NMFS RIVER HERRING CLIMATE CHANGE WORKSHOP

JULY 18-19, 2012

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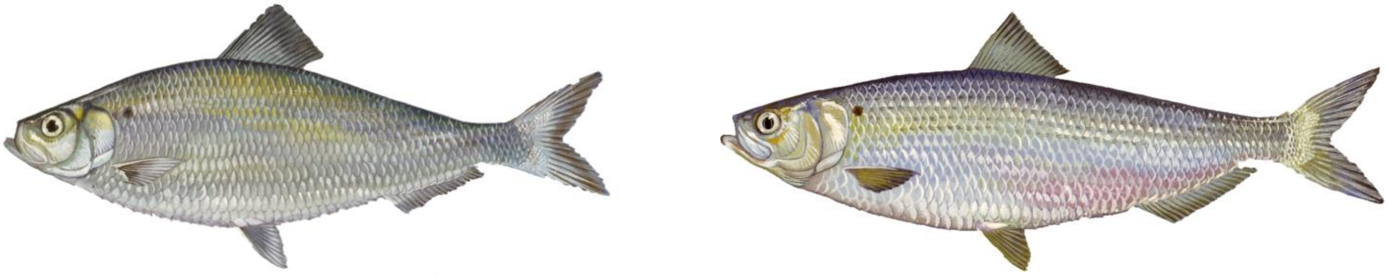
Supplemental Information Provided By
Various Invited Workshop Participants
(as of August 8, 2012)

River Herring: Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*)



Alewife (left) and blueback herring (right) images courtesy U.S. Fish and Wildlife Service

NOTE: The order of the submissions (one-page requested) from presenters corresponds to the River Herring Climate Change Workshop agenda. Information should not to be cited without author's permission. The information contained in this document should not be construed to represent any agency determination or policy. Additional information can be found at the following website: http://www.nero.noaa.gov/prot_res/CandidateSpeciesProgram/RiverHerringSOC.htm

Management update

Overview of Atlantic States Marine Fisheries Commission River Herring Stock Assessment

Katie Drew (ASMFC)

The river herring assessment used both fishery-dependent and independent data as well as information about river herring biology and life history to assess the current status of alewife and blueback herring stocks on the Atlantic coast. Data from a total of 57 river and bay systems from Florida through Maine were included in this assessment.

The assessment included historical landings back to 1887, although the fisheries that target river herring date back to colonial times. Reported commercial landings of river herring peaked in 1965 and declined steadily and rapidly after that. Total incidental catch of river herring in ocean fisheries was estimated from sampling done by at-sea observers. The assessment also examined time-series of commercial catch-per-unit-effort (CPUE), a fishery-dependent index of abundance.

The assessment examined run size indices from five states, young-of-year indices from 10 states, adult net and electrofishing indices from three states, and 19 fishery-independent trawl surveys conducted in coastal waters. The fishery-independent data sets represent a relatively short time series, compared to the long history of the fishery, and all of them were initiated after the peak and sharp decline in landings.

Regional differences were seen in some of the fishery independent indices; for example, trawl surveys in southern regions were more likely to be below the 25th percentile of the time-series than trawl surveys from northern regions. However, it is hard to distinguish between differences in trends that result from climate change and those that result from differences in management exploitation, habitat loss, and other factors at the stock level.

Of the 52 stocks of alewife and blueback herring for which data were available, 23 were depleted relative to historic levels, one stock was increasing, and the status of 28 stocks could not be determined because the time-series of available data was too short.

Estimates of abundance and fishing mortality could not be developed because of the lack of adequate data. The “depleted” determination was used instead of “overfished” and “overfishing” because of the many factors that have contributed to the declining abundance of river herring, which include not just directed and incidental fishing, but also habitat loss, predation, and climate changes. The assessment concluded that management actions to reduce total mortality are needed.

An Overview of Canadian River Herring (Gaspereau) Fisheries Management

Jamie M. Cournane and Christopher Glass
University of New Hampshire, Durham, New Hampshire

River Herring Fisheries

The Canadian Maritimes mark the northern-most extent of the distributional range for alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*, collectively "river herring" (DFO 2001). Alewife are found slightly further north and are more abundant than blueback herring in the region. Other common names for the two species depend on local traditional terminology including: river herring (southern New Brunswick), gaspereau (inner Bay of Fundy, southern Gulf of St. Lawrence, and Atlantic Nova Scotia) and kiack/kyack (southern Nova Scotia).

River herring are caught as adults during their spawning migration in the spring (DFO 2001). They are exported (e.g. to Haiti) as salted food fish and provide an important seasonal bait supply to local fisheries (e.g. lobster, *Homarus americanus*, fishery). Fishers deploy different gear types depending on fishing locations (i.e. river, estuary) and restrictions (DFO 2001). Gears include gillnets, trap nets, dip nets, tip-traps, and square nets. Most fisheries target alewife, due to bait demands matching earlier spawning timing of alewife rather than blueback herring. The majority of fisheries capture greater than 100 mt of fish per year with a few larger fisheries (e.g. Saint John River, Bay of Fundy, NB and Miramichi River, southern Gulf of St. Lawrence, NB) greater than 1,000 mt of fish per year. Catch reporting includes logbooks and dealer records, but these methods of reporting are not ubiquitous in all river herring fisheries (DFO 2001, DFO 2007).

River Herring Fisheries Management

The last Maritimes-wide stock assessment of river herring occurred in 2001 (DFO 2001). Updates to the stock assessment are forthcoming within the next one to two years (*personal communication*). Active commercial and recreational fisheries occur in Canadian waters, although only data from commercial harvest is collected. The Canadian federal government (Department of Fisheries and Ocean) has jurisdiction over river herring fisheries management. In most river herring fisheries, the fisheries management objective is to maintain harvest near long-term mean levels (DFO 2001). Effort controls to achieve this objective include licenses, permits, limits on new entrants, temporal closures, and fishing seasons or some combination.

In addition, managers use specific reference points, as appropriate (DFO 2001). The St. John River stock is managed at the Mactaquac Dam based on a fixed escapement target derived from stock and recruitment data. The Bay of Fundy and Atlantic coast is managed so that fisheries exploitation does not exceed a level of 0.65. For the Southern Gulf of St. Lawrence stock, the fishing mortality level should not exceed the natural mortality rate, in which exploitation rates range from 0.33-0.39.

For example, the Gaspereau River (inner Bay of Fundy, NS) fishery 5-year (2002-2006) fishery management plan set a spawning escapement goal of 400,000 adults (maximum sustainable yield at an exploitation rate of 63%) (DFO 2007). To do so, managers added an additional closed day to reduce fishing pressure and improved fish passage. At the last assessment, escapement was below the target but on the rise, with average escapement for 2002-2006 at 279,278 fish and up from the 1997-2000 average at 111,823 fish (DFO 2007).

Uniquely, eastern New Brunswick has an integrated fishery management plan for river herring (DFO 2006). The six-year management plan (2007-2012) covers coastal and inland waters of eastern New Brunswick, including all watersheds between Dalhousie and Baie-Verta, and applies to 129 commercial license holders using trap nets and gill nets in this fishery. The plan works in conjunction with annual adjustments to management measures linked to fishing areas, season, and catch limits. An updated plan has not been established beyond 2012.

References

DFO, 2001. *Gaspereau Maritime Provinces Overview*. DFO Science Stock Status Report D3-17.

DFO, 2006. *Integrated Gaspereau Fishery Management Plan, Eastern New Brunswick Area, Gulf Region 2007-2012*.

DFO, 2007. *Assessment of Gaspereau River Alewife*. DFO Can. Sci. Advis. Sec. Sci. Advis. Report 2007/030.

Setting the Stage

A Review of the Biology and Ecology of River Herring from a Climate Change Perspective (Summary)

Dr. Karen Wilson, Department of Environmental Science, University of Southern Maine
July 2012

The term "river herring" refers to two difficult to distinguish species of anadromous Alosid herring, alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*). Both spend most of their life in marine habitats, and return to their natal freshwater rivers and/or lakes to spawn. River herring range from Florida to the St. Lawrence River, with blueback herring more dominant in southern rivers, and, generally, alewife more dominant in northern rivers. In their northern range, it is not uncommon to find "repeat spawners" returning to spawn multiple times (i.e., iteroparity), a degree of life history plasticity that allows individuals to try again next year if environmental conditions make spawning difficult. Adult river herring move up coastal rivers in early to late spring in response to water temperature. Alewife typically spawn in lakes (or, in southern ranges, in slow moving stretches of larger rivers); blueback herring are considered a river-spawning species, again, in slower moving reaches. Both males and females return to the ocean after spawning although alewives, at least, can feed in freshwater and may stay in lakes for weeks to months, particularly if dropping water levels prevent egress. In lakes young of the year (YOY) alewives are pelagic, feeding on zooplankton; as they grow they can move inshore and their diet may include benthic invertebrates. YOY alewives emigrate from lakes as early as July or as late as October depending on numerous factors that may include lake productivity, population density, and access to outlet streams. Juveniles spend their first few years in estuaries and the ocean although details are not well known; adults spend their time well off shore. Adults return to their natal rivers to spawn at age 2-4; there are more repeat spawners (i.e., fish who have spawned the previous year) the further north the spawning run. Climate change could affect river herring in a multitude of ways. Those related to the biology and ecology of river herring include:

Temperature: Temperature is an important river herring spawning and migration cue. For example, in the spring of 2012, many spawning runs in northern states began 2-3 weeks earlier than normal, correlated with unusually warm spring temperatures. In addition, temperature has important energetic implications for river herring. The warmer the water, the more energetically costly it is for the fish to linger in that water. In more northerly rivers, it is not uncommon for water temperatures to drop due to spring storms and for fish to "fall back" into estuaries or larger rivers. Changes in the timing of spawning may contribute to "match – mismatch" between predator and prey.

Water flows: Water flows dictate, in large part, the ability of fish to pass both natural and anthropogenic barriers in rivers. Too much or too little flow can render fish passage ineffective, or delay fish at a barrier long enough as to deplete the fish's energy stores before spawning, or prevent a spawned-out fish from reaching the ocean. Fish passage devices on dams require an "attraction flow" to attract migrating fish – if this flow is too little compared to that coming over the dam or through turbines fish will not "find" the intended passage. Outmigration is also impacted by flows: greater flows may ease outmigration by reducing time spent while minimal flows may block outmigration of young of year in late summer and fall.

Analysis of Climate Models Specific to River Herring

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NOAA/Earth System Research Laboratory

Co-authors: Jamie Scott, Janet Nye, Patrick Lynch, Jon Hare and Charles Stock

The distribution and abundance of river herring (alewifes and blueback herring) along the east coast of North America strongly depend on the physical environment including the climate. As river herring are anadromous, they are influenced by climate variability and change both in freshwater and marine environments.

Global climate models have been used examine climates of the past, present and future, including projected changes due to anthropogenic greenhouse gas forcing. The projected changes depend on human behavior and the resulting input of carbon into the atmosphere and natural variability in the climate system. The former can be studied via different “scenarios” of human activities, while the later can be estimated from the spread in an ensemble of simulations using the same scenario and model but initialized with different states. Here we briefly describe how climate models work, various scenarios for greenhouse gasses through the 21st century, and how and why ensembles are created.

Results from the climate models from the IPCC 4th assessment indicate an increase in the surface and 200 m temperature during the 21st century over most of the global oceans including the northwest Atlantic. In the Atlantic, salinity increases in midlatitudes (up to ~45°N) and decreases over portions of the subarctic in the Atlantic. The temperature and salinity changes enhance the stratification in the North Atlantic, which may impede the mixing of nutrients (not included in these models) into the surface waters.

To study climate change on a regional basis, output from climate models can be estimated at finer resolution using statistical or dynamical downscaling. In the latter, a higher resolution regional model is embedded within the climate model over a portion of the globe. In the North American Regional Climate Change Assessment Program (NARCCAP) fields from the global climate models are used to provide boundary conditions for regional atmospheric models covering most of North America and extending over the adjacent oceans.

Results from NARCCAPP suggest that temperature will warm throughout the year over the northeast, mid-Atlantic and Southeast US. Even though there is an increase in precipitation over the northeast US during winter, albeit with a wide range of variability among the simulations, runoff (a crude estimate of river flow) decreases, likely due to an increase in evaporation. The results suggest that water temperatures in the rivers will be warmer and that there will be a decrease in the river flow in the northeast and mid-Atlantic states in late winter/early spring.

Ongoing river herring climate assessments

Projecting the effects of climate change on river herring in both freshwater and marine habitat

June 29, 2012

Patrick Lynch, Janet Nye, Jon Hare, Kiersten Curti, Katie Drew, Mike Alexander, Jaime Scott, and Charlie Stock

Alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), collectively river herring, are two species of anadromous Alosine fishes that utilize marine, estuarine, and freshwater habitats along the east coast of North America. The necessity to utilize multiple habitats across life stages suggests that river herring populations may be sensitive to alterations of any or all of these habitats. Potential cascading effects of habitat alterations may include changes in population abundance, distribution, and structure (among others). There have been well documented anthropogenic effects on habitats throughout the distributional range of river herring, resulting from changes in land use (e.g., development, pollution, nutrient loading, etc.), freshwater use (i.e., dam construction and removal), and fishery harvests. Anthropogenic climate change caused by increasing greenhouse gas emissions is an additional stressor that has not been addressed. Decreases in the size of spawning runs have been detected in numerous coastal rivers, and a northward shift in the marine distribution of alewife has been documented, suggesting that climate may be playing an important role in modifying river herring habitat and population size. However, while environmental and population changes are occurring simultaneously, causal relationships are not well understood.

In this study, we are estimating and projecting the effects of climate change on river herring populations in both freshwater and marine habitats. We are using historical data to explore relationships between river herring populations, habitats, and environmental variability with a focus on water temperature and river flow. We are using downscaled global climate models to project regional environmental changes in river herring habitats. Then, by linking projected environmental changes to river herring population models, we are predicting the population response to future climate scenarios. To date, our analyses focus on environmental effects in marine habitat. The preferred spring and fall sea surface temperature ranges were similar for alewife (spring: 2.2 – 6.2 °C; fall: 3.8 – 9.8 °C) and blueback herring (spring: 2.2 – 6.2 °C; fall: 8.8 – 10.8 °C). There have been significant increases in mean latitude of occurrence for both species (i.e., northward distribution shifts). Results using Generalized Additive Models that incorporate marine habitat suggest that water temperature plays an important role governing the distribution and abundance of river herring in the marine realm, and by using these models we have shown that the response of river herring abundance to increasing water temperature is complex. However, this relationship is based on the assumption that all variables affecting river herring populations in addition to water temperature (e.g., fishing intensity, freshwater habitat, etc.), do not change from their present conditions.

Climate science and river herring research and/or information relevant to climate change assessments

An example of simulation of in-stream water temperatures related to projections of climate change in the southeastern U.S.

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The importance of effective stream temperature modeling, related to determination of suitability and management of ecological habitat, has been demonstrated in several studies. Likewise, watershed hydrology models have been used to project the hydrologic response of watersheds to a variety of changing climatic and land-use scenarios. The software package P2S combines these two approaches by coupling the Precipitation-Runoff Modeling System (PRMS) and Stream Network Temperature (SNTemp) simulations models.

PRMS is a modular, deterministic, distributed-parameter, physical-process watershed model used to simulate and evaluate the effects of various combinations of precipitation, climate, and land use on watershed response. Response to normal and extreme rainfall and snowmelt can be simulated to evaluate changes in water-balance relations, streamflow regimes, soil-water relations, and groundwater recharge. Each hydrologic component used to model the generation of streamflow is represented within PRMS by a process algorithm that is based on a physical law or empirical relation with measured or estimated characteristics. Because PRMS is usually operated in a daily time step, the streamflow time of travel within a watershed should be less than 24 hours. However, for larger watersheds that have longer travel times a stream routing component can be used.

SNTemp is a model that predicts in-stream water temperatures based on hydrological, meteorological, topographic and vegetative shading, and stream channel conditions. SNTemp has been described as being “applicable to any size watershed or river basin with a stream network of any stream order and complexity;” however, shortcomings have been found when applying SNTemp to networks where the travel time is much larger than the simulation time step. These limitations with SNTemp have been overcome by improving the streamflow routing algorithms of PRMS. Despite this, SNTemp incorporates several relevant features, including: (1) a heat transport model that predicts the daily-mean water temperature and diurnal fluctuations in water temperature as functions of stream distance; (2) a heat-flux model that predicts the energy balance between the water and its surrounding environment; and (3) a shade model that predicts the solar radiation-weighted shading resulting from both topography and riparian vegetation. These two models have been applied together in a study of the Apalachicola—Chattahoochee—Flint River Basin in the southeastern U.S. the as part of the U.S. Geological Survey Southeast Regional Assessment Project. Preliminary results from this simulation are presented here.

An example of simulating hydrologic response to projections of climate in the southeastern US

Jacob LaFontaine
USGS Georgia Water Science Center

The U.S. Geological Survey (USGS) Southeast Regional Assessment Project (SERAP) was initiated in 2009 to help environmental resource managers assess the potential effects of climate change on ecosystems. One component of the SERAP program is the development and calibration of a set of multiresolution hydrologic models of the Apalachicola–Chattahoochee–Flint (ACF) River Basin. The ACF River Basin, which is home to numerous fish and wildlife species of conservation concern, is regionally important for water supply and is a focus of complementary environmental and climate-change research. Hydrologic models of varying spatial extents and resolutions are required to address varied local-to-regional water-resource management questions as required by the scope and limitations of potential management actions. These models were developed by using the USGS Precipitation Runoff Modeling System (PRMS). The coarse-scale model developed for the ACF River Basin has a contributing area of approximately 50,700 square kilometers. Six fine-resolution PRMS models, ranging in size from 396 to 2,690 square kilometers, are nested within the coarse-scale model and have been developed for the following basins: the upper Chattahoochee, Chestatee, and Chipola Rivers, and Ichawaynochaway, Potato, and Spring Creeks. Both coarse- and fine-scale models simulate basin hydrology using daily timesteps, measured climatic data, and basin characteristics, such as land cover and topography. Measured streamflow data are used to calibrate and evaluate computed basin hydrology. Being able to project future hydrologic conditions for this set of models will rely on the use of land cover projections in conjunction with downscaled Global Climate Model results. Both current and future simulated hydrologic conditions, flows and statistics of flows, are output by PRMS and are being used as inputs to simulations of stream temperature and ecological response.

In addition to the seven hydrologic models previously described, an eighth hydrologic model is being developed for the upper Roanoke River Basin in Virginia. This hydrologic model and the existing upper Chattahoochee River model are being used in a collaborative effort between USGS and the U.S. Forest Service (USFS) to simulate the effects of potential climate-change and management actions, such as land development, water use, and stream fragmentation, on stream fish, their habitats, and the services they provide to local communities. These study basins in Georgia and Virginia were selected by team members based on three criteria: (1) the basins are along the cold- and warm-water interface and contain both cold- and warm-water stream ecosystems; (2) the basins contained USGS stream gages; and (3) contemporary fish collection data from each basin were available. Similar to the SERAP effort, hydrologic model output will be used as input for simulations of stream temperature and ecological response.

Regional Hydroclimatic Flood Trends and Relevance for River Herring Habitat

Mathias J. Collins, P.H., NOAA Restoration Center, Gloucester, MA

The NOAA Restoration Center, in collaboration with its partners, designs and implements fish passage restoration projects for river herring and other diadromous species in streams of the Northeast United States. These include dam removals, culvert replacements/upgrades, nature-like fishways, and structural fishways. Fish passage restoration projects, as with other floodplain infrastructure projects like bridges, require estimates of flood magnitudes and frequencies likely to affect the project during its design life. Recent research in the Northeast United States shows increasing flood magnitudes and frequencies in watersheds minimally impacted by human development, suggesting that climate change is affecting flood flows region-wide (Armstrong *et al.*, 2012; Armstrong *et al.*, in review; Collins, 2009; Hodgkins, 2010, NOAA, 2011). Trends in this region suggest that it is important to include the most recent decades of record when computing flood frequency estimates to ensure that projects are designed properly for the modern flood regime. Our work also suggests that small, frequent floods have been disproportionately affected by regional hydroclimatic change. High frequency floods are very important for forming stream channel geometry, and thus habitat, for aquatic organisms including river herring. This presentation will summarize our analyses of flood data from climate-sensitive stream gauges with long records in the northeast United States and Atlantic Canada. We will also explore the implications of our results for stream habitat and the design of fish passage restoration projects for diadromous fish like river herring.

References:

Armstrong, W.H., Collins, M.J., and Snyder, N.P., in review, Hydroclimatic flood trends in the northeastern U.S. and linkages with large-scale atmospheric circulation patterns. Submitted to *Water Resources Research* on 09 April 2012.

Armstrong, W.H., Collins, M.J., and Snyder, N.P., 2012. Increased frequency of low magnitude floods in New England. *Journal of the American Water Resources Association (JAWRA)* 48(2):306-320, doi:10.1111⁄j.1752-1688.2011.00613.x

Collins, M.J., 2009. Evidence for changing flood risk in New England since the late 20th century. *Journal of the American Water Resources Association (JAWRA)* 45(2):279-290, doi:10.1111/j.1752-1688.2008.00277.x

Hodgkins, G.A., 2010. Historical changes in annual peak flows in Maine and implications for flood frequency analyses. U.S. Geological Survey Scientific Investigations Report 2010-5094, 38 pp. http://pubs.usgs.gov/sir/2010/5094

National Oceanic and Atmospheric Administration (NOAA), 2011. Flood Frequency Estimates for New England River Restoration Projects: Considering Climate Change in Project Design. NOAA Fact Sheet FS-2011-01, 4pp. www.habitat.noaa.gov/pdf/flood_frequency_estimates.pdf

A Brief Overview of Canadian River Herring (Gaspereau) Datasets

Jamie M. Cournane and Christopher Glass
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River Herring Datasets

Many alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*, collectively “river herring”, datasets exist within the Canadian Maritimes, principally covering juvenile and adult life stages. These datasets include fishery dependent and independent information. Some examples include the St. Croix River (New Brunswick and Maine border), the Mactaquac Dam (St. John River, Bay of Fundy, NB), the Gaspereau River (Bay of Fundy, NS), and Department of Fisheries and Ocean (DFO) oceanic trawl surveys.

St. Croix River

Historically, the river herring stock in the St. Croix River contained an estimated 31.7 million fish (Lotze and Milewski 2004). Current counts at the Milltown Dam (lowest dam on the St. Croix River) fish trap at the fishway were 25,142 fish in 2011 and 36,178 fish in 2012 (*personal communication*). The low count was 900 fish in 2002, and the high count was 2.6 million fish in 1987. The Milltown Dam fish trap counts have been conducted since 1981 jointly by DFO, the St. Croix International Waterway Commission, and the Atlantic Salmon Federation with modification in sampling protocols in 1999 and 2001. Current counts reflect blocked upstream fishways beyond the Milltown Dam by the State of Maine in 1995 (Woodland Dam and Great Falls Dam), subsequent DFO trucking of fish around Woodland Dam (2001-2007), and reopening of Woodland Dam fishway by the State of Maine (2008). Restoration of fish passage has been subject of intense debate across the border.

Mactaquac Dam

The St. John River stock is managed at the Mactaquac Dam and is based on a fixed escapement target derived from stock and recruitment data (DFO 2001). The current escapement objectives are 800,000 alewives and 200,000 blueback herring, with excess available for harvest (DFO 2001). Data collected at the fishlift includes information on both species such as age and sex composition and spawning escapement. Additionally, river herring fishery harvest is monitored. The fishery began in 1974, since river herring at the time were clogging the fish ladder and believed to be blocking the upstream migration of early-run Atlantic salmon, *Salmo salar*, and to reduce the cost of trucking river herring upriver from the fishlift (DFO 2001). Exploitation rates since 1974 vary widely from 12% to 90% (median 43%) for alewives and 33% to 99% (median 79%) for blueback herring (DFO 2001). The proportion of previous spawners for both species has declined since the 1970s (DFO 2001).

Gaspereau River

The Gaspereau River fishery is managed under a 5-year fishery management plan (DFO 2007). The management goal is spawning escapement of 400,000 adults (maximum sustainable yield at an exploitation rate of 63%) accomplished by reducing fishing pressure (DFO 2007). To monitor the fishery and stock, data collection includes fishery logbooks, fishery officer pail counts, and counts at a fish ladder above the fishery. Fish spawn in Gaspereau Lake after ascending two fish ladders at White Rock and Lanes Mills. Monitoring takes place at White

Rock fish ladder, beginning in 1970 but not steadily each year until 1997 (DFO 2007). A new fish ladder and assessment facility, that included video monitoring, was constructed in 2002. Fish counts were hand counts prior to 2002 and estimated from video counts (sub-sampling and extrapolation) starting in 2002. At the last assessment, escapement was below the target but on the rise, with average escapement for 2002-2006 at 279,278 fish and up from the 1997-2000 average at 111,823 fish (DFO 2007).

Oceanic Trawl Surveys

DFO operates several oceanic trawl surveys in the Canadian Maritimes that capture alewife and blueback herring. Stone and Jessop (1992) conducted an analysis of oceanic trawl survey data collected between 1970 and 1989. They concluded that oceanographic features strongly tie to river herring distributions at sea. River herring were most abundant in spring in the warmer deeper waters of the Scotian Shelf. They occurred in the Bay of Fundy and off southwestern Nova Scotia in spring, summer and fall surveys, in places with strong tidal mixing and upwelling. They were rarely found on the eastern Scotian Shelf.

Stone (unpublished data) recently plotted multi-year composites of alewife distribution and relative abundance (average weight (kg)/tow aggregated by 5 minute squares) for summer oceanic trawl surveys. Changes in both distribution and relative abundance are evident from visual inspection and remain the subject of further examination.

References

DFO, 2001. *Gaspereau Maritime Provinces Overview*. DFO Science Stock Status Report D3-17.

DFO, 2006. *Integrated Gaspereau Fishery Management Plan, Eastern New Brunswick Area, Gulf Region 2007-2012*.

DFO, 2007. *Assessment of Gaspereau River Alewife*. DFO Can. Sci. Advis. Sec. Sci. Advis. Report 2007/030.

Lotze, H. K. and I. Milewski. 2004. Two centuries of multiple human impacts and successive changes in a North Atlantic food web. *Ecological Applications* 14(5), 1428-1447.

Stone, H. H., Jessop, B. M., 1992. Seasonal distribution of river herring Alosa *pseudoharengus* and *A. aestivalis* off the Atlantic coast of Nova Scotia. *Fisheries Bulletin* 90, 376-389.

Population Trends of Alewives and Blueback Herring in Maine

Claire Enterline, Maine Department of Marine Resources

The most reliable long-term, fisheries-independent river herring datasets in Maine are adult counts at fishways, annual beach seine surveys conducted in the Kennebec and Merrymeeting Bay estuary complex, and the near-shore trawl survey. While some commercial harvest data may go back to the 1800's, catch numbers may be more reflective of fishing effort and methods rather than actual population trends. The majority of long-term data in Maine are collected at fishways that pass alewives almost exclusively. Above the majority of these head-of-tide dams, there is little appropriate blueback herring spawning habitat. Blueback herring may spawn below these dams, but no survey targets adult spawning bluebacks. The juvenile beach seine survey is the only survey that targets blueback herring in addition to alewives, both natal to the system. The biannual near-shore trawl survey, beginning in 2000, catches juvenile blueback herring and alewives, the origins of which are unknown. In addition to the effect of climatic changes on populations, the ability of river herring to reach spawning habitat and the amount of available habitat must also be considered.

Adult River Herring Counts at Fishways

Adult river herring returning to spawn are counted at many fishways; however, data from the Saco (1994-2011), Androscoggin (1982-2011), Union (1981-2011), and St. Croix (1980-1995) may best reflect actual population trends. Counts from the Damariscotta River may be complicated by changes in survey effort and fishway efficiency problems. Populations are stable on the Saco and Union Rivers and are increasing on the Androscoggin, due in part to stocking and increases in available habitat. Although the St. Croix population has recently declined due to fish passage closure, data before the closure may provide information about how climatic changes may have impacted the population. Trends in the number of returning adults in a given year seem to have a relationship with spring and fall discharge 4-years prior (both species are fully recruited at age-4).

Juvenile Beach Seine Survey

Annual beach seine surveys are conducted July-September in five major areas in the Kennebec and Merrymeeting Bay estuary complex. The survey does discriminate between blueback herring (data available 1992-2011) and alewives (1979-2011). Young-of-the-year (YOY) blueback herring were likely spawned in the associated river, and environmental data for each area may be used to explore relationships for both larval and juvenile stages. Because the timing of this survey is before the observed emigration of juvenile alewives from lakes and ponds in the upper watershed, it may be assumed that YOY alewives caught in this survey may also have been spawned below dams.

Near-Shore Trawl Survey

The near-shore trawl survey (2000-2011) is conducted annually in May-June and September-October. While few adult river herring are caught, juvenile alewives and blueback herring dominate hauls in some areas. Comparison with near-shore sea surface temperature data may give insight into habitat preference. Specifically, daily sea temperatures taken at the Boothbay Harbor laboratory and at near- and off-shore data collection buoys may provide insight into trends in population data.

Environmental Monitoring related to River Herring Populations and Habitats in Massachusetts

Bradford C. Chase, Massachusetts Division of Marine Fisheries

Anadromous river herring runs occur in nearly 100 coastal rivers and streams in Massachusetts. The spring spawning runs have been closed to harvest since 2006 out of concern for sharply declining run counts in the past decade. The Massachusetts Division of Marine Fisheries is working with Federal, State and local partners to monitor population abundance in specific rivers, identify causal influences on recruitment and mortality, and to restore river herring populations.

Fishery-independent monitoring of river herring spawning runs are mainly conducted using electronic counting stations and visual volunteer counts. Age and size data are also recorded at six rivers where counting occurs. Water chemistry and temperature are measured at each station while local environmental conditions such as discharge, tide stage, precipitation, and air temperature are recorded from independent sources. Our goals are to produce long-term indices of population abundance and age-structure and identify environmental relationships to population demographics.

The Massachusetts Division of Marine Fisheries has developed a Quality Assurance Program Plan (QAPP) for water quality measurements at diadromous fish habitat. The QAPP has Standard Operating Procedures on: water temperature loggers, water chemistry multi-probe sondes, smelt spawning habitat assessment and river herring spawning and nursery habitat assessment. The primary program objective is to develop standardized data collection and processing protocols for water quality sampling during diadromous fish monitoring. The QAPP will also help prioritize diadromous fish restoration projects and contribute to Massachusetts Department of Environmental Protection efforts to assess the ability of water bodies to support designated uses and remediate pollutant loads under Clean Water Act processes. Both the river herring spawning run monitoring and habitat assessment projects rely on the QAPP guidance to produce comparable and reliable water quality data.

The identification of suitable river herring spawning and nursery habitat and restoration targets depends on the availability of physical criteria that relate to biological thresholds important to river herring life history. There is limited guidance from the scientific literature on water chemistry and habitat criteria for river herring. This issue becomes increasingly important under scenarios of warming freshwater and marine habitats for river herring. The QAPP attempts to address this by assessing habitat suitability based on criteria adopted from state surface water quality criteria, US EPA ecoregion thresholds for nutrients, and documented temperature thresholds for river herring. River herring habitat assessments began in 2008. The results to date have documented periodic impairment due to high water temp-erature, low pH, and low water clarity; and more common impairment from low dissolved oxygen, low stream flow, and high nutrients (TN and TP). In urban settings, the common presence of hypolimnetic anoxia raises concerns over limitations on river herring nursery habitat. These and other efforts to address river herring habitat impairment will benefit from laboratory studies that document biological responses to water chemistry and habitat thresholds.

Water temperature loggers have been deployed at marine stations off the coast of Massachusetts since the mid-1980s and in rivers where diadromous fish are monitored since 2002. These ongoing efforts along with readily available data sources on local environmental conditions will contribute to analyses of long-term run count data. An example of this progress is a multiple regression model developed for the Monument River. A variety of covariates were analyzed with 30 years of spawning run count data. The best model for predicting recruitment (4 and 5 year lag) was most influenced by fall precipitation.

North Carolina Anadromous River Herring Studies Related to Climate Change

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Tar/Pamlico Watershed: The four alosine species (alewife, American shad, blueback herring and hickory shad) spawn in the Tar River downstream of the dam at Rocky Mount, North Carolina. Alewife are more abundant than blueback herring. Smith (2006) reported alewife first spawning in the Tar River March 12, 2004 and spawning was ended on May 17 for a total of 67 days. The first peak was observed March 29, second peak on April 5, and third peak on May 14, 2004. Water temperatures ranged from 12.4-17.9^o C. In 2005, alewife spawning was first observed on April 22, but it was sustained only 4 days ending on April 25, 2005. Water temperatures were 13.7-20.2^{o}C during the four-day period. The blueback herring run is vestigial at best. Spawning was observed on May 17, 2004, and on April 11, 2005. Water temperature in 2004 was 21.2^o C, and 17.6^o C in 2005. This study will provide a baseline for climate change and sea level rise. Spawning and potential nursery habitats will be pushed upstream and squeezed against the dam as these two aspects increase later in the century.

Albemarle Sound and tributaries: Zapf (2012) just completed his MS thesis on river herring nursery habitat, comparing his results based on otolith chemistry with the state agency work on identifying Strategic Habitat Areas (SHAs) for fish. In 2010, the western and eastern Albemarle Sound were good habitats and supported juvenile river herring; the central portion of the Sound including the Perquimans River, Little River, North, Scuppernong, and Yeopim rivers were poor habitats and did not hold young river herring within their boundaries. In 2009 and 2010, adult blueback herring were collected from the Chowan, Scuppernong, and Perquimans rivers. (No adult alewife were collected, likely too late in the season). Homing was best observed for the Chowan River, and lowest rates to the Scuppernong and Perquimans rivers. The Alligator, Chowan, and Roanoke rivers along with western Albemarle Sound habitats are high quality river herring habitats, which corresponds well with the SHAs designated by the State of North Carolina. We need additional data on adult alewife as it was not captured here. A small increase in water temperature will certainly turn modestly strong alewife runs into weak vestigial runs at best.

Lake Mattamuskeet National Wildlife Refuge: This large (40,000+ acres) lake in the North Carolina Coastal Plain historically hosted a spawning run of alewife, and possibly blueback herring (Tyus 1971; H. Tyus, personal communication to RWL), and currently constitutes nursery habitat for alewife. Historic data on the alewife run exist from work conducted by the North Carolina Cooperative Fish and Wildlife Research Unit (formerly USFWS, now USGS; Tyus 1971) and more recently from work examining fish passage into the Refuge, conducted by

East Carolina University in collaboration with the U.S. Fish and Wildlife Service's Coastal and Fisheries programs (Wall 2003; Godwin 2004).

Spawning was later in the season in the 1970s compared to the late 1990s-early 2000s but at cooler water temperatures. Tyus (1971) reported a relatively healthy population in 1970 of an estimated 199,633 individuals running in Lake Landing Canal with a peak spawning time of April 5-6 at a temperature of 12.9^o C. In 1971, the Lake Landing Canal population had dropped to an estimate of 167,300 individuals with the peak spawn on April 2-3 at a temperature of 13.1^o C. Twenty-seven years later, Wall (2003) reported that the total alewife run in 1997 in lake Landing Canal was only 178 individuals, and in 1998 only 454 fish. Once new flapgates of the original design were installed, Godwin (2004) reported an estimated 8,836 fish through Waupoppin Canal between March 14-May 6 in 2001. In 2003, the Waupoppin Canal spawning run occurred February 21 through May 1 with the peak during March 23-29 at a temperature of 18.4^o C. The spawning run had increased to 38,731 fish. In Lake Landing Canal, the run was from February 26-April 30, 2003, but the run size could not be estimated. Interestingly, the Refuge has over 40 years of water level data and it shows the rise in water level during that period. Also, I believe that North Carolina was in a severe drought during the late 1990s and early 2000s, which could have forced earlier spawning at higher temperatures.

The USFWS currently is planning to begin continuous water quality monitoring of the lake, in conjunction with planned highway construction activities by the North Carolina Department of Transportation (Augspurger 2012). These studies could potentially be modified to include a river herring component. Since the river herring fishery in North Carolina is currently under moratorium, changes in river herring populations may be more easily attributed to climatic changes (presuming that management measures being undertaken by the Mid-Atlantic and New England Fishery Management Councils are successful in reducing or eliminating bycatch in offshore fisheries).

References

- Augspurger, T. 2012. Automated collection of core metric water quality data at Mattamuskeet National Wildlife Refuge, North Carolina's largest natural lake, as a foundation and model for refuge water quality monitoring partnerships. Ecological Services Field Office, U.S. Fish and Wildlife Service, Raleigh, North Carolina. 4 pp.
- Godwin, C.H. 2004. Performance assessment of retrofitted water control structures at Mattamuskeet National Wildlife Refuge, North Carolina. MS thesis, Department of Biology, East Carolina University, Greenville.
- Parthree, D.J. 2005. Diet analysis of some pelagic predatory and filter feeding fishes of the nearshore northern North Carolina and southern Virginia coasts, winter 2005. Chesapeake Bay Trophic Interactions Laboratory Services, Virginia Institute of Marine Sciences, College of William and Mary, Gloucester, Virginia. 11 pp. + tables.
- Smith, M.C. 2006. Habitat use of early *Alosa* spp. And striped bass *Morone saxatilis*, in the lower Tar River, North Carolina. MS thesis, Department of Biology, East Carolina University, Greenville.
- Tyus, Harold M. 1971. Population size, harvest , and movements of alewives, *Alosa pseudoharengus* (Wilson), during spawning migrations to Lake Mattamuskeet, North Carolina. PhD dissertation, Zoology Department, North Carolina State University, Raleigh. 77 pp.
- Wall, B.L. 2003. Fish passage through water control structures at Mattamuskeet National Wildlife Refuge, North Carolina. MS thesis, Department of Biology, East Carolina University, Greenville.
- Zapf, D.H. 2012. River herring nursery habitat in Albemarle Sound, North Carolina, inferred from otolith microchemistry. MS thesis, Department of Biology, East Carolina University, Greenville.

Blueback herring in Florida

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Papers Discussed:

McBride, R. S., J. E. Harris, A. R. Hyle, and J. C. Holder. 2010. The spawning run of blueback herring in the St. Johns River, Florida. Transactions of the American Fisheries Society 139:598-609.

Williams, R. O., W. F. Grey, and J. A. Huff. 1975. Anadromous fish studies in the St. Johns River. Completion report for the anadromous fishes of Florida, project AFCS-5, 1 May 1971-30 June 1974, National Marine Fisheries Service, St. Petersburg, Florida. (Online 6/29/2012 at: http://research.myfwc.com/publications/publication_info.asp?id=43194)

Talk Summary:

We examined aspects of life history for blueback herring *Alosa aestivalis* in the St. Johns River, Florida, during spawning migrations in 2002-2005. The St. Johns River is the southern extent for spawning by blueback herring and provides a unique opportunity to examine life history for the species where it does not co-exist with alewife. Blueback herring were collected in the St. Johns River from January to April and histological examination of gonads suggested that most spawning occurred from February to April, especially in April. The spawning period for blueback herring was generally later than that for hickory shad *A. mediocris*, and was similar to that for American shad *A. sapidissima*. Some gravid females were collected almost 400 rkm from the river mouth. Specific spawning sites were not identified, but our data suggest that spawning may occur at multiple sites in the river. Like other alosines, blueback herring appear to be batch spawners and may spawn batches of eggs every 3-4 days during the spawning period. There was no evidence of declining body condition during the spawning period and blueback herring appeared to actively feed in freshwater during daylight hours.

Comparisons between recent collections (ours in 2002-2005 and more recent collections by A. Reid Hyle, personal communication) and data from the 1970s collected by Williams et al. (1975), potentially suggest population decline. Both male and female adult blueback herring are now smaller than they were historically, although the sex ratio is generally similar between decades and not different from 1:1 in most years. Recent juvenile surveys in the St. Johns River suggest that blueback herring juveniles are much rarer than American shad juveniles.

A Spatially-Explicit Model of Anadromous Alosine Hotspots at Sea

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Significance

Since the early 1990s, little attention has focused on understanding river herring (alewife, *Alosa pseudoharengus*, and blueback herring, *Alosa aestivalis*) coastwide distributions at sea. Improved understanding of these distribution patterns can provide a baseline to inform the development of potential management strategies to reduce oceanic bycatch of river herring and to compare to suspected distributions under future climate and environmental conditions. The objective of this research is to develop a detailed and dynamic model that captures spatial and seasonal differences in the relative abundance of river herring. Here, we present a spatially and temporally-explicit model to identify river herring "hotspots" at sea.

Data Sources and Selection

Data includes National Marine Fisheries Science (NMFS) bottom-trawl survey tows from winter (1964-2007), spring (1968-2008), summer (1948-1995), and fall (1963-2008) surveys, for a total of 30,427 tows. All surveys overlapped the US Eastern Continental Shelf, with the exception of the winter survey covering predominantly Georges Bank and the Mid-Atlantic. Attributes from individual survey tows consist of survey station characteristics (unique tow identifier, year, season, starting latitude, and starting longitude) and biological sampling data (presence/absence of river herring and the catch of river herring as the number of individuals, thus combining alewife and blueback herring data). We treated seasonal surveys separately in the analysis, pooling all years within a seasonal survey.

Methods

To identify river herring hotspot areas, we conducted analyses using winter, spring, summer, and fall survey tows aggregated by quarter degree squares (QDS). QDS are approximately 30 nautical miles on each side. We retained only those QDS with at least 11 tows per square. Our chosen aggregation balanced having sufficient data for analysis while maintaining a representative spatial unit.

We determined seasonal river herring hotspots by developing an algorithm to select QDS with relatively high percent occurrence and catch of river herring. Thus, identified QDS provide information on the relative likelihood of encountering river herring. Within each QDS, we defined percent occurrence as the count of tows with river herring present divided by the total tows, and we calculated summary statistics, the mean, median, and 75th quantile of river herring catch. We ranked QDS by these two variables and omitted QDS with no river herring catch from the analysis. We then selected hotspots as the intersection of the set of QDS above a selected quantile for percent occurrence and set of QDS above a selected quantile of a summary statistic for river herring. We identified QDS as river herring hotspots using three approaches: 1) mean approach: percent occurrence and mean catch ≥ the 75th quantiles of both variables, 2) median approach: percent occurrence and median catch ≥ the 75th quantiles of both variables, and 3) 75th quantile approach: percent occurrence and catch ≥ the 75th quantiles of both variables. We generated maps with three hotspot configurations for each season. For all twelve hotspot configurations, we provided summary statistics by QDS and demonstrated how QDS were selected in bi-variable (percent occurrence and catch) plots.

Results

In general, each of the identification approaches produced slightly different river herring hotspot configurations, with substantial overlap within a season for the three approaches. The median approach consistently identified the greatest number of QDS as river herring hotspot areas for each season, followed by the 75th and mean approaches. Recognizing that spatial coverage varies by season especially in the winter survey, the order of QDS identified as river herring hotspots by season was spring, fall, summer, and then winter. In general, patterns of seasonal river herring hotspot areas reflected river herring at sea migratory patterns, traveling south to north from winter through fall, presumably due to temperature fluctuations and food availability, and then returning south to overwinter. More specifically winter river herring hotspots included QDS in Southern New England waters and in the Northern Mid-Atlantic Bight. Spring river herring hotspots included QDS throughout the study area with the exception of Georges Bank. Summer river herring hotspots roughly followed the 100 m bathymetric contour, from Southern New England waters northward to the waters of Downeast Maine. Fall river herring hotspots were nearly exclusively north of Cape Cod with two exceptions in Southern New England Waters.

A Bayesian habitat suitability model: A technique developed for American shad could be used to examine potential impacts of climate change on river herring spawning habitat

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Paper:

Hightower, J. E., J. E. Harris, J. K. Raabe, P. Brownell, and C. A. Drew. *In Press.* A Bayesian habitat suitability model for spawning American shad in southeastern United States rivers. Journal of Fish and Wildlife Management 3(2):xx-xx. (Online early at http://fwspubs.org/doi/pdf/10.3996/082011-JFWM-047)

Talk Summary:

We developed updated habitat suitability index models for spawning American shad *Alosa sapdissima*, including data from multiple rivers and input from experts, using Bayesian methods. We surveyed biologists to identify main spawning sites in rivers along the Atlantic coast to examine potential factors that could affect spawning at a landscape scale. We also obtained data on environmental variables and the presence or absence of American shad eggs or spawning splashes to examine potential factors that could affect spawning at a microhabitat scale. We held a meeting of American shad experts to discuss the available data and to decide which environmental variables were important to include in the model. We evaluated those selected variables using data from multiple rivers in a Bayesian framework. Bayesian methods can include information from previous studies along with new data to generate results, allowing results to be useful for current management, as well as to be incorporated into future research as more data are collected. We included temperature, water velocity, water depth, and substrate in the final model for identifying suitability of riverine habitat for spawning American shad.

A similar modeling process could be used to update habitat suitability models for both blueback herring *A. aestivalis* and alewife *A. pseudoharengus*. This process could be used to develop models that are entirely data-driven and include information from multiple systems, but also include expert opinion to select the important environmental variables (for each life stage) and the types of studies to include; thus, conclusions could be based on the strengths of both strategies and the knowledge of all people involved. Clear understanding of habitat suitability for each species as well as potential changes to selected habitats as a function of climate change (potential shifts in temperature and discharge rates, for example) would be important. By integrating models with both types of information, the potential impacts of climate change on specific populations as well as ecosystems as a whole, could be better evaluated.

Ocean River Herring Studies Relevant to Assessing Climate Change Impacts

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Cooperative Winter Tagging Cruise: The Cooperative Winter Tagging Cruises (Cruises) were conducted from 1988 through 2010, by the Atlantic States Marine Fisheries Commission (ASMFC), Maryland Department of Natural Resources-Fisheries Service, National Oceanic and Atmospheric Administration, North Carolina Division of Marine Fisheries and U.S. Fish and Wildlife Service, along with other partners, primarily as a monitoring component of the ASMFC Atlantic sturgeon and striped bass Fishery Management Plans. The Cruises have taken place in the nearshore Atlantic Ocean off North Carolina and Virginia. In many years, the locations of river herring capture were noted (USFWS, South Atlantic Fish and Wildlife Conservation Office, unpublished data). During the 2005-2007 Cruises, specimens were collected and retained for diet analysis in collaboration with the Virginia Institute of Marine Sciences (see Parthree 2005). In the last three historic Cruise years (2008, 2009 and 2010; ECU and USFWS, unpublished data), river herring specimens were retained and otoliths (about 400 pairs for 2008-1010), along with scale samples, archived at East Carolina University. Taken collectively, these data enable documentation of the winter distribution of river herring and may form a basis for comparison to observed changes in distribution as documented during future Cruises. Funding has been secured for a 2013 Cruise from the North Carolina Coastal Recreational Fishing License grant program, and funding will be available for Cruises in 2014 and 2015, pending securing matching funds. During the 2013 Cruise, all river herring collected will be retained for analysis, and tissue will be provided for genetic analysis to researchers at Duke University (RWL personal communication with E. Palcovics, DUML).

Bay of Fundy Anadromous Studies: Rulifson (1984) and Rulifson et al. (1987) tagged and released alewife and blueback herring in Cobequid Bay and Minas Basin, two upper regions of the Bay of Fundy, in 1983 (3,584 fish), 1985 (13,429 fish) and 1986 (1,946 fish). The ocean circulation patterns of the upper Bay likely contribute to the pattern of migration observed in the commercial weirs; the pattern resembles that of American shad. Tag returns showed that alewives were of Canadian and New England origin (Massachusetts). Blueback herring were returned from as far south as North Carolina. Anatomical characteristics (Stone 1985; Rulifson et al. 1987) indicated that both species present in 1985 were of heterogeneous origin. Both species contribute to the marine fisheries (LeBlanc and Chaput 1991), but blueback herring were not involved in the freshwater fisheries. River herring are capable of migrating long distances (over 2,000 km) in ocean waters of the Atlantic seaboard.

References

Harris, R.J. and R.A. Rulifson. 1989. Investigations of ocean landings for American shad and river herring from United States East Coast waters. Completion Report to Atlantic States Marine Fisheries Commission, ICMR Technical Report 90-02, East Carolina University. 99 p.

LeBlanc, C.H. and G.J. Chaput. 1991. Landings of estuarine fishes in the Gulf of St. Lawrence 1917-1988. Canadian Data Report of Fisheries and Aquatic Sciences No. 842, fisheries and Oceans Canada, Moncton, new Brunswick.

Parthree, D.J. 2005. Diet analysis of some pelagic predatory and filter feeding fishes of the nearshore northern North Carolina and southern Virginia coasts, winter 2005. Chesapeake Bay Trophic Interactions Laboratory Services, Virginia Institute of Marine Sciences, College of William and Mary, Gloucester, Virginia. 11 pp. + tables.

Rulifson, R.A. 1984. Tagging studies of river herring (*Alosa aestivalis* and *A. pseudoharengus*) in Bay of Fundy, Nova Scotia. Report to NC Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City, NC.

Rulifson, R.A., S.A. McKenna, and M. L. Gallagher. 1987. Tagging studies of striped bass and river herring in Upper Bay of Fundy, Nova Scotia. Completion Report for Project AFS-28-1 (as amended) for NC Department of Natural Resources and Community Development, Division of Marine Fisheries, Morehead City, NC. 175 p.

Stone, H.H. 1985. Composition, morphometric characteristics and feeding ecology of alewives (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*) (Pisces: Clupeidae) in Minas Basin. MSc thesis, Acadia University, Wolfville, Nova Scotia.

Otoliths as natural tags of river herring provenance and climate change impacts

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Summary: Otoliths, small calcified structures that form part of the hearing and balance system in teleost fishes, grow incrementally and thus generate temporal records of age and growth. Over the past several decades, interest about their chemical constituents has grown, as researchers explore and interpret these chemistries as potential "natural tags." A suite of roughly 30-40 trace and minor elements are known to be taken up by otolith incrementation, as well as perhaps half a dozen isotope ratios. All require sensitive instrumentation to measure, and there is no "universal" analytical method that will cover all analytes. Furthermore, work is in progress to understand the influence of both internal (e.g., growth, genetics) and external (e.g. temperature, salinity) factors influencing uptake.

In general, the trace elements barium and strontium are taken up in proportion to ambient concentrations relative to calcium in the water, although temperature may affect the uptake. Oxygen isotopes are taken up in proportion to ambient concentrations, and because this is related to climate, oxygen isotopic ratios (delta ^{18}O) may serve as "internal thermometers" if salinity is known. Strontium isotope ratios ($^{87/86}$Sr) may serve as salinity markers, because the $^{87/86}$Sr signature of modern seawater is constant.

Manganese to calcium ratios (Mn:Ca) in otoliths has been shown to correlate with intensity of hypoxia events (Limburg et al. 2011, *PNAS 108 (22) 8931–8931*). Unpublished evidence suggests that growth is also a mediating factor. Most elements are taken up in dissolved form; for manganese this is the reduced form Mn^{2+}, which becomes available when dissolved oxygen declines to hypoxic conditions. As a climate change tool, it can be useful to track an important effect of climate warming together with nutrient loading, as both are increasing.

In the context of river herring, we are developing a "geochemical atlas" of otolith chemistries of the coastwide populations, in conjunction with a genetic analysis (preliminary data were reported at the first ESA workshop on river herring stock discrimination). When combined with age and growth analysis, these data will be able to illuminate many early life history properties, such as age (in days) at first emigration to the sea, size of same, hypoxia exposure, and thermal history in the nursery habitat. Sea experiences may be more difficult to discriminate at this point, but thermal records may be possible. The small size of river herring otoliths provides challenges to obtain high-resolution data in the adult phase, but newer technologies hold promise of being able to do this.

Provided by Dr. Eric Schultz, UCONN, who was invited to the workshop but was unable to participate. This information was provided in his absence to inform the workshop discussions.

River Herring Climate Change Workshop
Summary of University of Connecticut research on river herring life history relevant to climate change effects

Life history features influencing responses to climate change: migration timing

Juvenile migration timing. Pulses of outmigration of alewife juveniles from Bride Lake, a coastal pond in Connecticut, were associated with precipitation events, transient decreases in water temperature, and transient increases in stream discharge (fig. below right, Gahagan et al. 2010 Trans Am Fish Soc 139: 1069–1082). Individuals that hatch early and/or grow rapidly migrate at a younger age. In both river herring species, migration at a younger age is associated with larger size-at-age and higher fecundity at maturation (Gahagan, unpubl. data). Outflows from some coastal ponds (e.g. Bride Lake) dry up during some summers (Gahagan et al 2010), preventing the outmigration of alewife juveniles and potentially reducing their growth and probability of survival. Changes in climate, combined with changes in land and water use patterns, are likely to have pronounced and complex effects on juvenile prospects. *Adult migration timing*. Using contemporary and historic data on the temperature-dependence of adult migration timing, Ellis and Vokoun (fig. center, 2009 N Am J Fish Mngmnt 29: 1584-1589) estimate that alewife run timing has shifted 12-13 days earlier over three decades.

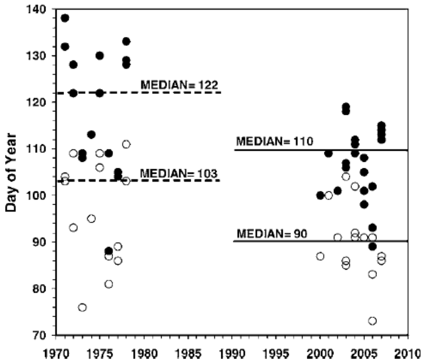


FIGURE 2.—First day of year at which each site reached 9°C (open circles) and 13°C (filled circle). The dashed lines show the medians of the historical data and the solid lines the medians of recent data.

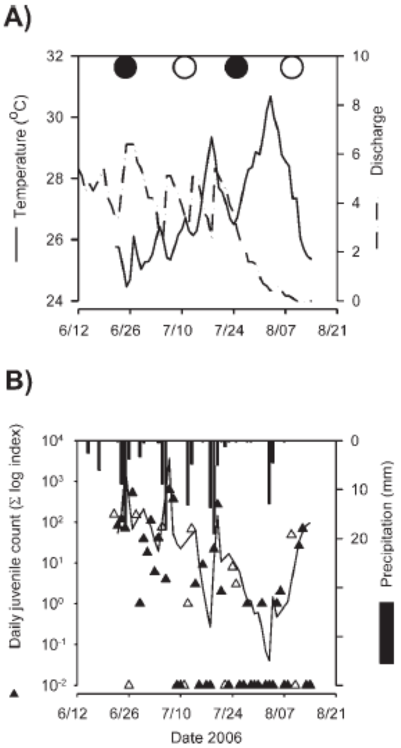


FIGURE 2.—Seasonal timing of juvenile alewife migration in Bride Lake, Connecticut, and associated environmental variables during 2006: (A) daily values of temperature (°C) and stream discharge (ft^3s^{-1}), with moon phases represented along the top (solid circles = new moon; open circles = full moon); and (B) daily migration rate (solid triangles; ordinal scale of 0–5, with values of 0 plotted as 0.01; see Methods) for each date of the video record (open triangles represent data that were discarded because the video record on these dates was incomplete). Temporal migration pattern predicted by the best regression model (including two predictors: temperature and the previous day's rainfall) is represented by the solid line in (B); precipitation (mm) is represented by vertical bars. Date on both x-axes is month/day.

Features influencing vulnerability to perturbations: population structure

Relative to their demography in the 1960s, the breeding populations of both alewives and blueback herring are younger and more semelparous (table to right representing data for alewives, Davis and Schultz 2009 Mar Coast Fish 1: 90-106, data for blueback herring, Davis unpubl.). Such changes indicate a reduction in population viability. Some local populations consist mostly of breeding adults returning to their natal site to spawn (Gahagan et al. 2012 Mar Coast Fish 4: 358-372). This suggests that connectivity among breeding populations may be limited and if a local population is depleted its recovery may be slow.

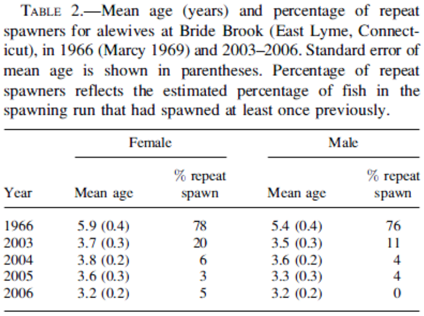


TABLE 2.—Mean age (years) and percentage of repeat spawners for alewives at Bride Brook (East Lyme, Connecticut), in 1966 (Marcy 1969) and 2003–2006. Standard error of mean age is shown in parentheses. Percentage of repeat spawners reflects the estimated percentage of fish in the spawning run that had spawned at least once previously.

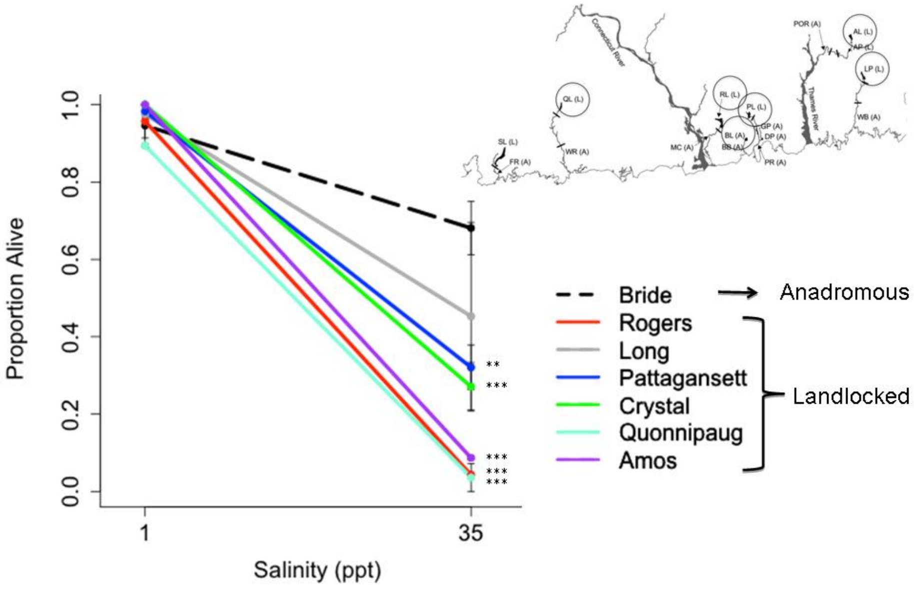
	Female		Male	
Year	Mean age	% repeat spawn	Mean age	% repeat spawn
1966	5.9 (0.4)	78	5.4 (0.4)	76
2003	3.7 (0.3)	20	3.5 (0.3)	11
2004	3.8 (0.2)	6	3.6 (0.2)	4
2005	3.6 (0.3)	3	3.3 (0.3)	4
2006	3.2 (0.2)	5	3.2 (0.2)	0

Provided by Dr. Eric Schultz, UCONN, who was invited to the workshop but was unable to participate. This information was provided after the workshop.

Salinity tolerance of anadromous and landlocked alewives

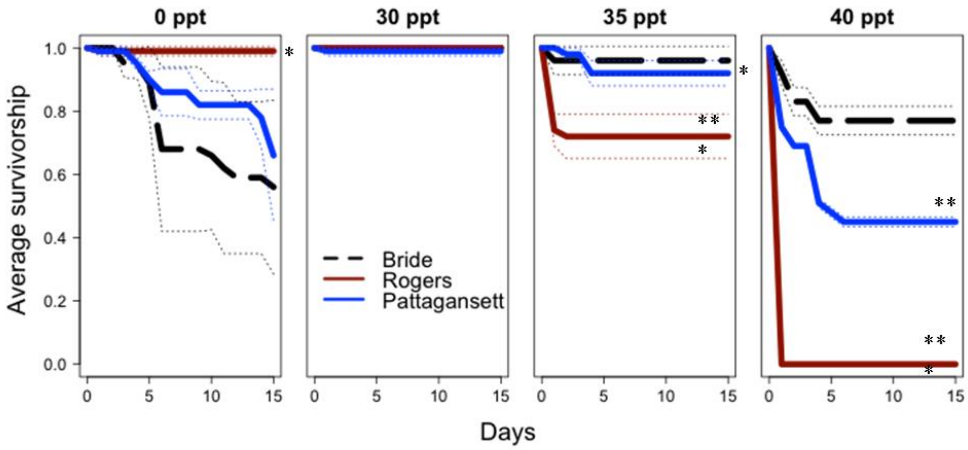
Jon Velotta, Eric Schultz, University of Connecticut; Steve McCormick, USGS

Juvenile alewives were captured from six landlocked and one anadromous location in CT during summer and autumn and subjected to FW and SW for 24 hours. Anadromous fish are more tolerant of ocean-level salinity than landlocked fish (see figure). We have linked this to osmoregulatory performance, the abundance of proteins that function in osmoregulation in the gills, and the expression of osmoregulatory genes in gill tissue.



Generalized linear model, ** p < 0.001, *** p < 0.0001, compared to Bride Lake

Juvenile alewives from two of these landlocked locations and the anadromous location were transported to the lab in October and acclimated for 1 month, then tested for two weeks at multiple salinity levels.



At 0 ppt, survival was highest in alewives from Rogers Lake (landlocked), while at 30 ppt there was no difference in survival

At 35 ppt and 40 ppt survival was lowest among landlocked sites

FW and SW tolerance differ among landlocked sites