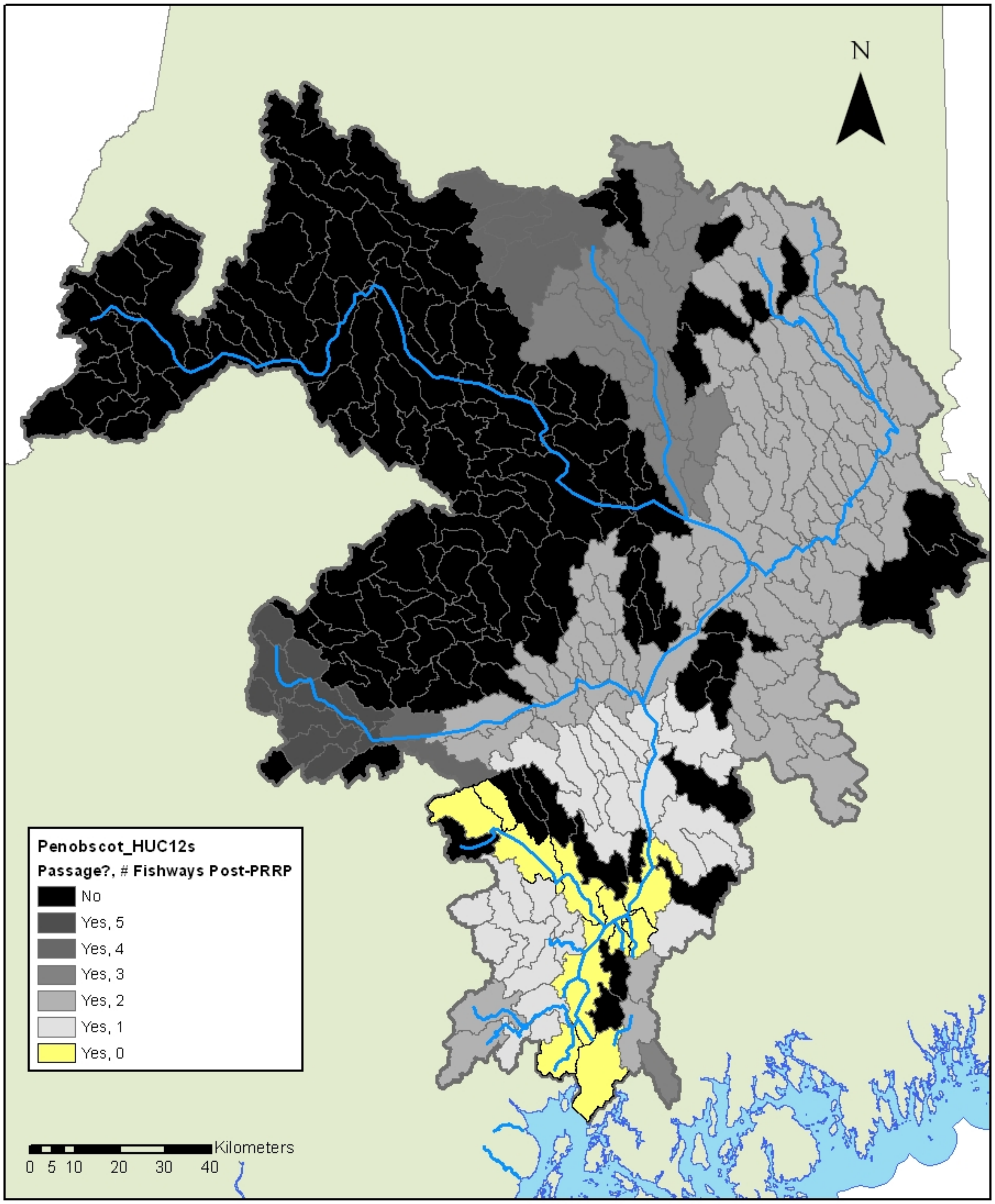

Figure 3. Penobscot River HUC12 (twelve digit hydrologic unit code) subbasins post-Penobscot River Restoration Project. Subbasins in yellow will be accessible for diadromous fish without the aid of fishways. All other HUC12s require the passage of one to five fishways (greyscale) or are currently inaccessible due to dams (black).

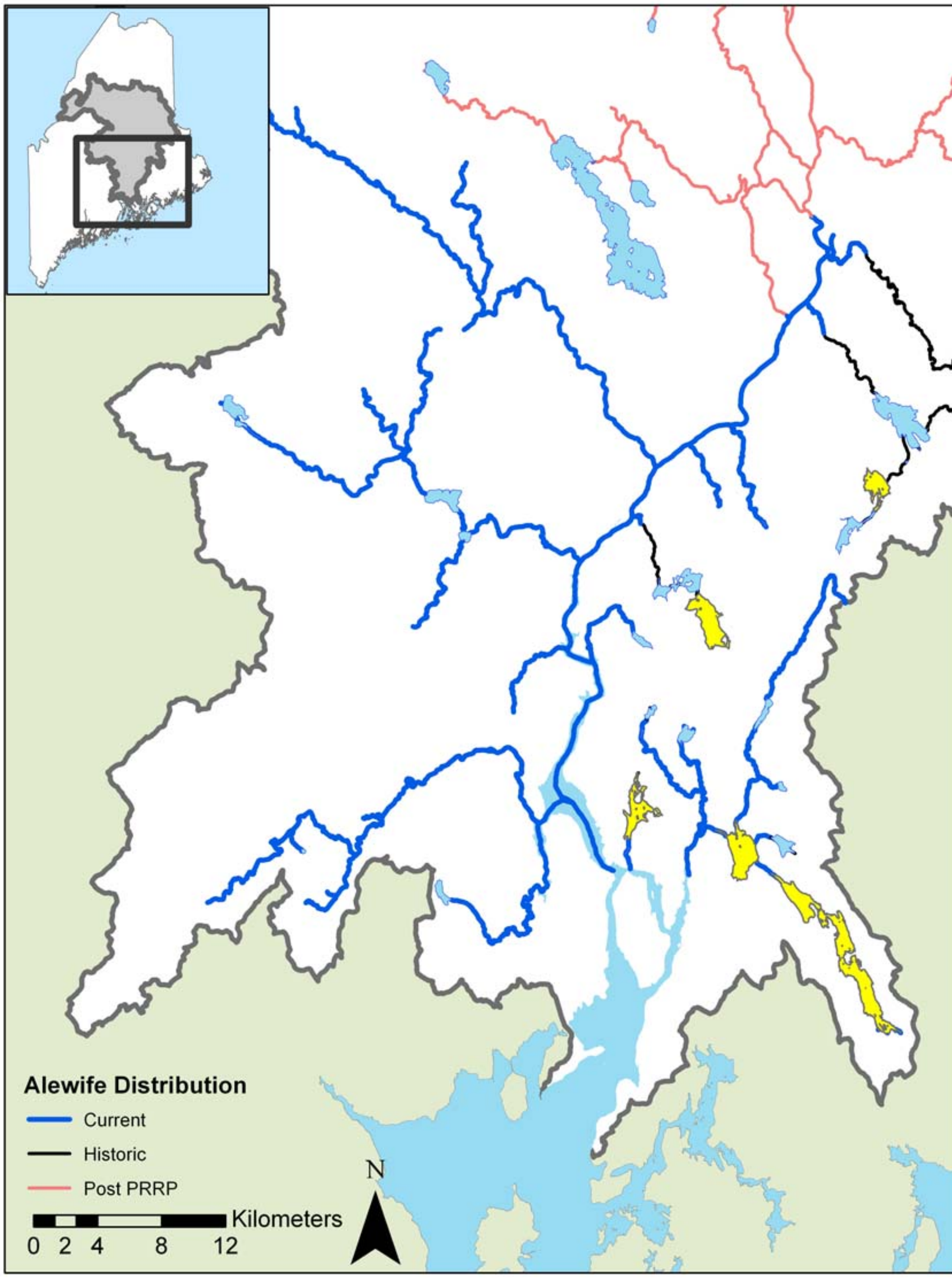

Figure 4. Commercial fishing scenario displaying top alewife production lakes (yellow) that are within 30km of the coast. Current alewife distribution is shown in blue, along with historic (black) and predicted post PRRP (pink). Potential alewife lakes are displayed in light blue.

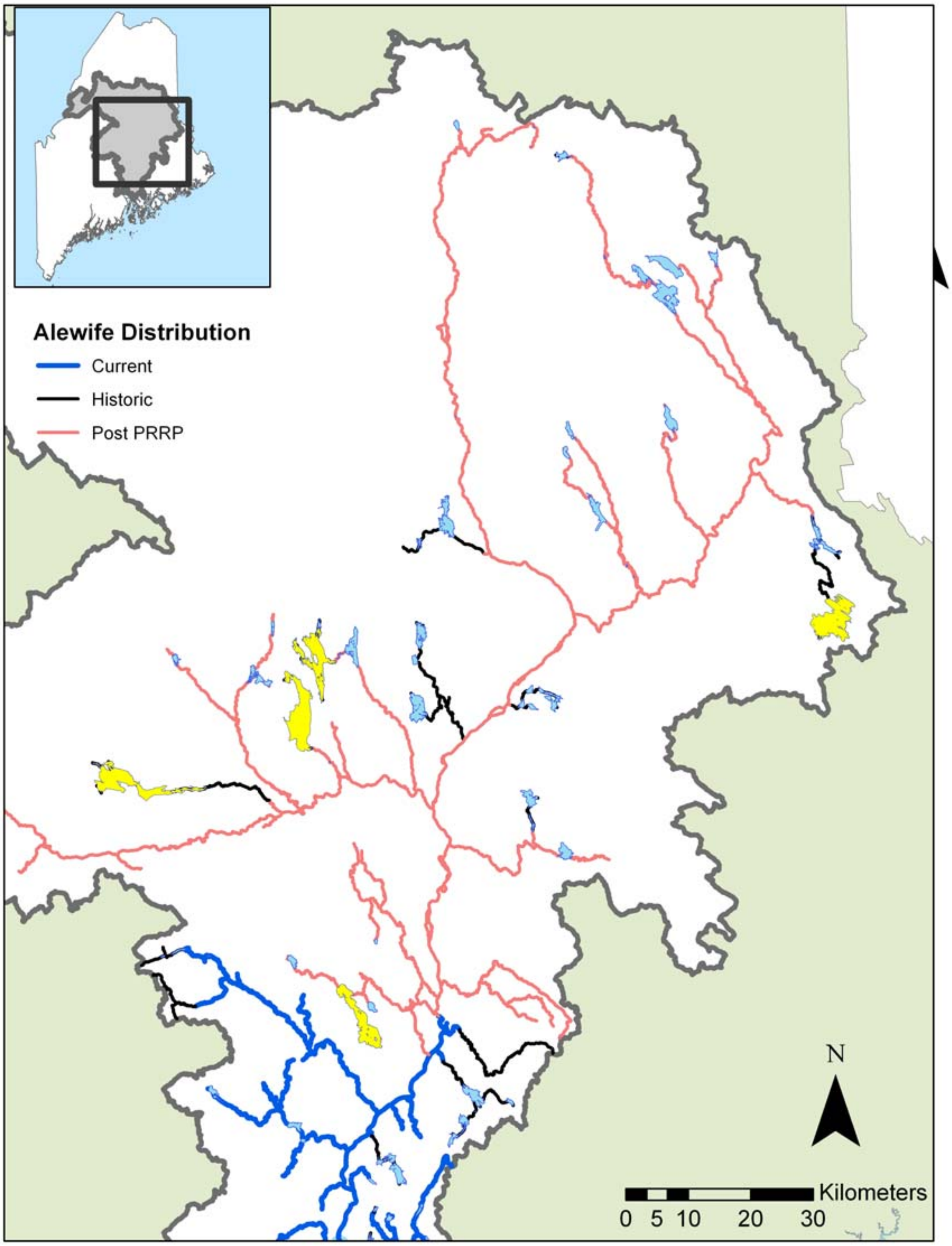

Figure 5. Maximum alewife production scenario displaying top alewife production lakes (yellow) that are within the drainage. Current alewife distribution is shown in blue, along with historic (black) and predicted post PRRP (pink). Potential alewife lakes are displayed in light blue.

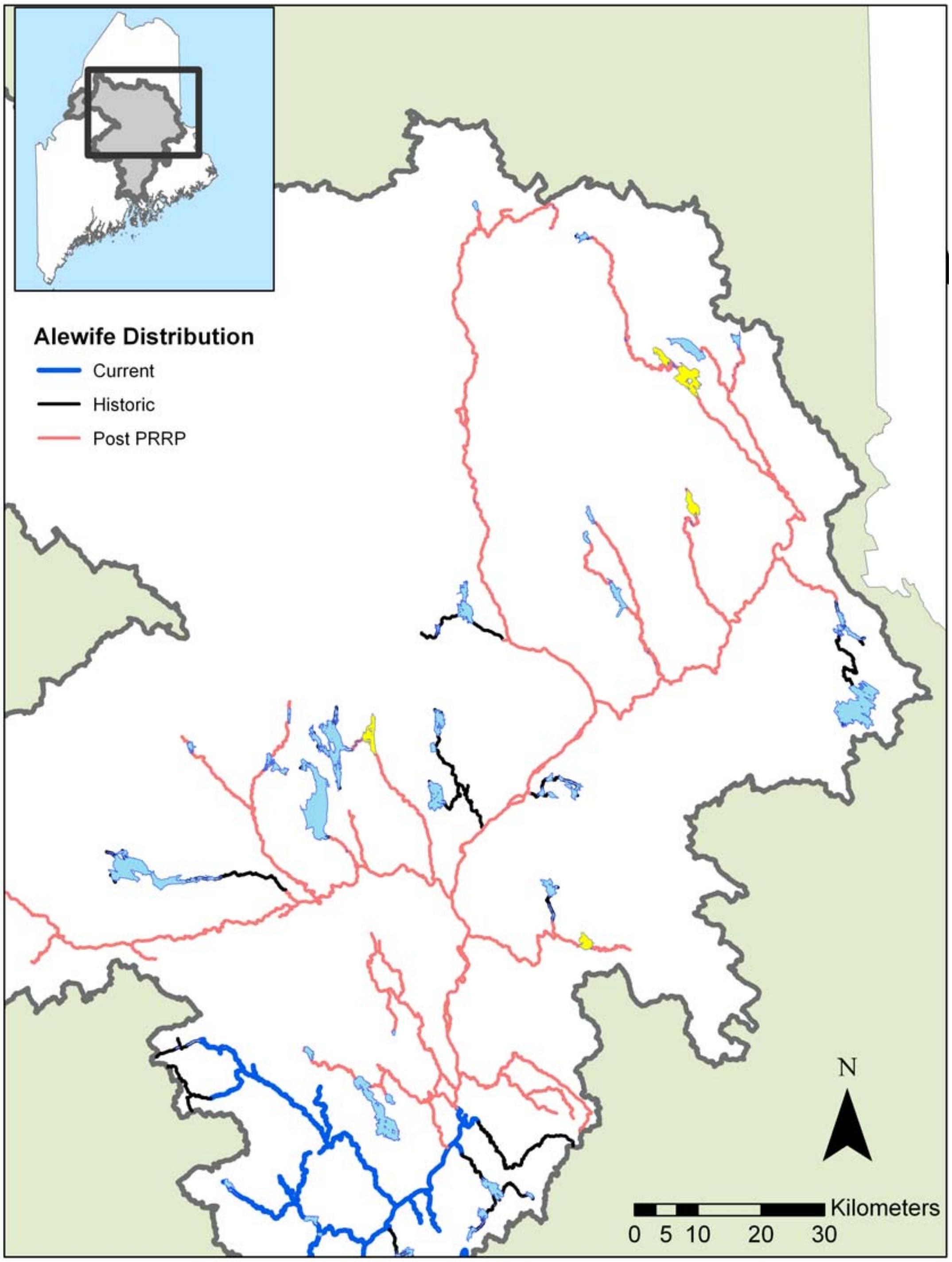

Figure 6. Proximity to salmon habitat scenario displaying top alewife production lakes (yellow) that are located near predicted salmon spawning and rearing habitat. Current alewife distribution is shown in blue, along with historic (black) and predicted post PRRP (pink). Potential alewife lakes are displayed in light blue.

REFERENCES

Abbot, A. 2008. 2007 Lower Penobscot River Stream Barrier Surveys. Maine Forest Service. Augusta, ME. 17pp.

Baum, E.T. 1983. The Penobscot River: An Atlantic salmon river management report. State of Maine, Atlantic Sea Run Salmon Commission. Bangor, ME. 67pp.

Bernhardt, E.S., E.B. Sudduth, M.A. Palmer, J.D. Allan, J.L. Meyer, G. Alexander, J.Follastad-Shah, B. Hasset, R. Jenkinson, R. Lave, J. Rumps, L. Pagano. 2007. Restoring rivers one reach at a time: results from a survey of U.S. river restoration practinioners. Restoration Ecology 15(3):482-493.

Burdick, S. M., and J. E. Hightower. 2006. Distribution of spawning activity by anadromous fishes in an Atlantic slope drainage after removal of a low-head dam. Transactions of the American Fisheries Society. 135:1290–1300.

Flagg, L.N. 2007. Historic and current distributions and abundance of anadromous alewife (*Alosa pseudoharengus*) in the St. Croix River. A report to the State of Maine. Atlantic Salmon Commission. Augusta, ME. 53pp.

Foster, N.W. and C.G. Atkins. 1869. Second report of the Commissioners of Fisheries of the state of Maine 1868. Owen and Nash, Printers to the Sate, Augusta, ME.

Goode, A. 2006. The plight and outlook for migratory fish in the Gulf of Maine. Journal of Contemporary Water Research & Education 134: 23-28

Houston, R., K. Chadbourne, S. Lary and B. Charry. 2007. Geographic Distribution of Diadromous Fish in Maine [CD-ROM v1.0].U.S. Fish & Wildlife Service and Maine Audubon Society, Falmouth, Maine.

Mooring, J.R. 2005. Recent trends in anadromous fishes. *In* R. Buchsbam, J. Perderson, W.E. Robinson, eds. The decline of fisheries resources in New England: evaluating the impact of overfishing, contamination, and habitat degredation. MIT Sea Grant College Program, Cambridge, Massachussetts, MITSG 05-5.

Munroe, T.A. 2002. Herrings. Family Clupidae. Pp 111-160. in B.B. Collette and G. Klein-MacPhee ,eds. Bigelow and Shroeder's Fishes of the Gulf of Maine. 3rd ed. Smithsonian Institute Press, Washington and London.

Oldani, N. O., C.R.M Baigún, J.M. Nestler, and R.A. Goodwin. 2007 Is fish passage technology saving fish resources in the lower La Plata River basin? Neotropical Ichthyology 5(2), 89-102.

Pauly, D., Christensen, V., Gue´nette, S., Pitcher, T., Sumaila, U. R., Walters, C., Watson, R. & Zeller, D. 2002. Toward sustainability in world fisheries. Nature 418, 689–695.

Saunders, R., M. A. Hachey, and C. W. Fay. 2006. Maine diadromous fish community: past, present, and implications for Atlantic salmon recovery. Fisheries 31(11): 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 1(1):31-37.

Schindler, D. E., P.R. Leavitt, C.S. Brock, S. P. Johnson, and P.D. Quay. 2005. Marine derived nutrients, commercial fisheries, and production of salmon and lake algae in Alaska. Ecology 86: 3225-3231.

Wohl, E., P.L. Angermeier, B. Bledsoe, G. Mathias Kondolf, L. MacDonnell, D.M. Merritt, M.A. Palmer, N.L. Poff, D. Tarboton. 2005. River restoration. Water Resources Research 41:W10301.