Is the recovery of cod (*Gadus morhua*) along the Maine coast limited by reduced anadromous river herring populations?

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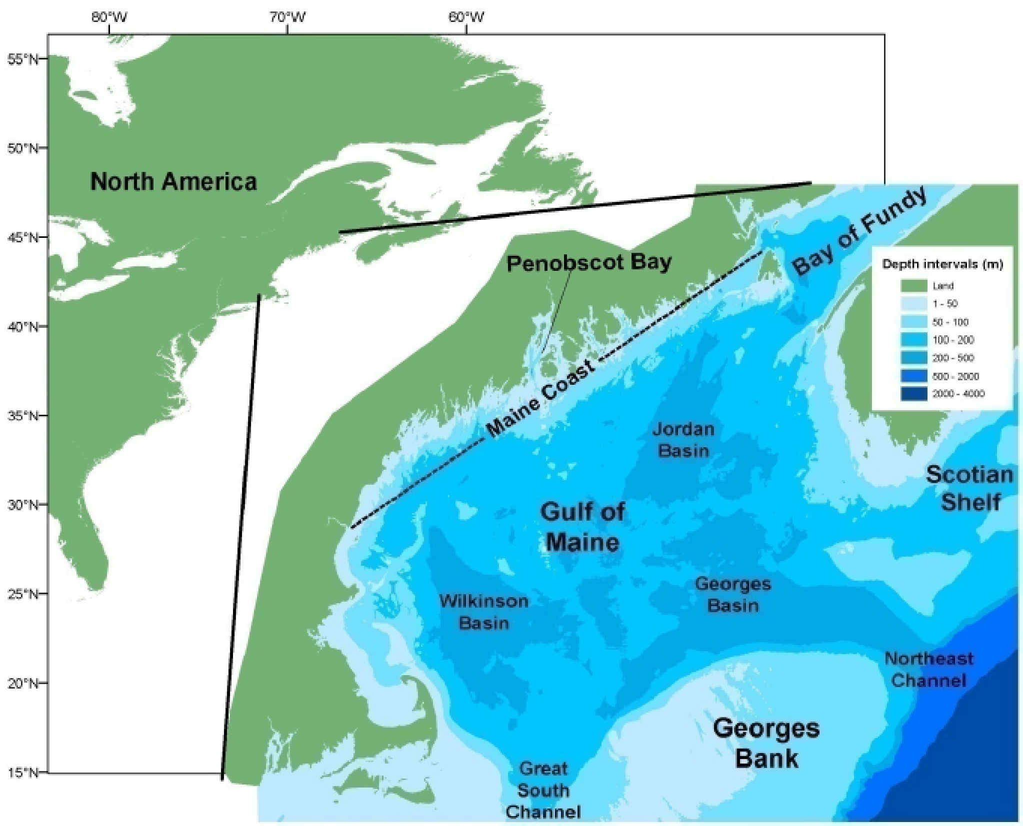

Figure 1. Location of the coast of Maine and other features in the Gulf of Maine region.

Introduction

It has been suggested that coastal cod populations followed and fed on formerly large populations of river herring returning to natal rivers to spawn in spring (Shaw et. al., 1824; Baird, 1874; Graham et al., 2002; Ames, 2004). In the Gulf of Maine (Figure 1), cod and river herring both have similar trends of decline with fisheries collapsing in the last 30 years. The 2007 Atlantic States Marine Fisheries Commission (ASMFC) Fishery Management Plan for shad and river herring reported a 90% decline in commercial landings from over 13 million pounds in 1985 to about 1.33 million pounds in 1998 (ASMFC, 2007). The ASMFC report also confirmed that pollution and loss of essential habitat due to dam construction are long-term contributors to the substantial decline of the current river herring populations, as proposed by Lotze and Milewski (2002) in an analysis of historical data.

Assessment of the results of the studies presented above poses the next question: could the decline of spawning river herring populations be a factor in the decline of the productivity of the inshore cod stock? To answer this question we will consider the patterns in alewife abundance over 4 time periods; pre-colonial (before 1600), early colonial period (1600-1750), late colonial period (1750-1900) and industrial period (1900-present).

Pre-colonial period

When establishing a baseline for understanding the impacts of colonization, it is important to consider the period before Europeans populated the Maine coast. Early reports claim large numbers of sturgeon, cod and alewives in coastal waters, although these observations must be tempered with the reality that they were made by Europeans whom had mills on their rivers since the Roman times (Syson 1965) and were advocates of settlement. In fact, an incomplete survey of England in 1086 AD identifies 5624 water-powered mills. It appears that prior to colonization, the cod stocks were made up of fish of 1.0 m average length versus 0.3 m average length presently (Jackson et al. 2001) and had orders of magnitude more biomass (Myers et al. 2001; Rosenberg et al. 2004).

Changes in forest communities reflect the climate (Shumer et al. 2002). The Early Archaic period (9000 to 8000 B.P.) began as open woodland dominated by spruce (*Picea*), aspen (*Populus*), and larch (*Larix*), which was eventually replaced by pine (*Pinus*) forests. During the Middle Archaic (8000-6000 B.P.), a hemlock (*Tsuga*) dominated forest developed by 7400 B.P. followed by a pine forest by 6400 B.P. The Late Archaic (6000-3000 B.P.) was a period of great transition with hemlock forest development by 5700 B.P. that was replaced by northern hardwood forest around 4700 B.P. The Late Archaic expansion of hardwoods provided better forage for beaver (*Castor canadensis*), which with the muskrat (*Ondatra zibethicus*), increased in faunal assemblages of local archaeological sites, while anadromous fish decreased (Almquist-Jacobson and Sanger 1995). It appears that beaver-dominated systems exclude alewives and strongly impact anadromous fish passage in general (Mitchell and Cunjak 2007). From archaeological, ethnographic, and historical sources it is clear that both species were widespread, common, and important in pre-European forest ecosystems and Indian economies (Bragdon, 1996).

Recent work (Walter and Merritts 2008) is causing a re-evaluation of pre-colonial watersheds favoring laterally extensive, wetland-dominated systems of forested meadows with stable vegetated islands and multiple stream channels. The preserved pre-colonial hydric soil contained abundant, well-preserved woody debris, seeds, nuts, roots, algal mats, pollen, and peat with mosses (Walter and Merritts 2008). In addition, vast numbers of beavers in North America contributed to significant landscape effects (Foster et al. 2002). Beaver are considered ecological engineers because their dams retain sediments, modify nutrient flow, and convert riparian areas to non-linear wetlands which synergistically alter geomorphology (Ives 1942, Naiman et al. 1986, Ruedemann and Schoonmaker 1938). All indications are that the watersheds of the pre-colonial period were wetland-dominated, with alewives and other anadromous fish restricted in their freshwater distribution.

Human population increases during the Late Archaic match an increase in the resource base within both as a result of the development of hardwood forest in response to climatic cooling (Almquist-Jacobson and Sanger 1995). By 1583 a substantial beaver trade had been initiated (Trigger 1985), before any permanent European settlement had been established.

Early colonial Period (1600-1750)

Beaver removal from watersheds across North America during the 1600s was intense enough that it has been considered whether the loss of methane production in beaver ponds of North America could have contributed to the cooling experienced during the little ice age (Varekamp 2006). Beaver were largely extirpated from New England by 1700 (Foster et al 2001). In 1632, there were 2300 beaver pelts traded by Abeneki along the Kennebec for shipment to England (Salisbury 1982). The “dam-effect” can persist for centuries in the absence of beaver (Ives 1942, Naiman et al. 1986, Ruedemann and Schoonmaker 1938), so changes to the landscape were not immediate. From our analysis of historical accounts, the removal of beavers was the most significant landscape change in the early colonial period and likely allowed for expansion of anadromous fish populations in parts of the freshwater not accessible since 4700 B.P. For a detailed discussion of wildlife population trends over the past 400 years, see Foster et al. (2001). However, permanent settlement brought damming and clearing of forests for agriculture and forest resources, as well as fishing pressures that quickly exceeded those imposed by native cultures.

Late colonial period (1750-1900)

Current baselines for cod (Rosenberg et al., 2004) and alewife (Lotze & Milewski, 2002) are established based on this period. Rosenberg et al. (2004) suggest that populations were close to what would be expected for unfished stocks, but that handline fisheries from sailing schooners in the 1850s were capable of depleting regional cod stocks. More fishing time was spent on the Scotian Shelf in 1852-1857 compared to 1859, suggesting that captains were searching for profitable concentrations of cod off the bank. Interestingly, estimates by Rosenberg et al. (2004) using logbook data were equivalent to those of Myers et al. (2001) who statistically calculated the carrying capacity of cod stocks around the North Atlantic. We assume that Myers et al. (2001) results can be broadly interpreted to estimate the biomass of unfished populations and calculate the carrying capacity for Gulf of Maine at 430000 metric tons (mt).

The presence of >65000 water-powered mills in the eastern United States by 1840 as well as the large scale clearing of land vastly altered the landscape (Walter and Merritts 2008). In Maine, the mills were constructed first in the western part of the state, followed by the eastern and northern rivers (Figure 1). In the mid-Atlantic region there is a 15 to 20 cm surface layer deposited by 1850 or earlier (Walter and Merritts 2008). This sediment is derived from erosion from clearing land for forestry or farming, eventually filling impoundments created by damming and becoming stable swamps, then meadows, and finally channel incision after the dam breaches to create the typical stream we envision in the Northeastern US (Walter and Merritts 2008).

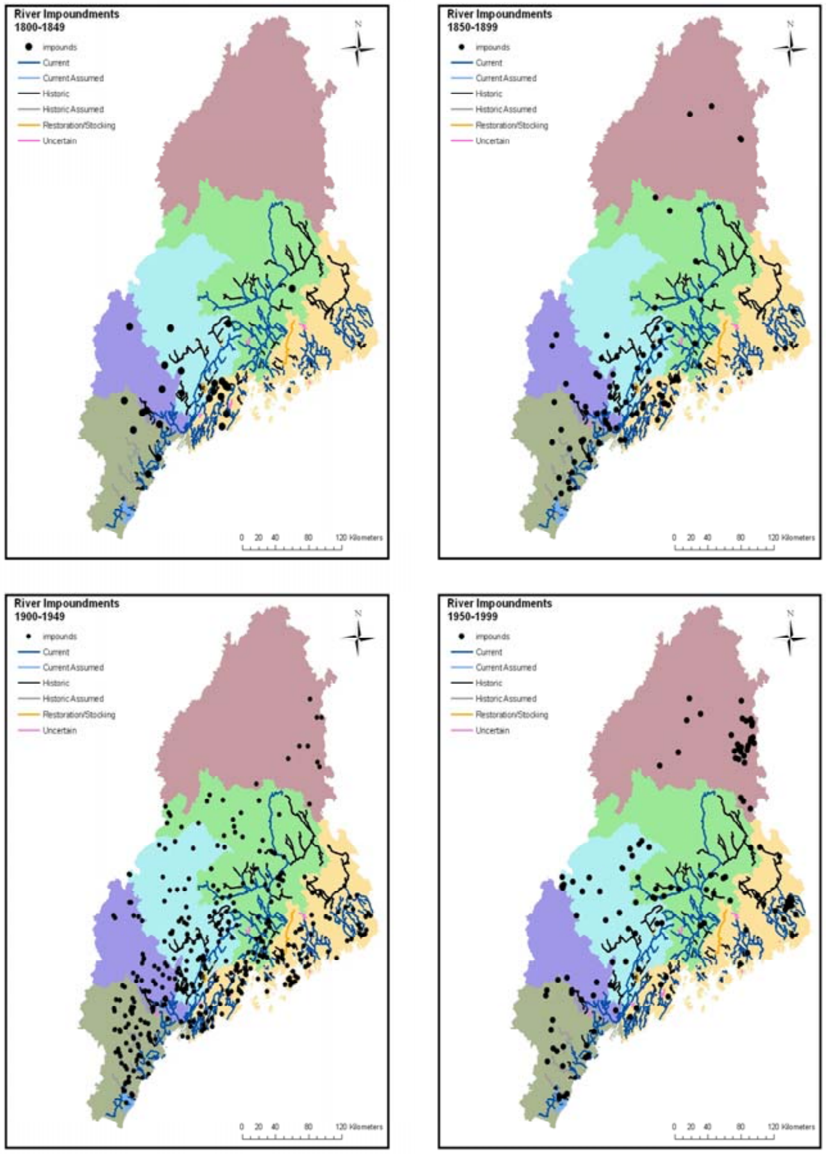

Figure 2. Present and historic alewife freshwater habitat (see legend) for major river systems and river obstructions built during 1800-1849 (top left), 1850-1899 (top right), 1900-1949 (bottom left) and 1950-1999 (bottom right).

The construction of dams and their effect on the anadromous fish populations were not lost on the local inhabitants, as displayed in the following three excerpts:

George Strout et al., August 22 1776. (Documentary History of Maine Vol. XV. 1910)

"The Petition of the Towns of Cape Elizabeth, Windham, Gorham and Pearsontown in the County of Cumberland… That the said towns lay bordering on the Presumscott River, so called, and for many years after the Settlement of this Eastern Country were plentifully supply'd with Salmon, Alewives, Shad & other Sorts of Fish that frequented the s[d] River in great abundance it being particularly commodious for the Spawn & increase of Fish by reason of a large pond called Sebago or Sebacook which extends upwards of thirty miles from the mouth of the s^{d} River as far as Pondicherry as also the many branches of s^{d} River that used to bring a plenty of the aforesaid Fish near to many of our doors, your Petitioners further shew that. By reason of several Mill Dams being built quite across the s^{d} River, without leaving a sluice way for Fish to pass up, as the Law is directed, and since the s^{d} Mills have been erected on the said River the passage of all kinds of Fish as afores^{d} " has been totally obstructed & stopt in their course up said River to the great prejudice of many back Towns which depended (in their Inland state) on the said River for a part of their support. Also to the prejudice of all the Inhabitants of the Sea Coast near the mouth of s' River by causing a scarcity of Codfish, Haddock, and many kinds of Fish that frequent the mouths of such extensive Rivers after a Quantity of small bait that abound in such places…"

Robert G. Shaw of Gouldsborough, Maine, 1824. (Shaw et al. 1824)

"…that the stream emptying into Prospect Harbour…was formerly visited…by great quantities of Alewives…[presently] obstructed by a mill-dam erected near the mouth…that in consequence of the obstruction aforesaid they have now mostly forsaken said Harbour and Stream; greatly to the injury of the Cod-fishery on the neighboring coasts; as it is well known that the Cod follow the alewives in great numbers…"

Spencer F. Baird, Commissioner of Fisheries, 1874 (COF 1883-1940)

"The general conclusions which have been reached as the result of repeated conversations with Captain Treat and other fishermen on the coast incline me to believe that the reduction in the cod and other fisheries, so as to become practically a failure, is due to the decrease off our coast in the quantity, primarily, of alewives….more than to any other cause."

Rivers in Maine have a long history of anthropogenic manipulation. Mill dams and tidal dams first appeared on smaller tributaries and along mouths of rivers in the late 1600s through 1700s and on the main stems of the major rivers to power the growing timber industry in the early 1800s (Carlton, 1983; MDMR et al., 1982). Using the Penobscot River as an example, in the mid 1800s alewives traveled to spawning sites 120 miles upstream (Atkins, 1887). In 1830, the first main stem dam was constructed beginning the flurry of construction that has led to over 10 dams on the main stem and before recent efforts to reestablish anadromous fish passage, alewives were rarely seen above the main stem Veazie Dam, only 25 miles up the river (MBSRFH, 2007). This pattern of dam construction impeding anadromous fish migration was repeated on most major and minor rivers of Maine. In addition, a number of industries have long histories of residence along the rivers including lumber mills, paper manufacturers, gas works and sewage discharge sites. These contribute to degradation of the health of the rivers by the addition of various pollutants including waste, sawdust, mercury, dioxins and coal tar (DMR, 2007).

Industrial period (1900-present)

Present-day population of alewives and cod are somewhere between 1-8% of 19th century estimates. River herring abundance are less than 1% the estimated 1825 abundance on the St. Croix River, attributed to long-term effects of dam construction, pollution from mills and effluents from industrial activities and sewage (Lotze & Milewski, 2002). Even in the past 50 years there has been a dramatic decline in the number of alewives, which is reflected in their landings by commercial fisheries (Figure 3). In 2003, there was 50000 metric tons (mt) of cod biomass on the Scotian Shelf, about 4% of the 1852 adult biomass, and in 2002 adult biomass was only about 3000 mt, or less than 0.3% the 1852 biomass (Rosenberg et al., 2004). The biomass estimates supplied by Northeast Fisheries Science Center (2008) were 11000 mt in 1997-1998, 25000 mt in 2002, 20500 mt in 2004, and an increase to 34000 mt in 2007. Based on our estimate of 430000 mt, and considering the present-day biomass, it appears that the Gulf of Maine cod stock(s) have varied between 2-8% the original biomass over the past decade. Even the target biomass (SSB_{MSY}) of 58248, is only about 13% our estimate of carrying capacity biomass. Of note is that the NMFS stock assessment claims ½ SSB_{MSY} as the actual target. Under the current conditions (ignoring baselines, etc.), is reduced alewife biomass preventing recovery of cod?

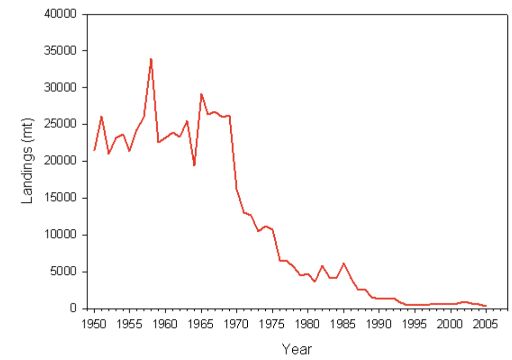

Figure 3. Gulf of Maine river herring commercial landings from NOAA website: www.nefsc.noaa.gov/sos/spsyn/af/herring/

Several studies have examined the historic abundance of cod in the Gulf of Maine and the neighboring Bay of Fundy and Scotian Shelf (Ames, 2004; Rosenberg et al., 2004; Graham et al., 2002) finding evidence of fewer feeding and spawning areas, or fruitful fishing grounds, today than in the past. Ames (2004) used fishery data and surveys of retired fishermen from 1920 to reconstruct and map historic spawning grounds, migration patterns and stock movement of cod in coastal Gulf of Maine. Current cod egg presence was used to identify active spawning grounds and compared to historic or lost spawning grounds illustrating the a 50% decline in inshore cod spawning populations in the past 50 to 70 years (Ames 2004). Ames (2004) specifically evaluated historical inshore cod populations in his study and a comparison of his estimated reduction of coastal cod spawning areas with total commercial landings of river herring in the Gulf of Maine over the past century suggests a relationship of river herring fishery collapse to cod spawning ground abandonment in the last 50 years. A simple correlation between alewife runs (adult returns) on the Damariscotta River and coastal cod recruitment in the spring following (one year lag), yielded a significant positive relationship (Figure 4). Data used are standardized Gulf of Maine alewife adult abundance data (ASMFC, 1990) from 1962-1989 and cod recruitment data from Ransom Myers' Stock Recruitment Database (NAFO Division 5Y) from 1963-1990. The one-year lag adjustment is used since the production of alewives in the year previous to cod recruitment would provide the energetic reserves required for successful cod reproduction. The significant relationship between cod abundance and the previous year's alewife abundance demonstrates an interdependence of cod population and alewife population production. Such significant correlations do not exist when comparing Gulf of Maine Alewife abundance to cod with a one year lag in other North Atlantic areas including the Bay of Fundy,

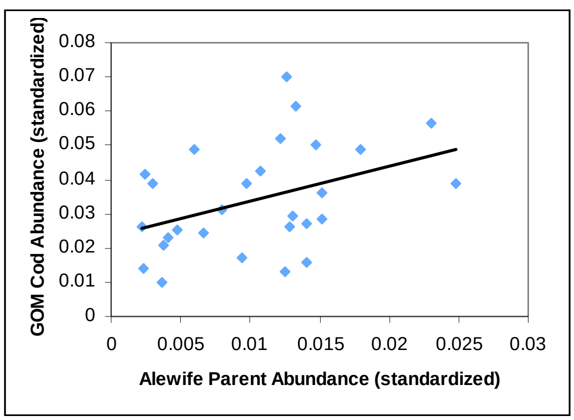

Figure 4. Gulf of Maine cod recruitment 1963-1990 regressed on Gulf of Maine alewife abundance 1962-1989. Cod = 0.39 (alewives) + 0.03, n = 28, p = 0.03. Alewife data from Damariscotta River, ASMFC, 1990. Cod data from NAFO Division 5Y, Ransom Myers' Stock Recruitment Database.

Scotian shelf and northern Georges Bank (NAFO Division 4X, $p = 0.19$) or Cape Cod and southern Georges Bank (NAFO Division 5Z, $p = 0.07$).

Cunningham et al. (2006) documented an 89% increase in the number of ponded wetlands in the landscape between the years of 1944 and 1997, similar to the expansion seen across Maine. Large sites lower in the watersheds were impounded first, followed by upstream and downstream migration and colonization (Cunningham et al. 2006). Beaver have recently increased substantially (Foster et al. 2002), posing a potential management dilemma for wildlife management decision makers when considering an ecosystem perspective.

Conclusions

We conclude the following.

(1) Alewife abundance is contributing to loss of cod stock productivity in the present time period.

(2) Damming of rivers was a major force in the reduction in anadromous fish along the Maine coast in the post-colonial period

(3) Historically, climate effects on the growth of forests and the suitability for beavers, with increasing hardwoods creating a habitat conducive to beavers and limiting access to spawning grounds of alewives.

(4) These results and those detailed in the text are summarized in Table 1.

Table 1. Summary of historical changes discussed in text.

Time Period (Years before present – BP, or Year)	Landscape characterization	Alewife Population Status	Cod Population Status
Ice age (10,000 B.P.)	Ice-covered and drowned coastline	Unknown but likely displaced since area under ice sheet	Unknown
Early Archaic period (9000 to 8000 B.P.)	open woodland	Recovery?	Occupation of current distribution begins
Middle Archaic (8000-6000 B.P.)	Tsuga transitioning to Pinus dominated forest	Peak abundance?	Ecosystem stabilizes and cod stocks become dominated by large individuals
Late Archaic (6000-3000 B.P.)	Tsuga forest transitioning into northern hardwood forest ca. 4700 B.P	Peak abundance, then decline as damming by beavers changes landscape	Continuing towards large individuals dominating
Pre-colonial (1000 BC-1600)	Hardwood forests and marshland	Decrease in abundance as beavers become dominant	Coastal stocks fished for by coastal native inhabitants, later by Basque fishermen, still large population of large individuals
Early colonial period (1600-1750)	Deforestation, heavy erosion	Initial negative response to heavy sedimentation, but positive response to beaver removal, overall increase	Selection begins on large individuals and with initial compensatory effect of removals and increase in alewives
Late colonial period (1750-1900)	Open grassland and successional forests	Large population initially, but mill development begins to reduce access to spawning areas and fish are captured for food and fertilizer, populations decrease	Cod stocks are locally overfished by aggregations of fishing schooners, becoming smaller in average size
Industrial period (1900-present)	Fragmented mosaic of urban, managed woodlots, meadows, conservation lands, return of beaver	Heavy industrialization of waterways, pollution and continued damming of rivers decimates all anadromous fish populations, effects of climate change	Industrial fishing begins, forage stocks overfished/impacted by development, reduced productivity, overfishing for decades extirpates many local populations

Continuing work

Effect of colonial-period activity on available spawning and nursing habitat

We have collected a wealth of historical texts, tax records and town surveys that are being studied and relevant data extracted to determine a timeline of the appearance of anthropogenic activities with the potential to limit accessibility to anadromous fish and degrade spawning or migrating conditions e.g., large river side populations, dams, timber mills, industrial factories, and fishing traps/weirs. Also, negative reactions to development and loss of habitat often caused civil disputes and the recording of formal testimonies and petitions. Such documents will be investigated for mention of activities that impacted river quality.

In addition, research in local historical societies and interviews of locals in towns especially associated with historic runs or harvests of river herring will establish relationships with residents and historians of the area in order to get first-hand anecdotes and local information not previously recorded or included in earlier studies. Present-day dam owners have been contacted and many have documents and photographs, and are often uniquely able to discuss the history of their town.

Accounts of anthropogenic changes that limited or closed off spawning areas are being identified, mapped, dated and categorized according to the type and location. We are concentrating on obstructions initially, since they represent the earliest direct anthropogenic physical alterations to ecosystems. Obstructions will be used to estimate access to spawning sites. A website (see gomher.org under construction) with the mapped data with an interactive element allowing for site visitors to comment on knowledge of structures, presented on the map or previously unknown, condition of the river and recollections of river herring abundance specific to sites on the map.

Historic river herring spawning and nursing grounds will be mapped using ArcGIS according to accessibility over 50 year time periods in order to illustrate the spatial and temporal loss and gain of spawning areas to compare to current distributions and to estimate historical abundance. Current spawning area estimates have been obtained from institutions including the Maine Department of Marine Resources, the Gulf of Maine Research Institute, ASMFC and NOAA.

To complete this objective we are:

A) researching historical and current documents to find dates of the installation of obstructions to river herring spawning areas along the river systems of Maine during the period of 1600-present (see Figure 2)

B) assessing the history of obstructions and whether river herring passage may have increased and decreased at each site over the above period (see Figure 2 for sites)

C) obtaining GPS locations of obstructions to map all sites in ArcGIS and present obstructions on a publicly accessible website with current and historic status of each site and in 50 year time increments demonstrate the sequential changes in river herring spawning site access (see gomher.org, still under construction)

Historical and present abundance of river herring

Data on colonial river herring spawning sites and abundance has been collected from various historical texts, Commission of Fisheries reports and town fishery records. The historical river herring abundance data and changes in river, lake and pond spawning habitat calculated in the previous objective will then be used to develop abundance estimates of river herring populations from 1600 to present using available spawning habitat area. Alewife abundance calculations based on productivity per area using Lewis Flagg's production potential estimates for waterways in Maine (Flagg, 2007) will be evaluated with data we have collected and analyzed in within and among river comparisons.

Potential productivity provides an estimation of abundance by calculating the number of adults returning to a specific spawning area. The use of adult returns to provide a reference for abundance related to a specific site is based on the theory that alewives return to their natal streams as first proposed by Bigelow and Schroeder in their 1953 book <u>Fishes of the Gulf of Maine</u> (Bigelow & Schroeder, 1953; Flagg, 2007). Flagg (2007) estimated a range of 117.5-235 adult returns per surface area of spawning habitat as conservative figures derived from comparing long term (1950s-1980s) annual yields of alewives from the Damariscotta and St. George Rivers to those of today and adjusted to reflect a one day per week fishery closure equaling 15% escapement. The original yield data Flagg (2007) used was in pounds per acre and he calculated the number of adult returns based on an average adult alewife weight of 0.5 pounds. Adjustments to this equation for abundance will be made if research determines historic periods of different levels of escapement, yield or significantly smaller or larger fish.

The calculations of historic abundance as discussed above will then be fit to data from records of historical abundance or catch for the waterways and time periods that such quantitative data is available. Comparisons will also be made to current abundance or catch data to assess maximum historical baselines relative to today's numbers. Sources for this data include the Brunswick, Androscoggin and Kennebec Fishway Reports, Maine Department of Marine Resources alewife harvest data, and historic weir and harvest data from various archives. Those rivers with current abundance and harvest data and those few with historical harvest data will then be used to estimate abundance in river systems without quantitative data but with similar demographics, ie: distance upriver to site of natural obstruction to river herring migration, location of head of tide, length or area of drainage of watershed and total area of lakes on waterway. Sources for comparison and calculation of spawning area and river demographics include comprehensive studies of the river systems conducted by the State in the 19th and 20th centuries (Rounsefell & Stringer, 1945; Wells, 1869; MDIF&G, 1955-1964).

This study should result in a few key trends in estimated abundance during the colonial period. We are particularly interested in impacts during 1700s when the first appearance of dams on the tributaries, the 1820s with the first main stem dam and the 1830s due to growth of the smoked herring industry.

To complete this objective we will:

A) calculate the total historical accessible river herring spawning area available on Gulf of Maine river systems before colonial development using ArcGIS

B) calculate the loss or gain of spawning area on each river system over 50 year time periods during colonial development from 1600-present

C) calculate the changes in historical abundance of river herring over the above time periods based on spawning habitat availability and create a timeline showing potential river herring abundance in 50 year increments from 1600-present indicating historic events with significant impacts on river herring abundance along the timeline

D) research historical documents to find reports of river herring catch or abundance data from 1600-present and fit any available historical data to the calculated historical abundance values

E) compare calculated historical river herring abundance values to current abundance and catch data to demonstrate any changes in abundance

Implications of changes in river herring abundance on coastal cod and other ecosystem components

River herring spawning and nursing grounds will be mapped comparing those in use currently to estimated historical areas. Current estimates will be obtained from institutions including the Maine Department of Marine Resources, the Gulf of Maine Research Institute, ASMFC and NOAA. These historical and current maps will then be spatially compared to Ames' 2004 specific mapping of current and historical coastal cod spawning grounds and migration in the Gulf of Maine in order analyze the historical effect of changes in abundance of river herring on the decline of inshore cod populations.

Calculations will be used to estimate the cod biomass that could be supported by estimated river herring abundance during different periods. Historical cod catch data for the Gulf of Maine can then be fit to these estimates to see how well the predicted and empirical trends match.

Calculations of fitness of a predator can also be made comparing river herring as the principal prey to other prey options in the Gulf of Maine, e.g. cod biomass supported by river herring as opposed to lobsters. Other principal predators include, eagles, seabirds and game fish. And finally, a look at the impact spawning river herring have on inland freshwater habitats leads to evaluating nutrient transport, parasitic freshwater mussel survival, Alewife Floater (*Anodanta implicata*), and reduction of predator pressure on spawning Atlantic salmon. Some initial historical estimates of these ecosystem components based on my historical river herring productivity estimates.

To complete this objective we will:

A) establish a comparison of historical river herring spawning areas to historical inshore cod spawning areas

B) attempt to calculate correlations of historical river herring abundance to inshore cod abundance of corresponding time periods to assess potential dependence of inshore cod on river herring as a critical, principal prey source

C) estimate the energetic value of river herring as prey for cod compared to other prey sources

D) investigate historical relationships between river herring and other predators and prey of river ecosystems in the Gulf of Maine in an attempt to calculate correlations between their historical or current abundances and that of river herring

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