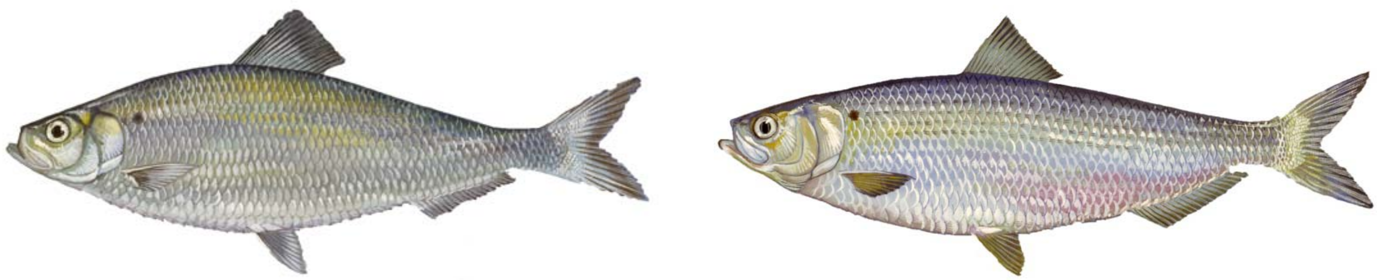
RIVER HERRING STOCK STRUCTURE WORKING GROUP REPORT

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



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

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River Herring Working Group
Stock Structure in Alewives and Blueback Herring

June 20-22, 2012

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Introduction

The Natural Resources Defense Council (NRDC) petitioned the National Marine Fisheries Service (NMFS) in August 2011 to list both alewives and blueback herring as threatened throughout their range. In November 2011, NMFS issued a positive 90 day finding indicating that the NRDC petitioned action may be warranted. As part of the required status review of alewives and blueback herring, NMFS identified stock structure as a data gap for both alewives and blueback herring and convened a working group of experts to gather the best available science on information related to potential stock structure. Information collected on stock structure of each species will be considered in the decision as to whether listing these species is warranted under the Endangered Species Act.

NMFS will use the information from the stock structure workshop to assess whether there are discrete and significant populations of alewives or blueback herring that might warrant separate protections under the ESA's Distinct Population Segment (DPS) policy. Upon applying the DPS policy, the evidence gathered at the stock structure workshop will help NMFS make an informed decision on whether the stock structure can adequately be protected as a single unit or, whether one or more distinct population segments are necessary to best protect certain stocks of alewives or bluebacks that represent a discrete and significant unit to the taxon as a whole.

Workshop Description

To obtain expert opinion about anadromous alewife (*Alosa pseudoharengus)* and blueback herring (*Alosa aestivalis)* stock structure, NMFS convened a working group in Gloucester, MA on June 20-21, 2012. This working group meeting brought together river herring experts from state and federal fisheries management agencies and academic institutions.

Participants presented information to inform the presence or absence of stock structure such as genetics, life history, and morphometrics. A summary of the working group was presented at a public workshop on June 22, 2012, and information on stock structure was sought from the public at this workshop.

Overview

The working group meeting was dedicated to individual expert presentations of evidence of stock structure which ranged from marine bycatch, run timing, run counts, Atlantic coast-wide genetics, finer scale genetic comparisons between the state of Maine and Canada, stocking history, length–at-age, etc. The group also sought out specific information from Dr. Roger Rulifson (East Carolina University, Greenville, NC) regarding a tagging study of river herring conducted in the early 1980's in conjunction with Dr. Mike Dadswell (Acadia University, Wolfville, NS., Ca.). During the second part of the working group meeting, the group reviewed and discussed the presented evidence regarding potential stock structure for both species and generated several stock structure hypotheses for alewife and blueback herring throughout their entire range. Subsequently, the group highlighted five potential stock structure hypotheses for both alewives and blueback herring.

For alewives, the stock structure hypotheses included: 1) a single stock complex; 2) a four stock complex as identified by the NRDC petition; 3) a four stock complex based on known natural geographic breaks (Cape Cod, Cape Hatteras) and management differences (U.S. and Canada); 4) a six stock complex based on genetics, and; 5) an individual river stock complex that would include hundreds of individual stocks throughout the range of the species.

For blueback herring, five stock structure hypotheses included: 1) a single stock complex; 2) a three stock complex as identified by the NRDC petition; 3) a four stock complex based on known natural geographic breaks (Cape Cod and Cape Hatteras) and management differences (U.S. and Canada); 4) a four stock complex based on genetics; and 5) an individual river stock complex that would include hundreds of individual stocks throughout the range of the species.

To assess the strengths and weaknesses of each hypothesis, the panel considered available data such as genetics, evidence of morphological or physiological differences, tagging studies, evidence of straying and homing, growth rates, run timing and abundance. The panel discussed their individual expert opinions for each factor and identified information that supports or rejects the hypotheses or noted when there was insufficient evidence to either support or reject the hypothesis.

While the work-group reviewed a large amount of information on river herring during the 2.5-day meeting, this report focuses primarily on the data presented that helps inform the question of stock structure. During the workshop we heard presentations of evidence that may suggest stock structure of alewives and blueback herring from, Steve Gephard (Connecticut Department of Energy and Environmental Protection), Dr. Theo Willis (University of Southern Maine, Alewife Harvesters of Maine), Dr. Michael Armstrong (Massachusetts Department of Marine Fisheries), Dr. Matt Cieri (Maine Department of Marine Resources), Kevin Sullivan (New Hampshire Fish and Game), and Dr. Adrian Jordaan (State University of New York-Stony Brook). This paper reviews those presentations and the discussions of stock structure that followed them.

Furthermore, the working group heard several presentations in respect to the status of river herring stocks in the U.S., and NMFS Policy, which have not been reviewed in this report but have been provided as supplemental information. The work-group heard presentations from Dr. Katie Drew (Atlantic States Marine Fisheries Commission) who summarized the recent

ASMFC River Herring Stock Status Report ; Marta Nammack (NMFS' National ESA Listing Coordinator) who presented on DPS Policy; Dr. John Kocik (NMFS, Population Dynamics) who provided an overview of how the DPS Policy has been applied in various ways for different species; and Tara Trinko Lake (NMFS) who presented on the river herring petition and NMFS' response to the petition.

The main objectives given to the group were: 1) determine whether there is evidence of stock structure for alewife and blueback herring; and 2) provide NMFS with an individual expert opinion on the extent (if any) of stock structure for alewife and blueback herring.

Evidence Presented Related to Stock Structure of Blueback Herring and Alewives

Genetics

Steve Gephard (Connecticut Department of Energy and Environmental Protection)

Gephard presented a preliminary U.S. coast-wide genetic analysis of alewife and blueback herring data (Palkovacs *et al.* 2012, unpublished data). Their study goals were: 1) explore genetic divergence among spawning runs of alewife and blueback herring; 2) identify higher-level population structure indicative of genetically distinct spawning stocks of both species at a larger geographic scale; and, 3) analyze the overall effect of geography (in this case latitude) on patterns of genetic divergence among spawning runs of both species. Palkovacs *et al.* (2012) employed 15 novel microsatellite markers on samples collected from Maine to Florida. For alewife, 778 samples were collected from spawning runs in 15 different rivers and 1,201 blueback herring samples were collected from 20 rivers (Table 1). Evidence of departure from Hardy-Weinberg Equilibrium (HWE) was detected at four loci in alewives and no substantial Linkage Disequlibrium (LD). For blueback herring, there was no evidence of departures from HWE, but there was evidence of LD in samples collected from the St. George River population located in Maine.

To assess genetic differentiation among spawning runs, they computed a pairwise fixation index (Fst) according to Weir and Cockerham (1984) using the program FSTAT (Goudet 2001) and controlled for variation in genetic diversity on population differentiation by calculating standard pairwise estimates of differentiation (F'_{ST}) following Hendrick (2005). Higher level population structure was determined using Bayesian clustering in STRUCTURE (Pritchard *et al*. 2000; Falush *et al.* 2003) and BAPS v 5.1 (Corander *et al.* 2006).

Bayesian analyses identified five genetically distinguishable stocks for alewife with similar results using both STRUCTURE and BAPS (Figure 1). The alewife stock complexes identified were: 1) Northern New England; 2) Southern New England; 3) Connecticut River; 4) Mid-Atlantic, and; 5) North Carolina. For blueback herring, no optimum solution was reached using STRUCTURE, while BAPS suggested four genetically identifiable stock complexes (Figure 2). The stock complexes identified for blueback herring were: 1) Northern New England; 2) Southern New England; 3) Mid Atlantic; 4) and Southern. However, it should be noted that these Bayesian inferences of population structure provide a minimum number of genetically distinguishable groups. Further tests examining structure within designated stocks should be conducted using hierarchical clustering analysis and genic tests.

The study also examined the effects of geography and found a strong effect of latitude on genetic divergence, suggesting a stepping stone model of population structure, and a strong pattern of isolation by distance, where gene flow is most likely among neighboring spawning populations. The effect was strongest in alewife, where latitude explained 92% of the variation in axis 1 scores of genetic distance among populations examined using Principle Component

Analysis (PCoA). Axis 1 itself explained 77% of the total variation in genetic distance among populations. In blueback herring, latitude explained 85% of the variation in PCoA axis 1 scores (which itself explained 55% of the total variation in genetic distance among populations). The preliminary results from the study found significant differentiation (F'_{ST}) among spawning rivers for both alewife and blueback herring. Based on the results of their study, the authors' preliminary management recommendations suggest that river drainage is the appropriate level of management for both of the species. This inference is also supported by genic tests, which were not examined at the time that the initial analysis was conducted. These tests have since been conducted for alewife, and suggest that there is substantial population structure at the drainage scale.

The authors noted a number of caveats for their study including: 1) collection of specimens on their upstream spawning run may pool samples from what are truly distinct spawning populations within the major river drainages sampled; thereby, underestimating genetic structure within rivers (Hasselman, 2010), 2) a more detailed analysis of population structure within the major stocks identified here (i.e., using hierarchical Bayesian clustering methods and genic test), would be useful for identifying any substructure within these major stocks, 3) neutral genetic markers used in this study represent the effects of gene flow and historical population isolation, but not the effects of adaptive processes, which are important to consider in the context of stock identification, 4) the analysis is preliminary, and there are a number of issues that need to be further investigated, including the effect of deviations in HWE encountered in four alewife loci and the failure of STRUCTURE to perform well on the blueback herring dataset, and, 5) hybridization may be occurring between alewife and blueback herring and may influence the results of the species-specific analyses.

Dr. Theo Willis (University of Southern Maine, Alewife Harvesters of Maine)

Bentzen *et al*. (2012) (presented by T. Willis) implemented a two part genetic analysis of river herring to evaluate the genetic diversity of alewives in Maine and Maritime Canada, and to assess the regional effects of stocking on alewives and blueback herring in Maine. For part 1 of the study, alewife and blueback herring genetic samples (n=881) from 15 different sites throughout mid-coast Maine were genotyped using 10 microsatellite markers. For Part 2 of the study, over 2,000 alewife samples from Maine and Atlantic Canada were genotyped using 14 microsatellite markers. The genetic analysis of alewives and blueback herring along mid-coast Maine revealed significant genetic differentiation among populations. Despite significant differentiation, the patterns of correlation did not closely correspond with geography or drainage affiliation (Figure 3). The genetic analysis of alewives from rivers in Maine and Atlantic Canada detected Isolation by Distance (IBD), suggesting that homing behavior indicative of alewives' metapopulation conformance does produce genetically distinguishable populations. Using PCoA F_{ST} values, Bentzen *et al.* (2012) identified four possible groupings based on genetic similarities between sites (Figure 4). These groupings include Cape Breton , Nova Scotia(3 populations), Gulf of St. Lawrence (9 populations), East Shore of Nova Scotia (8 populations), Bay of Fundy (3 populations), and Maine (13 populations). A STRUCTURE Bayesian Assignment Test further suggests that there may be interbreeding between alewives and blueback herring, especially at sample sites with impassible dams (Figure 5).

Willis explained that the unusual genetic groupings of river herring in Maine are likely a result of Maine's complex stocking history. He went on to explain that alewife populations in Maine have been subject to considerable within and out of basin stocking for the purpose of enhancement, recolonization of extirpated populations, and stock introduction. Alewife stocking in Maine dates back at least to 1803 when alewives were reportedly moved from the Pemaquid and St. George Rivers to create a run of alewives in the Damariscotta River (Atkins and Goode, 1887). These efforts were largely responsive to considerable declines in alewife populations following the construction of dams, over exploitation and pollution. Although there has been considerable alewife stocking and relocation throughout Maine, there are very few records documenting these efforts. In contrast, considerably less stocking of alewives has occurred in Maritime Canada.

<u>Morphological/Physiological</u>

Willis (2012, unpublished data) attempted to classify alewife populations in Maine and one population in Massachusetts using geometric morphometrics and analysis of otolith shape. Preliminary otolith shape results correctly classified all populations that were sampled 70-90% of the time. Overall, morphometrics correctly classified Eastern Maine from Western Maine, and Western Maine from Massachusetts 58% of the time. For the alewife population in Massachusetts, morphometric and otolith analysis correctly classified the population 100% and 90% of the time, respectively. Though the work is preliminary, Willis (2012) indicated that there appears to be some promise in using otoliths to classify populations, but at this point, geometric morphometrics appear less useful.

<u>Dr. Roger Rulifson (East Carolina University)</u>

Rulifson *et al.* (2012) examined growth and survival of river herring in comparison with Strategic Habitat Areas (SHA's) set aside to protect river herring spawning and nursery habitat. Juvenile river herring length and growth data, and adult and juvenile otolith microchemistry were used in combination to assess effective river herring nursery habitats. Both blueback herring and alewives were analyzed in the study. Evaluation of the otolith microchemistry showed no statistical difference between alewives and blueback herring, so the samples were pooled when used to classify juvenile herring back to SHA's. Otolith analysis of trace metals (Magnesium, Manganese, Strontium, and Barium) served as an elemental fingerprint to classify juvenile herring river-of-origin with 75-100% accuracy.

Rulifson *et al.* (2012) reported estimate homing rates of 0-64% for blueback herring in three North Carolina Rivers. Preliminary results estimate over 64% blueback site fidelity back to the Chowan River, 28.6% to the Perquimans River, and 0% to the Scuppernog River. Among the strays, there is some evidence to suggest that older fish tended to stray more than younger fish, though it is not conclusive. Rulifson *et al.* (2012) suggests that the variability in straying rates may be a function of survival differences between the rivers, or fish from these locations are spawning in other locations. Linking growth rates to straying rates indicates that areas with poor growth have lower return rates of natal adults.

Dr. Mike Armstrong (Massachusetts Department of Marine Fisheries)

Armstrong presented data primarily on alewives in Massachusetts rivers. He showed differences in alewife length-at-age in four rivers: the Nemasket, Town Brook, Monument, and the Mystic, which are listed from north to south respectively. The Nemasket had returning alewives that were consistently greater length-at-age than rivers to the north, and the trend continued with latitude for the other three rivers (Figure 6). Armstrong presented data from the 2007 ASMFC River Herring Stock Assessment showing cluster analysis results of New England rivers in CT, MA,NH, ME (Figure 7). Run counts do not appear to cluster together.

Additionally, a recent paper by Gahagan *et al.* (2012) was submitted to the group as evidence of stock structure in alewife and blueback herring populations. Gahagan *et al.* (2012) examined the use of otolith microchemistry for characterizing river of origin for alewife and blueback herring in the Connecticut River. Ten sites were sampled for juvenile and adult fish along with water chemistry in 2008 and 2009. Reclassification for juvenile alewives to natal rivers ranged from (50-100%) with adult alewives ranging from 10-85%. Reclassification for adult blueback herring to natal rivers ranged from (15-81%). This approach may be more appropriate as a tool for regional scale classification, as similar water chemistry in the sampled streams within the Connecticut River drainage potentially affected the ability to discern between runs.

Behavior/Life History

Kevin Sullivan (New Hampshire Fish and Game)

Sullivan presented data on river herring returns to six rivers along New Hampshires16 kilometer coastline. All rivers except the Taylor River empty into the Great Bay Estuary of the Piscatiqua River. In the case of the Exeter River and the Lamprey River, only 900 meters separate the two river mouths. In New Hampshire, all river herring are managed the same and no recreational or commercial harvest occurs within New Hampshire waters.

Sullivan reviewed the annual spawning run estimates for the six New Hampshire Rivers and noted that there is no noticeable consistency between populations (Figures 8 and 9). The Oyster and Taylor rivers historically had the largest reported river herring runs, with estimates exceeding 150,000 in1991 and 1992 and 350,000 in 1979 and 1980. Sullivan also noted that the Cocheco, Lamprey and Exeter rivers have historically been mixed-stock runs dominated by alewives; whereas blueback herring, historically dominated the Oyster River. During recent sampling efforts in the Cocheco, Lamprey, and Exeter rivers, no blueback herring have been observed. For the Oyster River, Sullivan notes that even though blueback herring still dominate the run, the slight increase in the proportion of alewives to blueback herring is a result of significant decreases in blueback herring returns, more so than an increase in alewife returns (Figure 10 and 11).

Sullivan noted the independent return response between the alewife dominated rivers (Cocheco, Lamprey, and Exeter) calling particular attention to the Cocheco River and the Lamprey River (Figure 12). Although both rivers have averaged 40,000 returns since the beginning of the time series (1985), there is a considerable variation between the runs on an annual basis. Most notable is the 2012 return data which reveals that the Cocheco River experienced a slight decline in run size from 40,000 to 30,000; whereas, the Lamprey River saw its largest return on record with more than a two fold increase in returns (~40,000 to more than 80,000). In respect to the two blueback herring dominated rivers (Taylor River and Oyster River), though both had runs that once exceeded 100,000 returns as recently as 1993, both have seen sharp declines throughout most of their time series, to the point of near extirpation (Figure 13).

Marine Migration

Dr. Matt Cieri (Maine Department of Marine Resources)

NMFS Bottom Trawl Survey

Cieri presented an analysis of the NMFS bottom trawl survey data (1968 – 2008 NMFS Bottom Trawl Surveys) to denote seasonal population clusters of river herring along the East Coast of the U.S. (N. Carolina to Maine). The spring trawl survey indicates that river herring are widespread across the extent of the survey area. Highest river herring occurrence during the spring are off Maine's Downeast coast and areas offshore, near Cape Ann and Cape Cod in Massachusetts, and a large area between Block Island, Rhode Island, and Long Island Sound (Figure 14). During the summer (1948 – 1995 NMFS Bottom Trawl Survey), river herring occur less frequently across the survey area, with most herring showing up along the New England coast north of Rhode Island, and the highest occurrences of river herring showing up off Downeast, Maine and south of Cape Cod, Massachusetts (Figure 15). During the fall survey (1963 – 2008 NMFS bottom trawl surveys), the occurrence of river herring shifts northward with highest occurrences north of Cape Cod, along the Maine Coast to the Bay of Fundy and another cluster off the eastern shore of Nova Scotia (Figure 16).

Maine/New Hampshire Inshore Survey

Cieri presented on the Maine and New Hampshire inshore trawl survey data reviewing fall and spring length data for alewives and blueback herring, and seasonal spatial occurrence of alewives and blueback herring for two different trawl periods along the Maine coast. Alewife length in the spring most frequently ranges from 7 to 13 cm, while in the fall, lengths most frequently range from 10 to 15 cm (Figure 17). Blueback herring length in the spring most frequently range between 10 – 15 cm, while in the fall they most frequently range between 18 and 24 cm (Figure 18).

With respect to seasonal spatial occurrence, Cieri identified alewives as being the most dominant species in the Maine/New Hampshire trawl surveys. During the fall 2000 – 2006 surveys, the Casco Bay region has the largest aggregation of alewives (Figure 19). The fall 2007 – 2011 trawl survey is similar to the 2000 – 2006 survey although more fish appear in the Penobscot Bay region, which Cieri noted could be the result of sampling stratification (Figure 20). Cieri also noted that in the Maine/New Hampshire fall survey there are a lot of early yearclass fish (0's and 1's) found proximate to river mouths – something that has not been observed in southern New England. For both the 2000 – 2006 and 2007 – 2011 fall trawl surveys, blueback herring occur less frequently along the Maine coast than alewives, except for an area clustered around the mouth of the Kennebec River (Figure 21 and 22).

The Maine/New Hampshire spring inshore trawl survey further reveals the broad distribution of alewives along Maine's coast, with areas of highest occurrence in the Casco Bay region. Cieri notes that in the 2001 – 2006 spring trawl survey, there appear to be more fish offshore than in the 2007 – 2011 spring trawl survey.

Bycatch Data

Cieri presented the occurrence of river herring in Atlantic herring fisheries bycatch, bringing attention to the high occurrence of river herring bycatch in the areas of Cape Ann and Cape Cod, Massachusetts during the fall (Figure 23), followed by a shift northward into the Gulf of Maine in the spring (Figure 24). Cieri noted that most of the offshore bycatch constitute adult river herring, whereas age 0 and 1 alewives remain in nearshore coastal waters all year around.

Dr. Adrian Jordaan (State University of New York- Stony Brook)

Jordaan presented on river herring distributions in the marine environment. He presented river herring distribution plots from NMFS trawl surveys (Figure 25) which showed wide distributions throughout the entire Atlantic coast sampling range. The majority of captures during the winter surveys appeared to be below Cape Cod, and during the summer, immature river herring were caught in the Georges Bank area. Further data presented from Jordaan from trawl surveys off of the Long Island coast showed catch per unit effort values for alewives, blueback herring and Atlantic herring were correlated during nine sampling efforts (Figure 26), suggesting that the three species have similar migratory timing and pathways around Long Island. Winter Atlantic herring distribution data from the NMFS trawl survey showed similar patterns to river herring distribution maps, further suggesting similar overwintering areas. However, Cieri noted that the data for the Gulf of Maine from the NMFS winter surveys are lacking because the winter survey did not extend into the Gulf of Maine.

Additionally, Jordaan presented data showing total catch from Georges Bank (Figure 27). While New England landings remained relatively stable during the time-period presented, a peak in total catch (~4x increase) was observed from 1960 to the late 1970s attributed to foreign fishing vessels. A similar pattern of peak landings during this time-period was shown in the Atlantic herring landings data from Georges Bank (Figure 28). Presumably, the bycatch for alewives and blueback herring would also peak during this time of high foreign fishing pressure if the three species exhibited similar distributions on Georges Bank.

Jordaan stressed that there is little research documenting migration patterns of alewives and blueback herring in the ocean and linking these migrations or aggregations to natal rivers. Preliminary data (Jordaan and Kritzer, unpublished data) showed normalized run counts of alewife and blueback herring did correlate with Atlantic herring landings in the Gulf of Maine, leading to speculation that river herring bycatch in the Gulf of Maine may partially explain declines. Jordaan referred to a paper by Stone and Jessop (1992) which identified marine aggregations of alewives off of the Scotian Shelf, especially in the spring and fall, indicating that this may be an important overwintering area for Gulf of Maine alewives (Figure 29). There was also a suggestion from Rulifson's work, and the fact that Maine river counts were not correlated with Atlantic herring landings in the Gulf of Maine, that alewife and blueback migrations are different with alewives tending to have more northerly distributions than blueback herring and potentially using the Nova Scotia wintering area more frequently. He also speculated on potential locations of river herring overwintering areas along the Atlantic coast, but again stressed that these were hypothesized migrations, and mixing in the ocean is still not well understood for these species (but also see Neves, 1981; and Rulifson *et al.* 1987). While the runs of blueback and alewives in Maine have exhibited higher run counts in recent years when compared to other U.S. rivers, Jordaan presented evidence to show that currently accessibility to habitat in Maine is limiting. Research presented showed that only approximately 5% of historical alewife habitat available in 1850 is accessible today (Hall *et al.* 2011, Hall *et al.*, 2012) and these changes may have impacted stock structure.

Rulifson (Ocean Migration)

While not present at the working group meeting, the group spoke with Dr. Roger Rulifson (EastCarolina University) about a tagging study completed from 1985-1986 in the Bay of Fundy (Rulifson *et al.*, 1987). Approximately 19,000 river herring were tagged and released in the upper Bay of Fundy, Nova Scotia with an overall recapture rate of 0.39%. Returned alewife tags were from freshwater locations in Nova Scotia, and marine locations in Nova Scotia and Massachusetts. Blueback herring tag returns were from freshwater locations in Maryland and North Carolina and marine locations in Nova Scotia. The authors suspected from recapture data that alewives and blueback herring tagged in the Bay of Fundy were of different origins, hypothesizing that alewives were likely regional fish from as far away as New England, while the blueback herring recaptures were likely not regional fish, but those of U.S. origin from the mid-Atlantic region. However, the low tag return numbers (n=2) made it difficult to generalize about the natal rivers of blueback herring caught in the Bay of Fundy.

Working Group Discussion

Genetics

- The working group raised questions in respect to how many years and what the sample sizes were for the genetic samples that were gathered? Gephard and Willis were confident that the genetic collections were well representative across year classes, indicating that genetic samples were gathered randomly from populations representing multiple year classes. Willis indicated that for their genetic groups, the sample size was around 25 for each river, representing fish ages three through six. Gephard stated that for the Palkovacs study, the sample size was mostly around 40 samples per river. For the Palkovacs study, scales and otoliths were also collected though they have not yet been analyzed. Members of the working group acknowledged that a longer time series of genetic data and broader spatial representation, especially in respect to the Connecticut River that appears to be an outlier among genetic groups, would be useful.

Morphological/Physiological

- As noted above, Willis presented evidence that otolith shape may be useful as one means of classifying populations. The working group raised questions in respect to otolith shape being a phenotypic response to environmental conditions, and therefore, asked whether it was conceivable that two geographically separate populations that occupy similar habitats types could have similar otolith shape. Willis stated that otolith shape could be similar given similar environmental conditions, and acknowledged that phenotypic studies are often not effective in determining stock structure. Willis explained that he wanted the opportunity to show the differences in otolith shape between herring stocks in Maine and the single herring stock analyzed in Massachusetts.

- Sullivan reported on alewife and blueback herring proportion in New Hampshire rivers that subsequently stimulated questions into their sampling methods. Sullivan noted that they take 450 fish from each river each year to differentiate species. In their surveys, they use field identification, scales, and observation of the peritoneum coloration to identify species.

Behavior/Life History

- The working group took note that stock structure today may be substantially different as a result of habitat loss that began in the 1700's and subsequently shifted the dominant production habitats from large river basins with enormous production capacities to a handful of small coastal watersheds with considerably smaller production capacity. Consequently, there may have been considerable reduction in diversity as well as homogenization of stocks. Gephard raised the question of whether stock structure has changed or whether genetic diversity has changed. He hypothesized that stock structure may, in fact, be very similar to what it was historically, though with considerably less diversity. Jordaan elaborated that there is too much uncertainty to know how a considerable decline in population over time will result in changes in stock-structure.

Marine Migration

- Cieri presented evidence of the marine movements of river herring along the Atlantic coast. The working group suggested that possibly the Northern New England stocks and Southern New England Stocks spend summers and falls in the Gulf of Maine and then migrate off of southern New England in the winter, but may not go as far South as the mid-Atlantic or below. Cieri was not able to confirm or deny this based on the trawl surveys. Armstrong noted that large amounts of river herring bycatch are taken in the area known as the "mudhole" off the New Jersey coast, but acknowledged that the origins of those fish are unknown. Jordaan elaborated on the "mudhole," recognizing the shelf break off the New Jersey Coast which results in high chlorophyll production, that subsequently could boost productivity in the region; thereby, providing a forage base for river herring.

<u>Stock Identification</u>

- The working group acknowledged that historic datasets and even some recent datasets, likely do not accurately distinguish alewives and blueback herring because of the similarities in their appearance. Willis mentioned that the accuracy of some of the old harvest data may not be that inaccurate given that historically, they purposefully selected alewives for curing over blueback herring.

<u>Landlocked alewives</u>

- The working group raised the question as to whether we need to make a decision with respect to landlocked alewives. Damon-Randall stated that while the petition notes that landlocked populations exist, it focuses on the anadromous populations and does not address the landlocked populations specifically. Consequently, given NMFS jurisdiction for marine and anadromous species, NMFS has made the determination that the petition pertains to the anadromous populations. The working group discussed the plasticity of alewives and the ability of anadromous populations to become landlocked and vise versa. The working group also noted how some resource agencies have successfully crossed landlocked populations with anadromous populations to jump start depleted anadromous populations.

Data Gaps

For both alewives and blueback herring, the expert panel identified numerous data deficiencies that would otherwise aid in identifying stock structure. Data deficiencies include:

- Limited information on historic run size, distribution, and trends through time;
- Inconsistencies and uncertainties in the proper identification of alewives and blueback herring in river herring datasets;
- Genetic structure of mixed stocks at sea;
- Information on movements and migrations at sea;
- Longer and finer scale genetic data for returning spawners;
- Otolith microchemistry range wide and at a finer scale;
- Straying rate data;
- Information on hybridization and conditions that contribute to hybridization (e.g. climate change, dams);
- Information on whether the abundance of Atlantic herring differentially affect bluebacks and/or alewives;
- Understanding if fishways inadvertently select for certain phenotypes or certain species;
- Understanding the hatchery effects of stocking on genetic diversity.

Synthesis

The working group assembled several stock structure hypotheses for both blueback herring and alewives following the presentations and discussion of the presentations. Subsequently, the working group evaluated the strengths and weaknesses of each hypothesis based on whether there was sufficient evidence to support the particular stock complex hypothesis. For both blueback herring and alewives, the working group evaluated five stock structure hypotheses:

Alewives

- Single stock complex
- Four stock complexes identified in the petition
- Four stock complexes identified by geographic boundaries (Cape Hatteras and points south, Cape Hatteras to Cape Cod, Cape Cod to U.S./Canada border, Canada)
- Six stock complexes which largely adopts the genetic partitions identified by Palkovacs *et al*. (*Gephard Presentation*) and Willis
- Hundreds of stock complexes representing individual rivers

Bluebacks

- Single stock complex
- Three stock complexes identified by the petition
- Four stock complexes identified by Palkovacs *et al.* (*Gephard Presentation*)
- Four stock complexes identified by geography (*same as alewives*)
- Hundreds of stock complexes representing individual rivers

Single Stock Complex Hypothesis

Evidence in support of a single stock complex:

- The working group discussed the adaptability and marine life history of river herring as evidence in support of a single stock complex for both species. There was discussion among the working group recognizing that both alewives and blueback herring spend the majority of their lives in the marine environment, and while in the marine environment, they appear to function as a mixed stock. Furthermore, evidence suggests that both alewives and blueback herring have demonstrated to be very adaptable which is supported by the success of managers to transfer stocks for the purpose of restoration and introductions.

Evidence against a single stock complex:

- The working group discussed how the genetic data presented by Gephard and Willis and the homing behavior displayed by both species is evidence of stock structure for both species. Furthermore, regional variability in abundance trends among alewife populations suggests that there may be more than one stock complex.

Palkovacs *et al.* and Willis stock complex hypothesis for alewives and Palkovacs *et al.* stock complex hypothesis for bluebacks

Supporting evidence:

- The working group discussed the genetic evidence presented by Gephard and Willis as evidence of stock structure for alewives and blueback herring. Regional variability in abundance and alewife return rates showed some semblance of overlap with the genetic studies. Furthermore, the working group discussed conformance of alewives and blueback herring to a metapopulation paradigm (homing and straying behavior) which further supports the preliminary results from the genetic studies.

Evidence against:

- The working group discussed the insufficient life history, physiological and morphometric data that would provide further evidence in support of, or against the Palkovacs *et al.* and Willis stock complex hypothesis. The working group discussed how blueback abundance trends were more consistent across their range and regional variability appears less then what has been observed with alewife populations. The similarities in abundance trend subsequently may provide more support for a single stock complex then a multiple stock complex.

<u>Alewife four stock complex and blueback herring three stock complex as proposed in the petition</u>

<u>Supporting evidence</u>

- The working group discussed how the stock complex boundaries proposed within the petition are partially supported by the genetic evidence presented by Gephard and Willis. The boundaries in the petition may also be supported by regional patterns of abundance and homing and straying behavior consistent with the evidence in support of the Palkovacs *et al.* and Willis stock complex hypothesis.

<u>Evidence Against:</u>

- The workgroup identified several geographic gaps where some important river herring rivers were not incorporated within the stock structure hypothesis put forward by the petitioners. Furthermore, consistent with the Palkovacs *et al.* stock structure hypothesis for blueback herring, the working group discussed how similarities in regional abundance trends for blueback herring and less variability between regions may provide more support for a single stock complex then a multiple stock complex.

<u>Four stock complexes defined by geographic boundaries</u>

<u>Supporting evidence:</u>

- The working group discussed how geography may influence migration behavior and subsequently influence stock structure of alewives and blueback herring. Cape Cod and

Cape Hatteras are both substantial geographic features that influence ocean currents that may influence river herring behavior. The separation with Canada represents a boundary where differences in resource management may have an influence on stock structure, as evidenced by the alewife genetic differentiation between U.S. and Canadian stocks presented by Willis. Most notably, widespread long-term stocking efforts in U.S. waters compared to very little stocking in Canadian waters may have influenced river herring stock structure differently. Genetic evidence, alewife abundance, homing and straying behavior as described for the multi-stock complexes above may partially support this hypothesis.

Evidence against:

- The working group discussed how even though the genetic evidence, alewife abundance, homing and straying behavior may partially support this hypothesis, data are largely insufficient to make strong linkages between stock structure and geography.

Hundreds of stock complexes representative of individual rivers

Supporting evidence

- The working group identified the hundreds of stock structure complexes hypothesis as a bookend to the single stock structure hypothesis. The working group discussed how genetic evidence, homing and straying, differences in growth rates, and differences in abundance (alewife) partially support this hypothesis.

Evidence against:

- The working group discussed how even though the genetic evidence, alewife abundance, homing and straying behavior may partially support this hypothesis, data are largely insufficient to support the hundreds of rivers hypothesis.

NMFS Management Recommendations following the Stock Structure Workshop

While no consensus was sought or reached at the working group meeting, experts provided their individual opinions regarding stock structure of alewife and blueback herring based on the discussions from the meeting (Appendix A).

All of the expert opinions received by NMFS suggested that evidence of regional stock structure (~100km scale) exists for both alewife and blueback herring as shown by the recent genetics data (Palkovacs *et al*., unpublished data; Willis, unpublished data). However, the exact boundaries of the regional stocks differed from expert to expert. The working group was not able to determine the migration patterns and mixing patterns of alewives and blueback herring in the ocean, though they strongly suspected regional stock mixing. Therefore, the ocean phase of alewives and blueback herring should be considered a mixed stock until further tagging and genetic data are available. Despite hypothesized regional differences in overwintering areas and migration patterns (for example, Figure 29), there is evidence to support regional differences in migration patterns, but not at a level of river-specific stocks.

NMFS has not yet determined if one or more distinct populations segments exist for alewives and blueback herring. In order to proceed with the extinction risk modeling effort, NMFS tasked the Extinction Risk Analysis working group with assessing extinction risk for each species in the following manner:

Alewives

- **Hypothesis 1:**
  - One continuous stock complex throughout the entire range from US to Canada
- **Hypothesis 2**:
  - Six stock complexes
    - Carolina (all alewife rivers south of, and including the Chowan River)
    - Mid-Atlantic (Rappahannock to Hudson River)
    - Long Island Sound (Byram River to Pawcatuck River)
    - Southern New England (Gilbert-Stewart to Mystic River)
    - Northern New England (Lamprey up to and including the St. Croix River)
    - Canada (all Canadian Rivers)

Blueback herring

- **Hypothesis 1:**
  - One continuous stock complex throughout the entire range from US to Canada
- **Hypothesis 2**:
  - Five stock complexes
    - Southern (St. John River to Cape Fear River)
    - Mid-Atlantic (Neuse River to Connecticut River)
    - Southern New England (Gilbert-Stewart to Mystic River)
    - Northern New England (Exeter River up to and including St. Croix River)
    - Canada (all Canadian Rivers)

There is a possibility that one or more stock complexes may be combined into a single DPS or multiple DPSs in the Endangered Species Act listing determination. Therefore, any extinction risk analyses or trajectories calculated for Hypothesis 2 should allow for the possibility of combining results from stock complexes in the future. As an example of potential stock structure combination, the alewife genetic results placed the Connecticut River in a group by itself. We have extended the stock structure boundary to include all rivers that drain into Long Island Sound from the Byron River in the east to the Pawcatuck River in the west. The

Long Island Sound stock complex should be considered tentative until further analysis is completed and may be combined with neighboring stock complexes.

Additionally, we have grouped alewives and blueback herring into one stock (by species) for all Canadian rivers. While the working group did not thoroughly examine evidence of alewife and blueback herring stock structuring within Canadian waters, there was evidence presented that suggested that the following three stock complexes exist for alewife within Canada: Inner Bay of Fundy (U.S./Canada border up to but not including the Tusket River); East Coast of Nova Scotia (Tusket River up to Cape Breton Island), and; the Gulf of St. Lawrence (Cape Breton Island to the Miramichi River, possibly further into the Gulf of St. Lawrence) (Bentzen and Willis, unpublished data). NMFS has decided to group St. Croix River alewives and blueback herring with the Northern New England Stock complex for the following reasons: 1) preliminary alewife genetic data presented by Willis suggested that the St. Croix River was similar to other rivers within Maine; and, 2) the 2005 closure of the Vanceboro Dam fishway by the State of Maine has shown that existing regulations within the Northern New England stock complex region have affected alewife and blueback herring success in the St. Croix River, and these regulations should be considered in the analysis of potential future U.S. ESA protections.

On August 13, 2012, we received updated genetic analyses from Palkovacs *et al*. (Appendix B) which resulted in changes to their preliminary alewife stock structure boundaries which were presented to the working group in June. This new information groups the Hudson and Connecticut Rivers with the Southern Atlantic stock and reduces the number of stock complexes from six to five. We have passed this updated stock complex delineation along to the Extinction Risk Analysis working group. Using this updated information, the hypothesized stock complexes would be represented as seen in the breakout box in Appendix B; however the exact boundaries of the stock complexes may continue to evolve as the genetic studies are refined.

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Tables and Figures

Table 2**.** Number of specimens (N) genotyped per species by river (Palkovacs *et al.*, unpublished data) *from Palkovacs and Gephard presentation on 06/22/12.* ** Indicates species may be extirpated.

River	State	Alewife (N)	Blueback (N)
East Machias (EMAC)	ME	59	58
St. George (STGEO)	ME	65	50
Lamprey (LAM)	NH	47	0
Exeter (EX)	NH	0	41
Mystic (MYST)	MA	69	69
Town Brook (TBRO)	MA	49	0
Monument (MON)	MA	46	51
Gilbert Stuart (GIL)	RI	44	38
Connecticut (CON)	CT	37	138
Hudson (HUD)	NY	61	79
Delaware (DEL)	NJ	47	49
Nanticoke (NAN)	MD	39	24
Rappahannock (RAP)	VA	62	58
James (JAM)	VA	0	98
Chowan (CHOW)	NC	54	72
Roanoke (ROA)	NC	50	50
Alligator (ALL)	NC	49	0
Neuse (NEU)	NC	**	65
Cape Fear (CF)	NC	**	57
Santee (SAN)	SC	NA	62
Savannah (SAV)	GA	NA	52
Altamaha (ALT)	GA	NA	53
St. Johns (SJR)	FL	NA	37

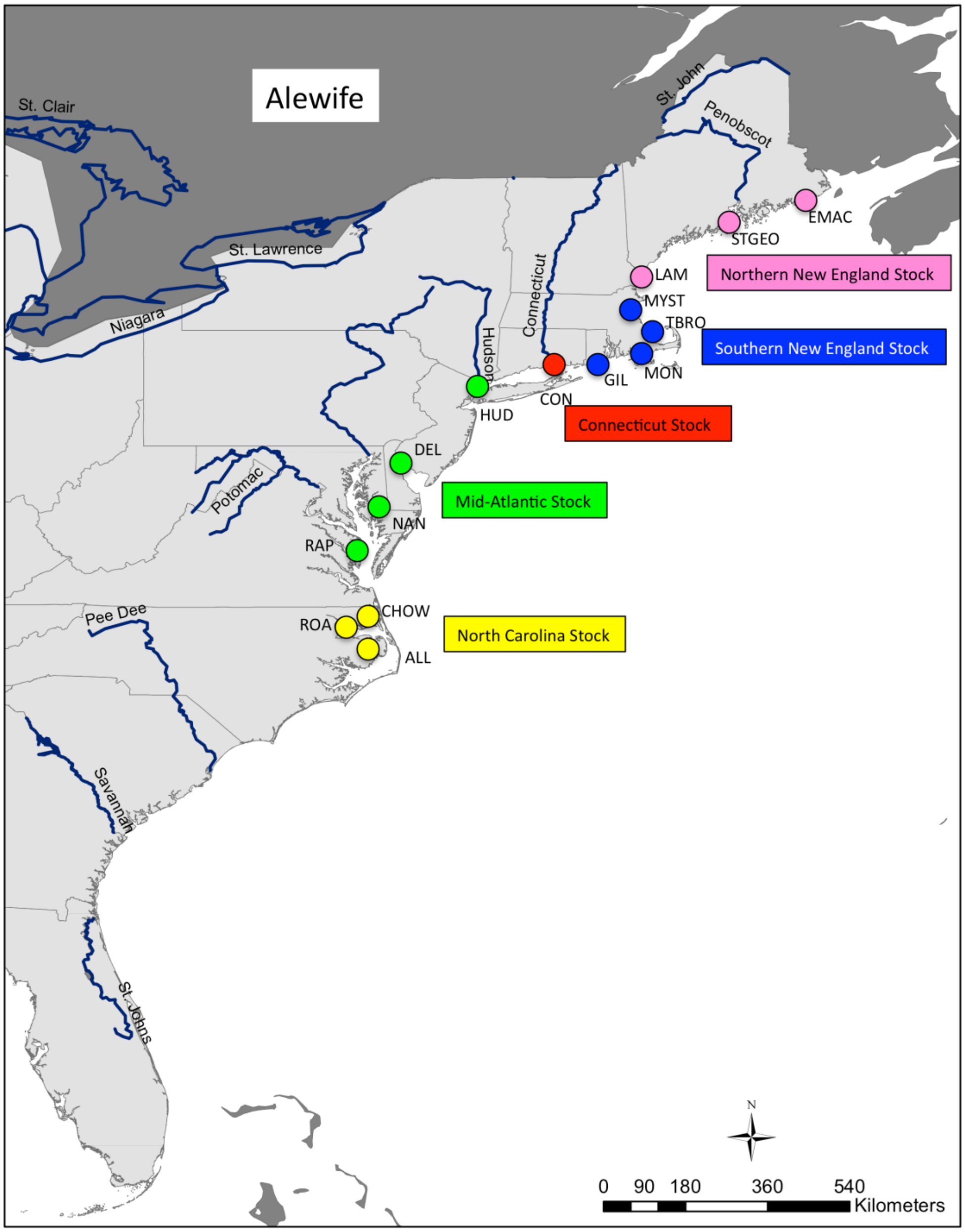


Figure 1. Alewife proposed stock structure was identified using the Bayesian clustering algorithm implemented in BAPS v.5.1 (Corander *et al.*, 2006)**.** The Connecticut Stock is the only stock in either species to be defined by a single river and, therefore, should be treated as tentative until further analyses can be performed (Palkovacs *et. al*, unpublished data) *from Palkovacs and Gephard presentation on 06/22/12.*

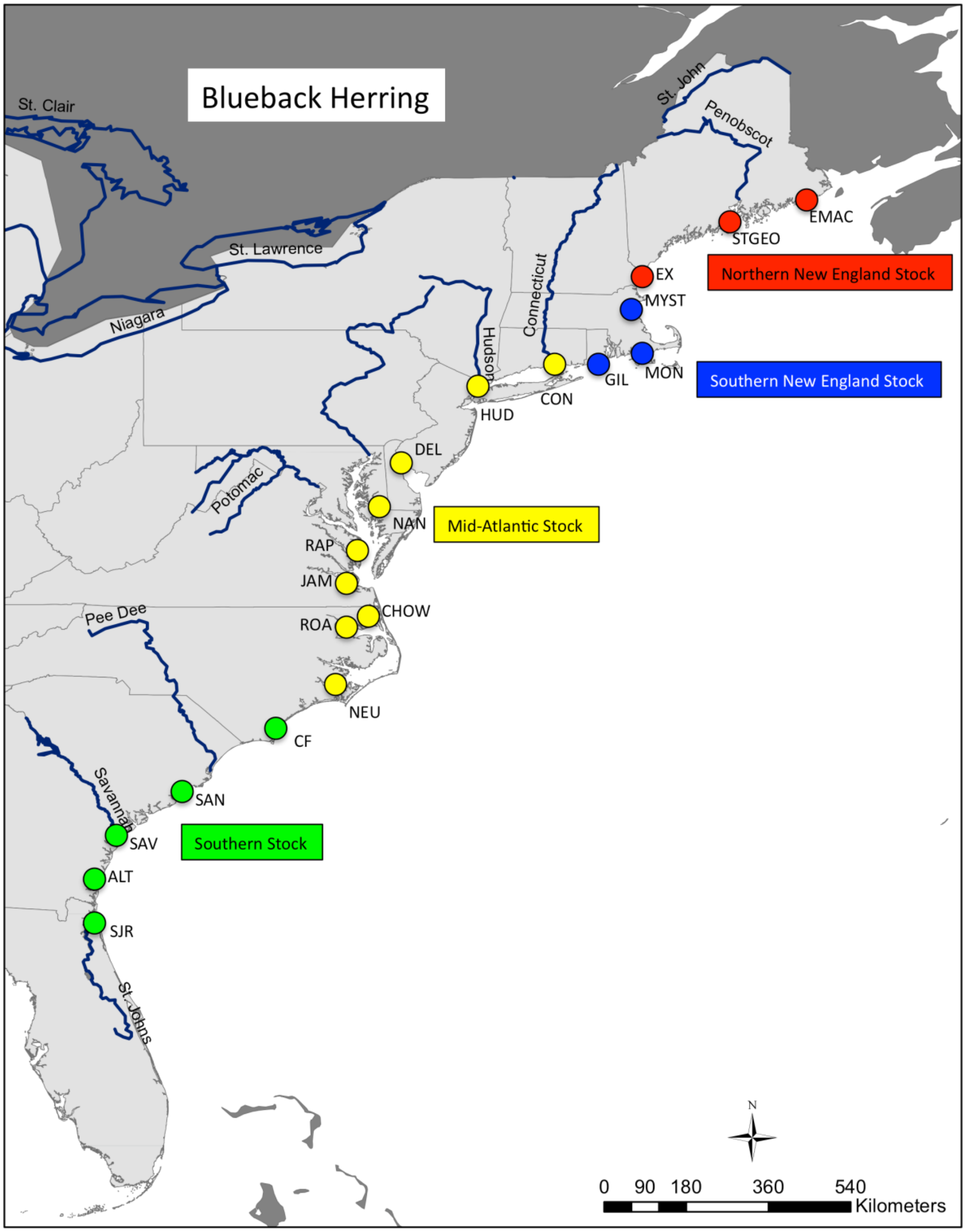


Figure 2. Blueback herring proposed stock structure (Palkovacs *et. al.*, unpublished data) was identified using the Bayesian clustering algorithm implemented in BAPS v.5.1 (Corander *et al.*, 2006) *from Palkovacs and Gephard presentation on 06/22/12.*

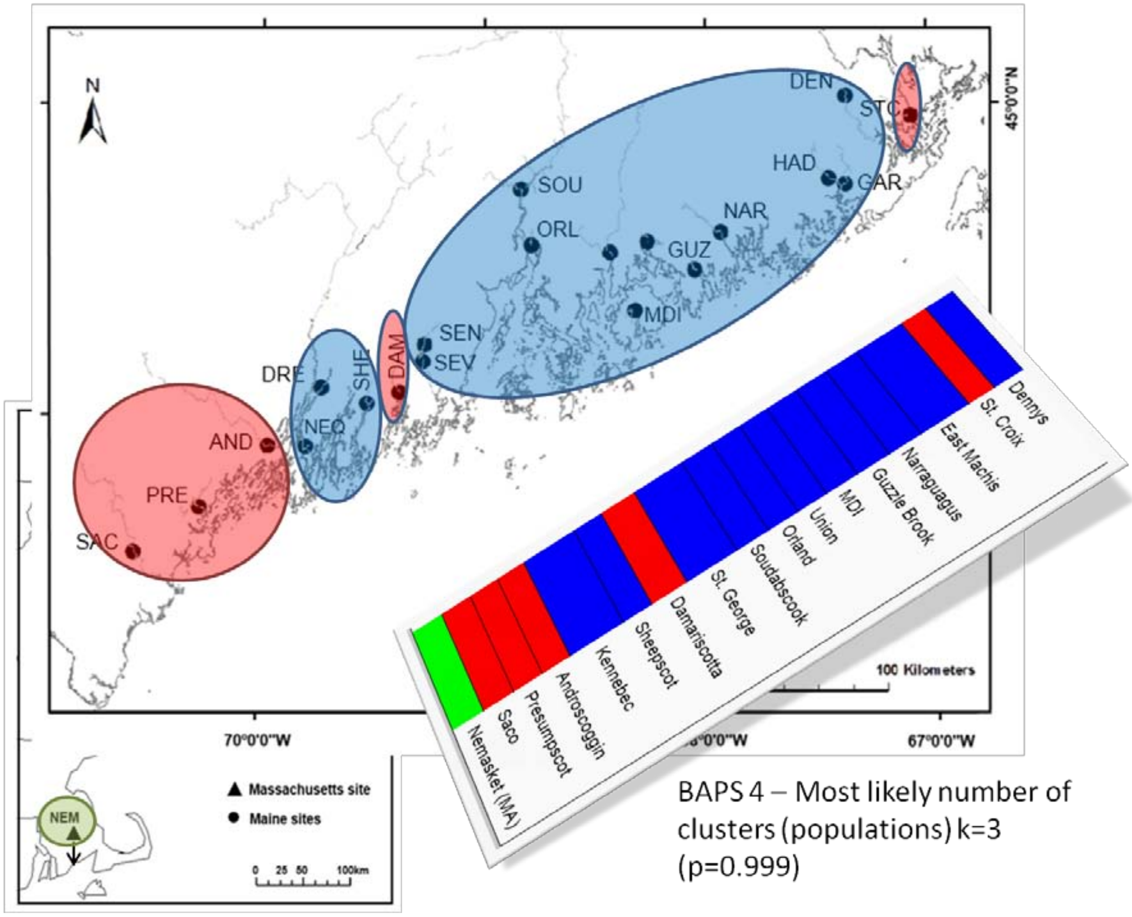


Figure 3. Alewife genetic classification of Maine alewife populations *(from Willis presentation on 6/22/2012, Gloucester, MA.).*

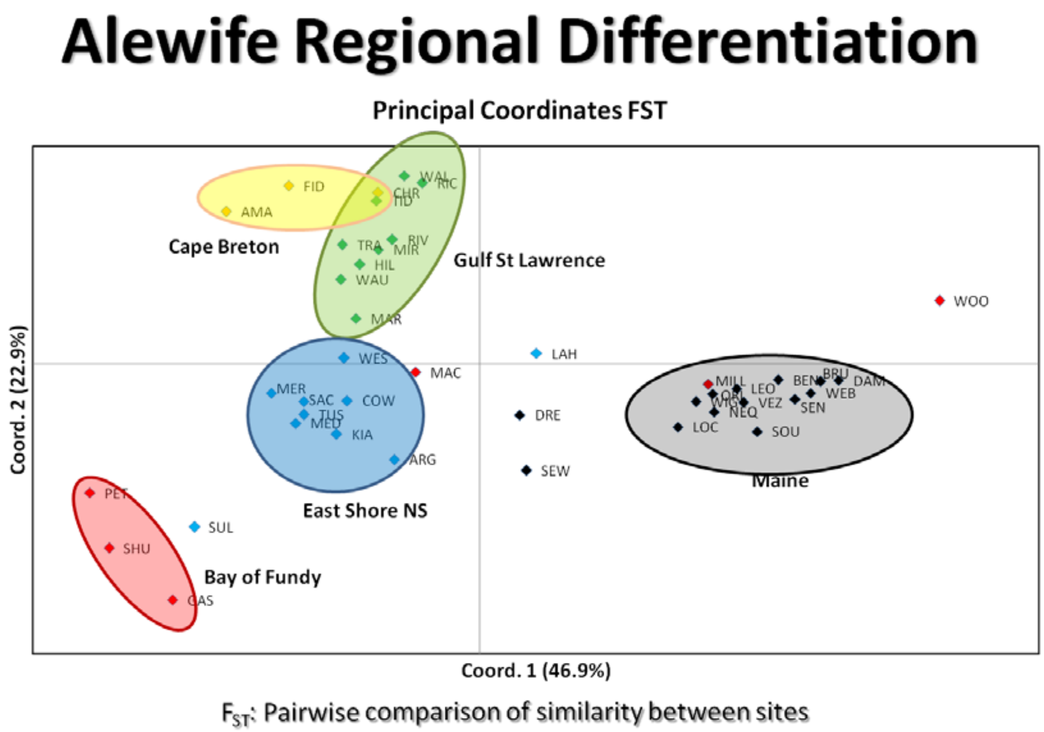


Figure 4. Regional differentiation of alewife populations in Maine and Atlantic Canada using Principal Coordinate Fst (Bentzen 2012) *(from Willis presentation on 6/22/2012, Gloucester, MA.).*

Code Names:

Canada: MIR = Mirimichi; PET = Petitcdiac; RIC = Richibucto; TID = Tidnish; TRA = Tracadie; WAL = Wallace; WAU = Waugh; FID = Fiddlehead; MAR = Margaree; CHR = Christmas Island Pond; WES = West; SHU = Shubenacadie Grand Lake; SAC = Sackville; COW = Cow Bay Lake; SUL = Sullivan's Pond; MER = Mersey; MED = Medway; LAH = LeHave; ARG = Argyle; TUS = Tusket; GAS = Gasparoux.

Maine: DAM = Damariscotta; SOU = Souadabscook; SEN = Sennebec; BRU = Brunswick; BEN = Benton; Lockwood; VEZ = Veazie; NEQ = Nequasset; WEB = Webber; LEO = Leonard; SEW = Sewall; DRE = Dresdon. WIG = Wight; WOO = Woodland; MILL = Miltown

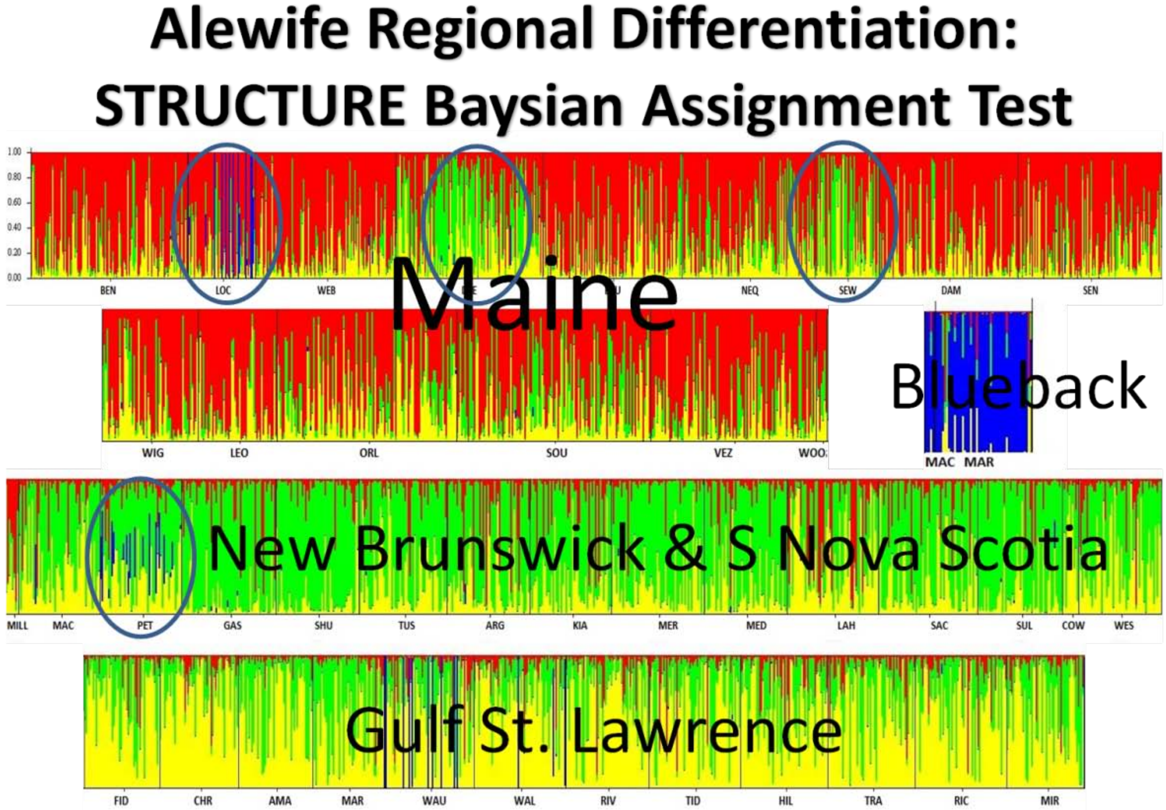


Figure 5. A STRUCTURE Bayesian Assignment Test of alewives and blueback herring indicating some interbreeding between species *(from Willis presentation on 6/22/2012 in Gloucester, MA.).*

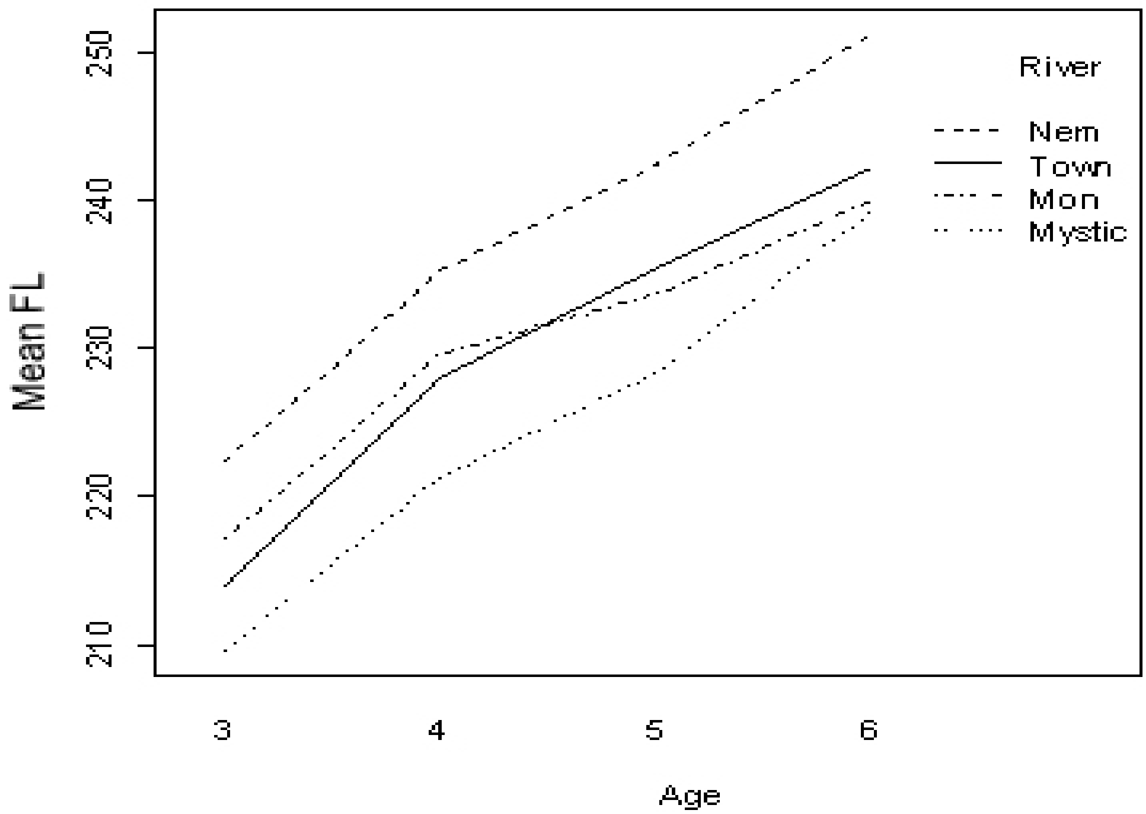


Figure 6. Evidence for fine scale stock structure: Differences in length at age for alewives in four Massachusetts' rivers: Namasket River, Town Brook, Monument River and Mystic River (*from Armstrong presentation on 06/22/12 in Gloucester, MA).*

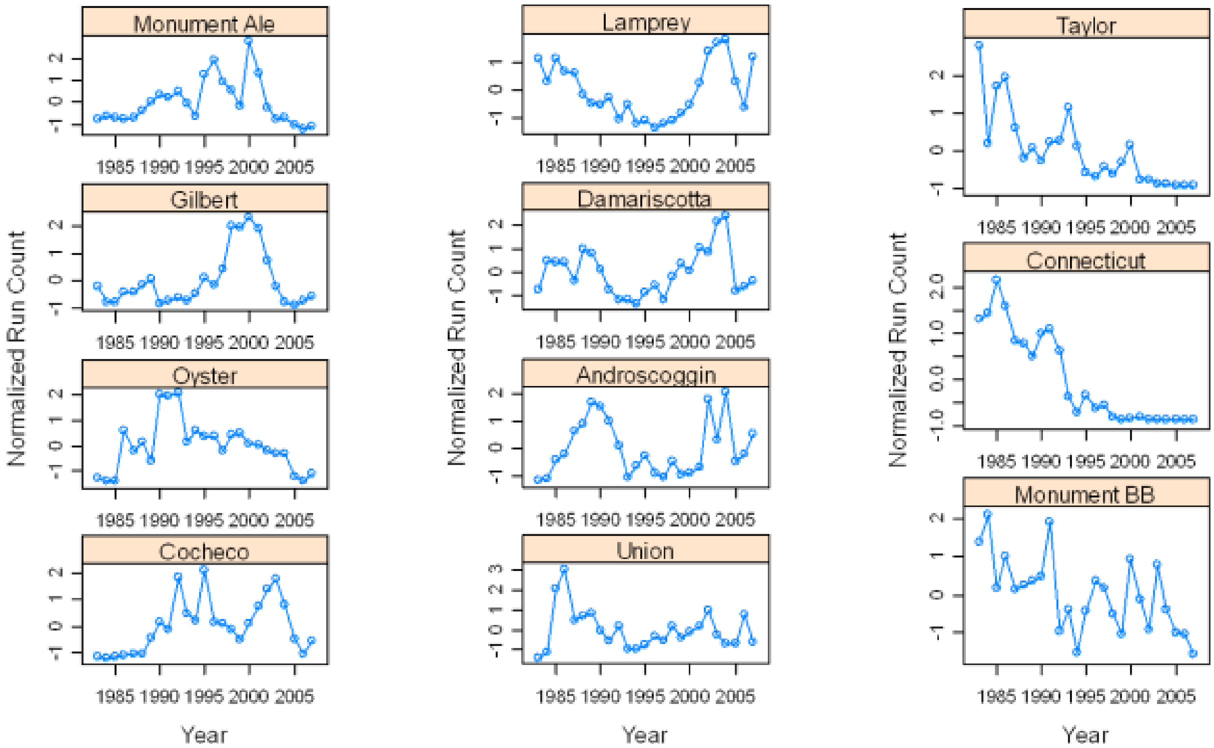


Figure 7. Run counts of alewives and blueback herring (Monument River) from 1983-2007 showing possible evidence of broader scale stock structure (*from Armstrong presentation on 06/22/12 in Gloucester, MA).* Run count patterns cluster together into three groups: 1)Monument (alewife run), Gilbert, Oyster and Cocheco; 2) Lamprey, Damriscotta, Androscoggin, and Union, and; 3) Taylor, Connecticut and Monument (blueback herring run). The third group consisting of the Taylor, Connecticut and Monument rivers has a large blueback herring component, showing that the blueback herring runs are behaving differently from the alewife dominated runs.

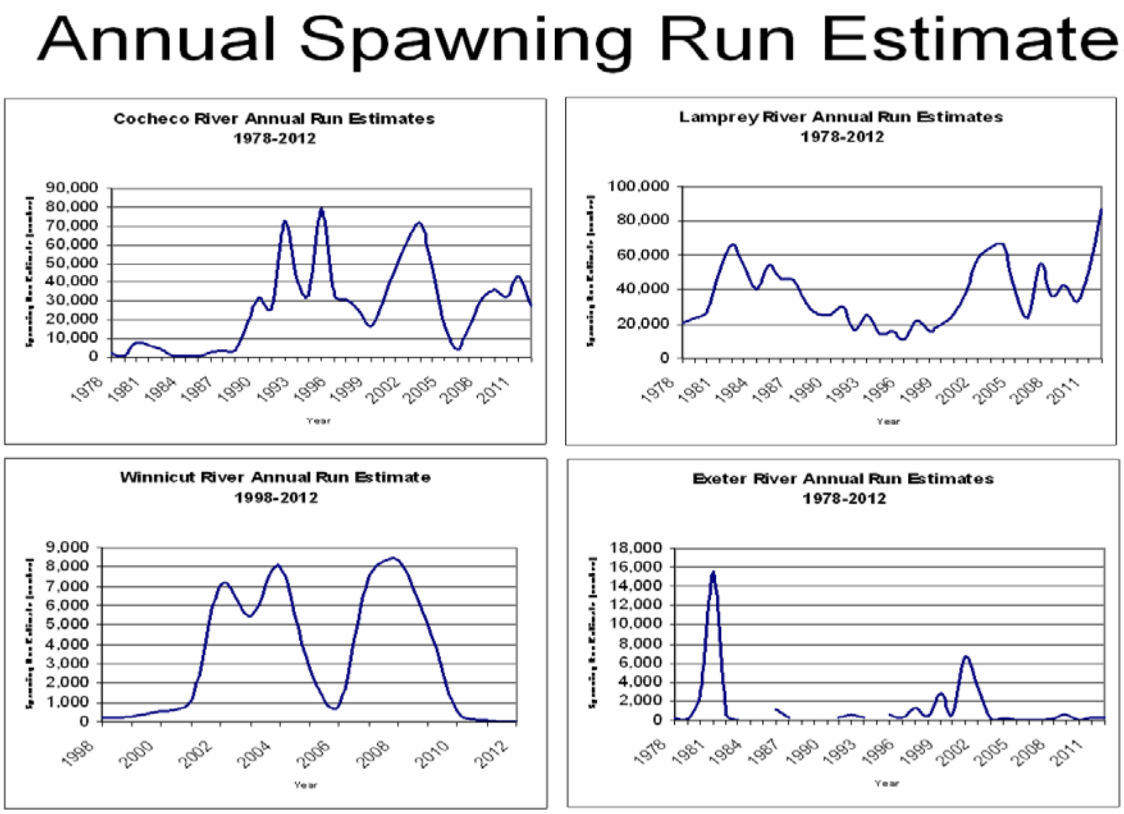


Figure 8. Alewife dominated river herring run estimates on the Cocheco, Lamprey, Winnicut, and Exeter rivers in New Hampshire *(from Sullivan presentation on 6/22/2012 in Gloucester, MA.).*

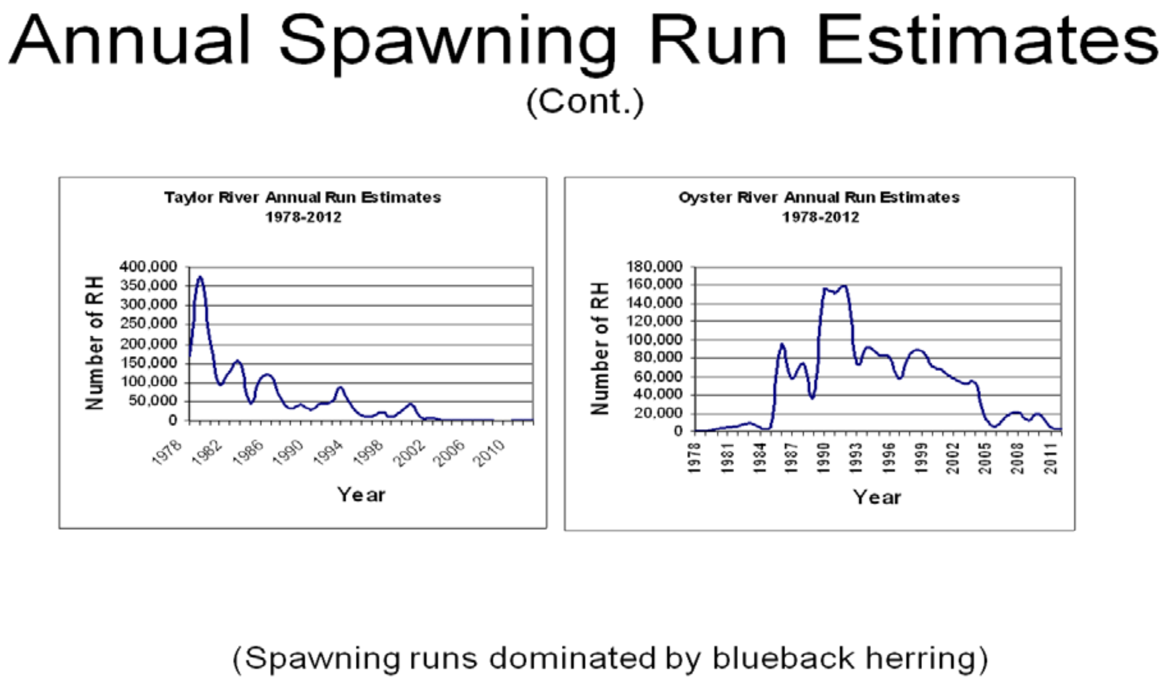
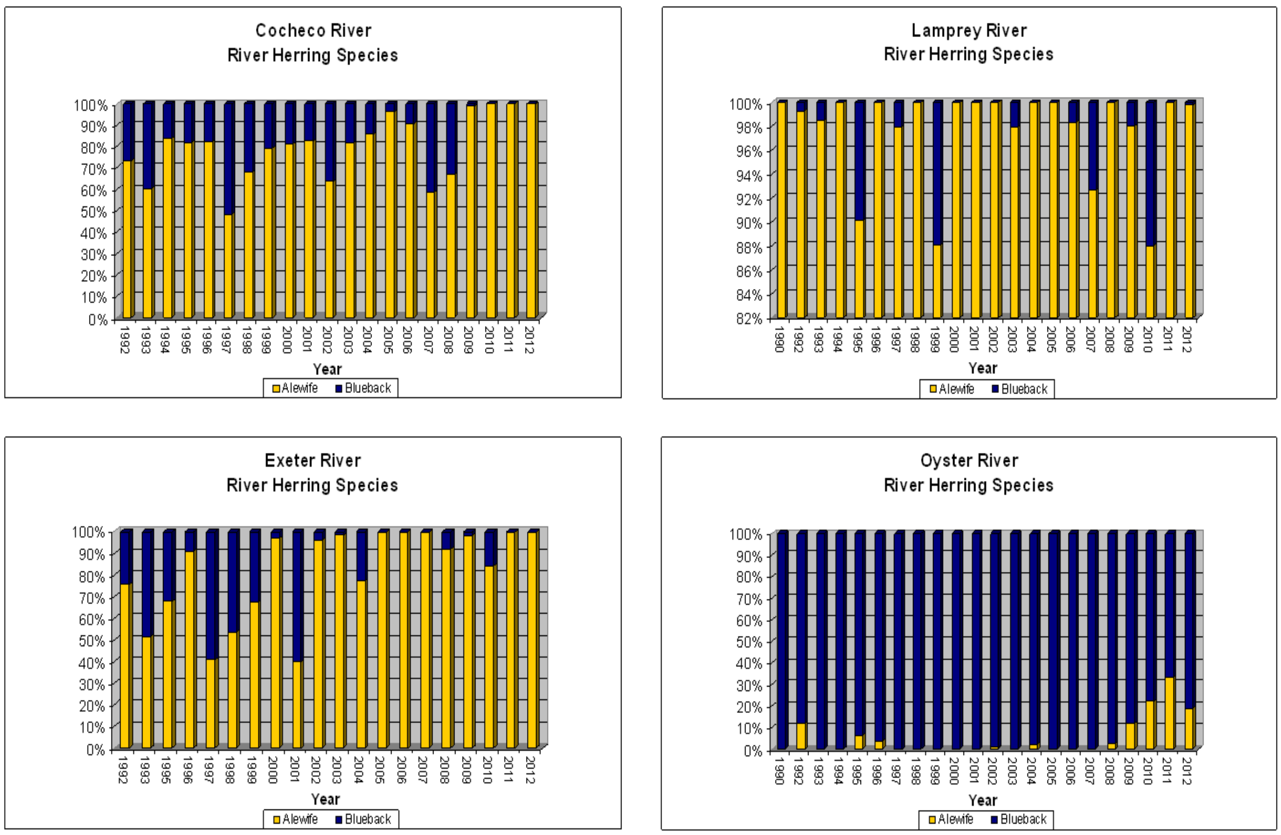


Figure 9. Blueback herring dominated river herring run estimates on the Taylor and Oyster rivers in New Hampshire *(from Sullivan presentation on 6/22/2012 in Gloucester, MA.).*

River Herring Species by River

Species Data Collection began in 1990

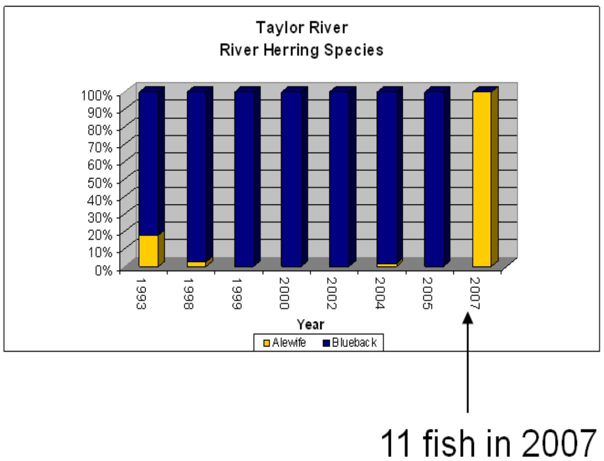


1992 to 2012

1990 to 2012

Figure 10. Proportion of alewife and blueback herring in the Cocheco, Lamprey, Exeter and Oyster rivers, New Hampshire *(from Sullivan presentation on 6/22/2012 in Gloucester, MA.)*

River Herring Species by River
(Cont.)



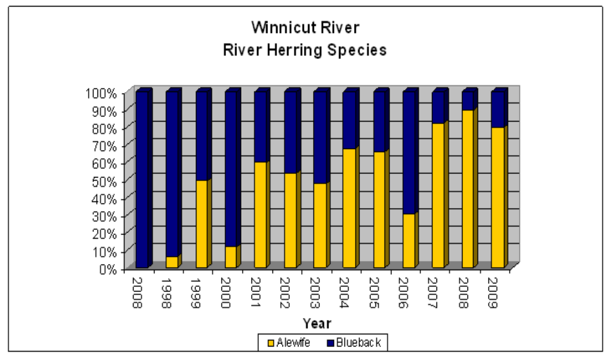


Figure 11. Proportion of alewife and blueback herring in the Taylor and Winnicut rivers in New Hampshire *(from Sullivan presentation on 6/22/2012 in Gloucester, MA.)*

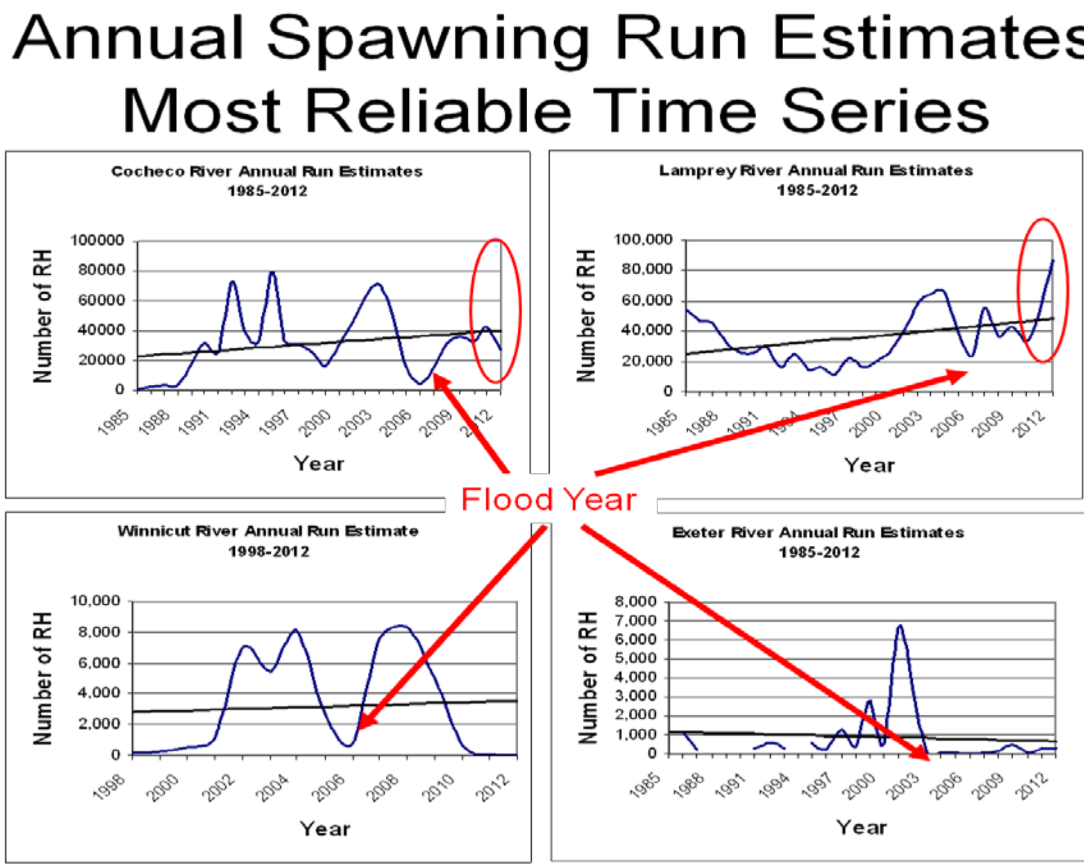


Figure 12. Independent return response between four alewife dominated rivers in New Hampshire *(from Sullivan presentation on 6/22/2012 in Gloucester, MA).*

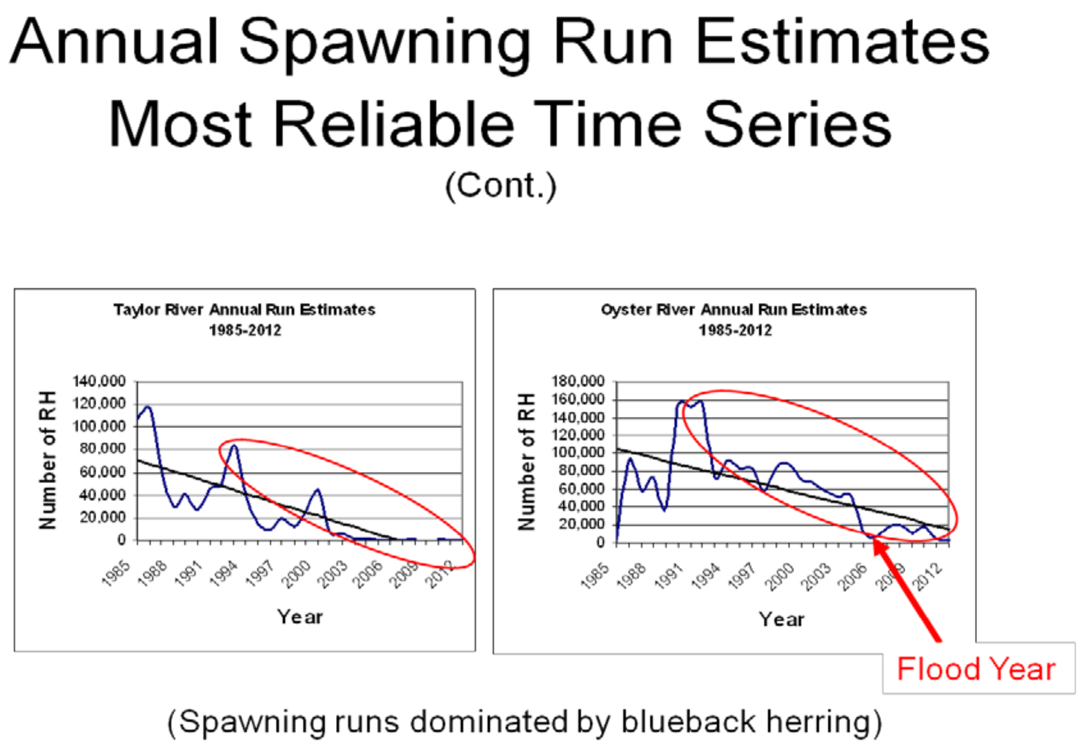


Figure 13. Similar response between two blueback herring dominated runs in New Hampshire *(from Sullivan presentation on 6/22/2012 in Gloucester, MA).*

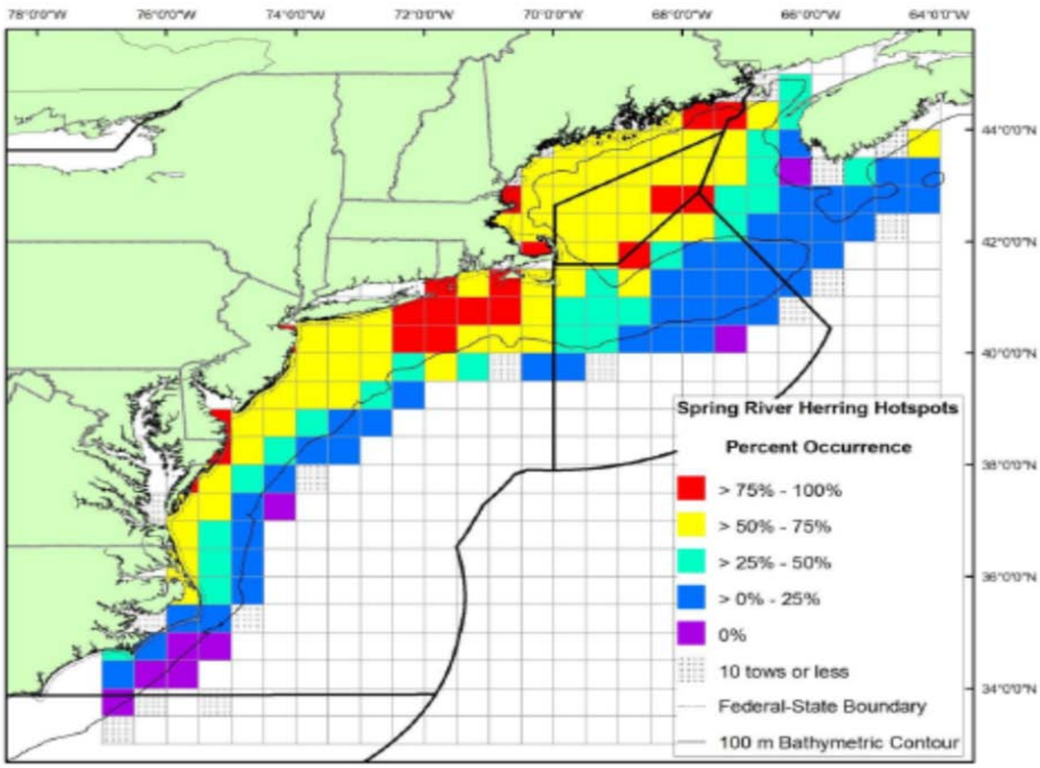


Figure 14. NMFS spring 1968 to 2008 bottom-trawl surveys showing percent occurrence of river herring *(from Cieri presentation on 6/22/2012 in Gloucester, MA.).*

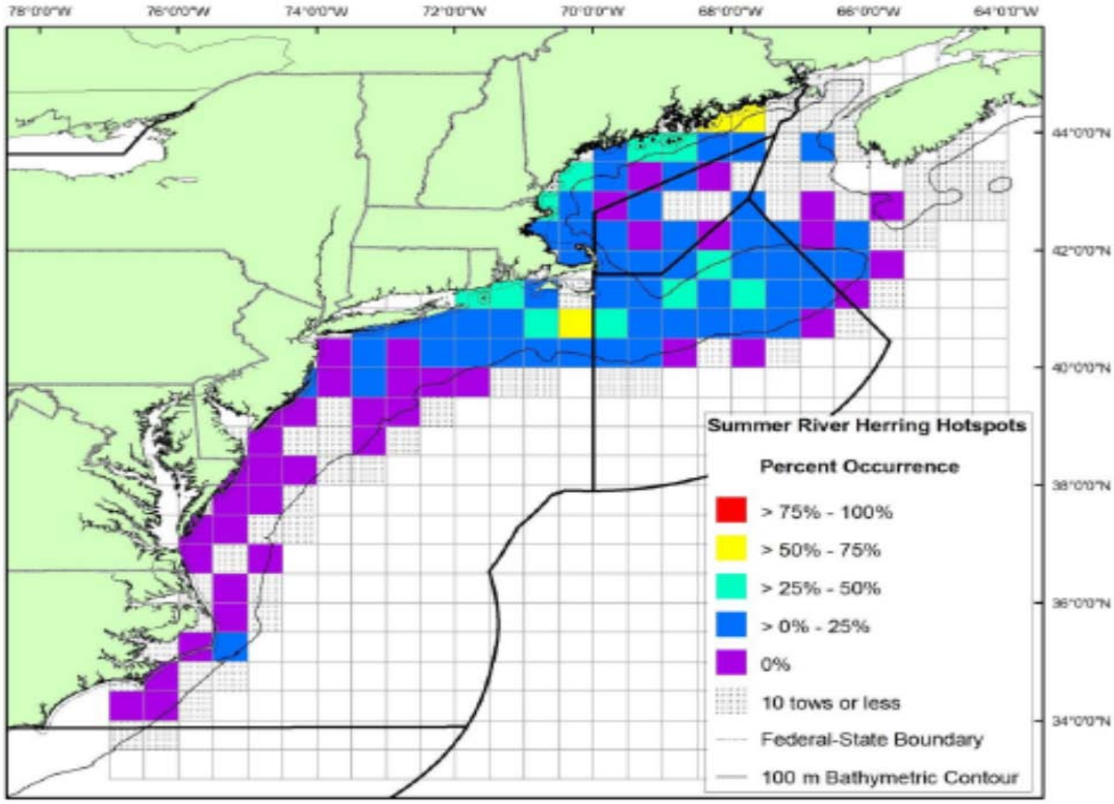


Figure 15. NMFS summer 1948 to 1995 bottom-trawl survey showing percent occurrence of river herring *(from Cieri presentation on 6/22/2012 in Gloucester, MA.).*

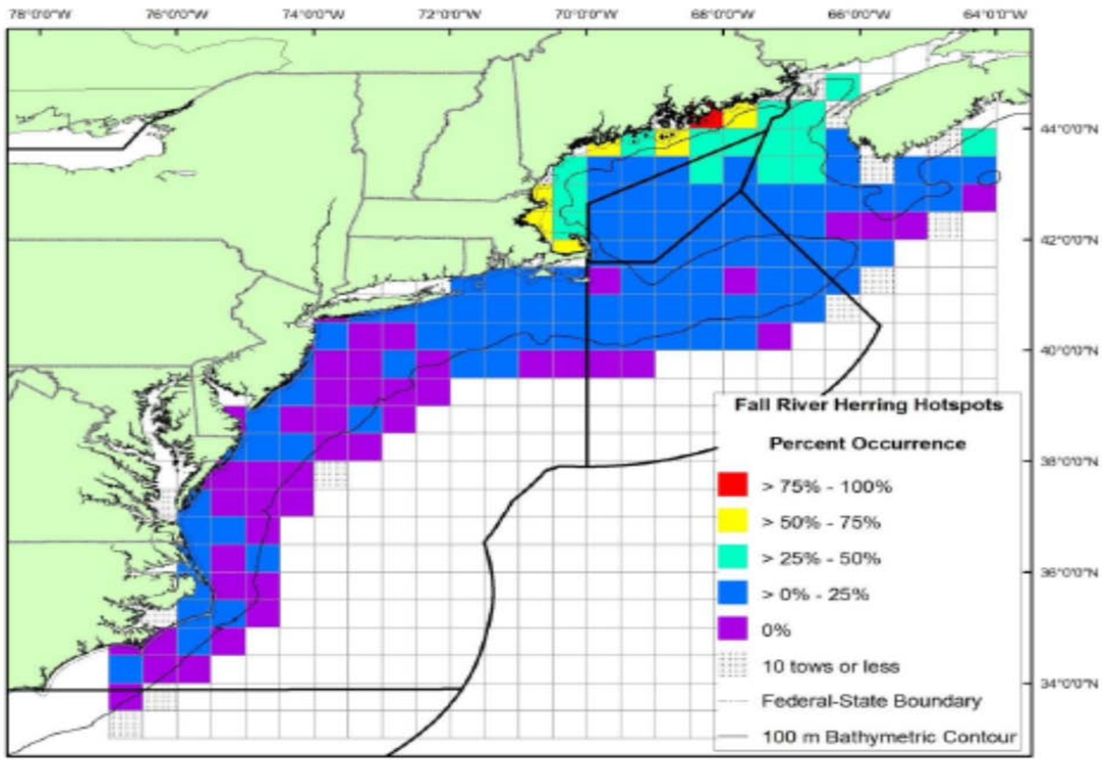


Figure 16. NMFS fall 1963 to 2008 bottom-trawl survey showing percent occurrence of river herring *(from Cieri presentation on 6/22/2012 in Gloucester, MA.).*

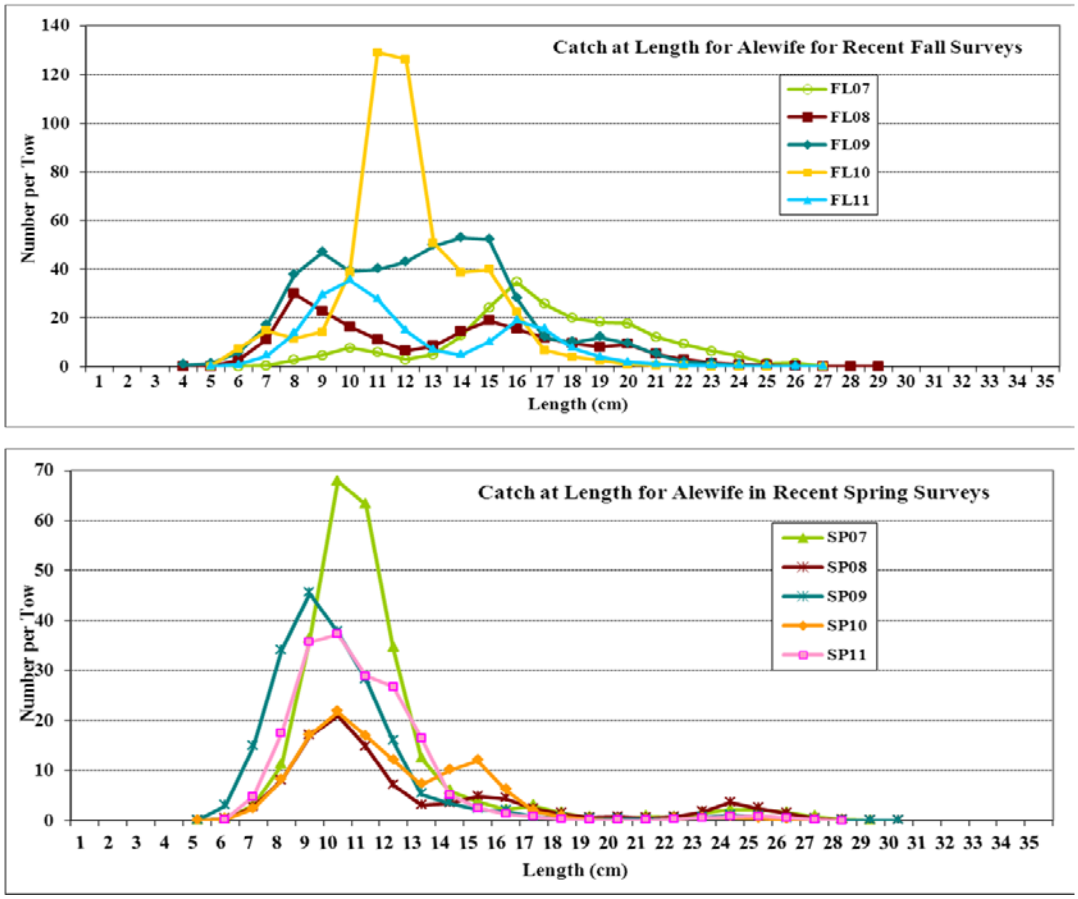


Figure 17. Maine and New Hampshire inshore fall and spring alewife length distribution *(from Cieri presentation on 6/22/2012 in Gloucester, MA).*

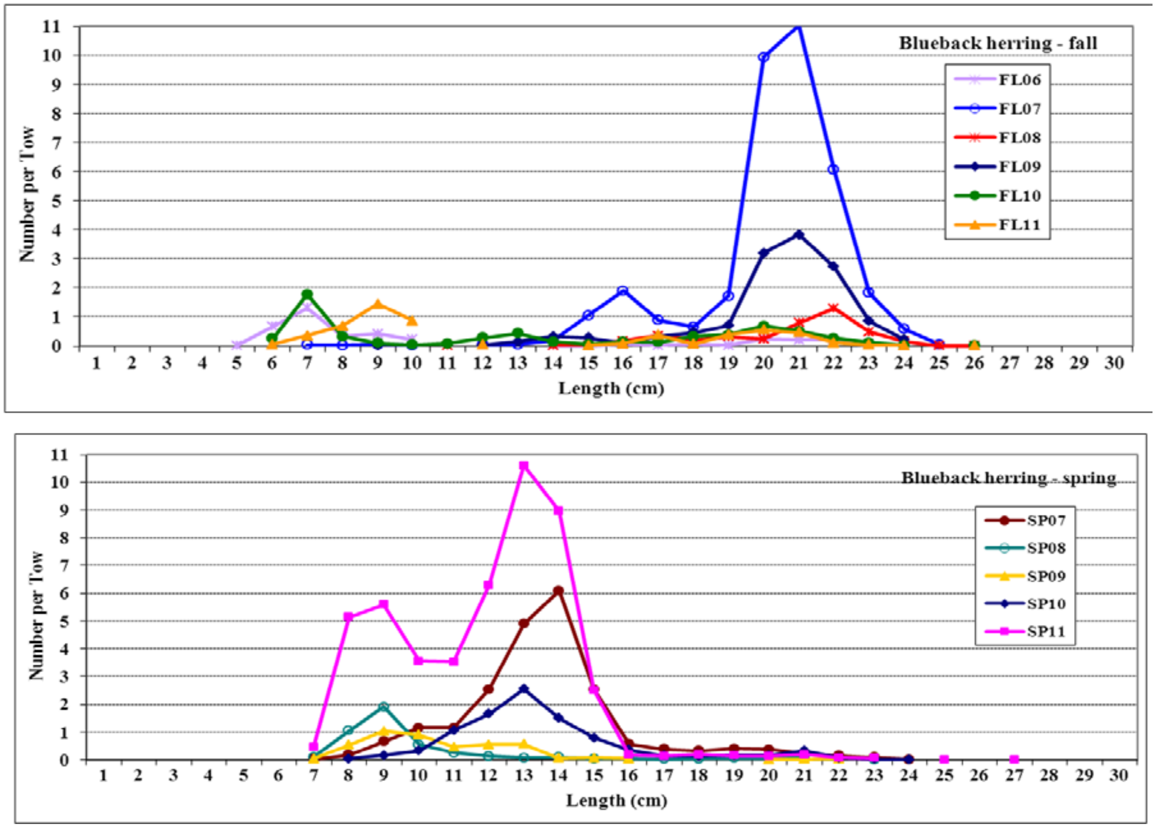


Figure 18. Maine and New Hampshire inshore fall and spring blueback herring length distribution *(from Cieri presentation on 6/22/2012 in Gloucester, MA).*

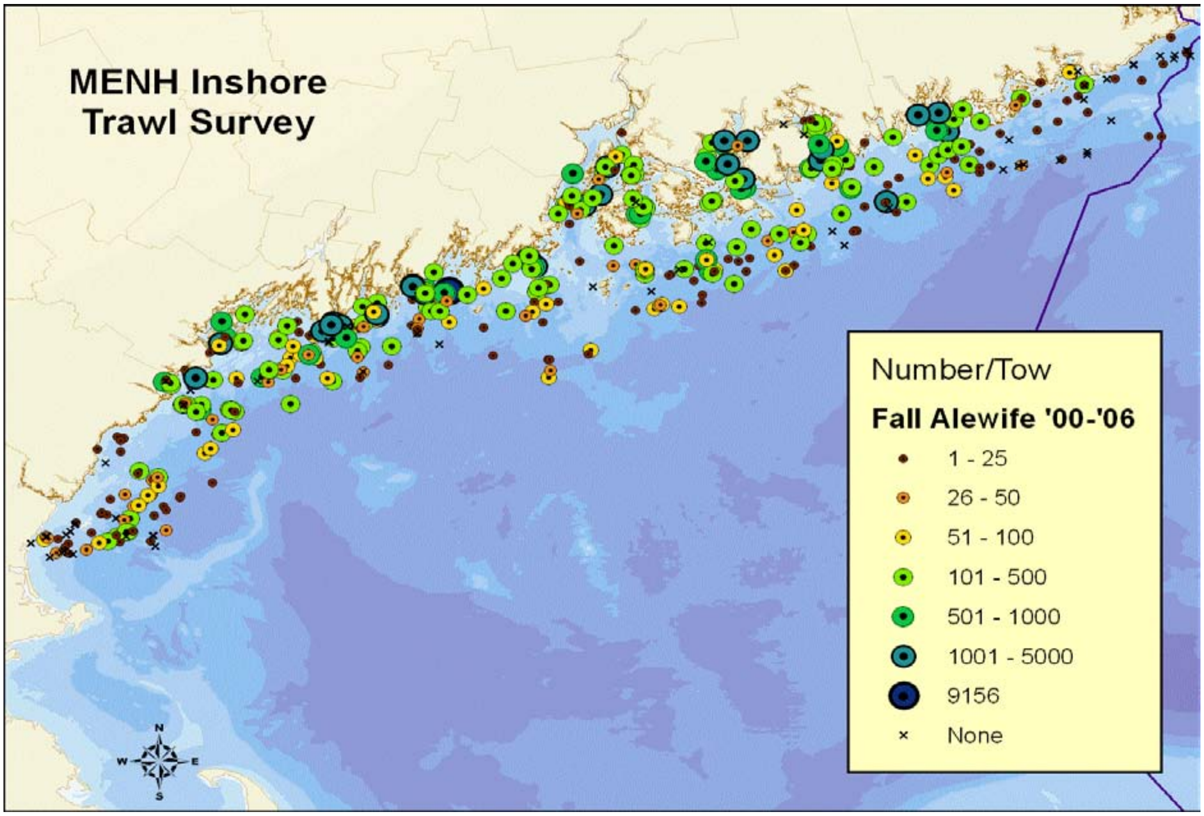


Figure 19. Aggregation of alewives observed during the fall 2000 – 2006 Maine/New Hampshire trawl survey *(from Cieri presentation on 6/22/2012 in Gloucester, MA).*

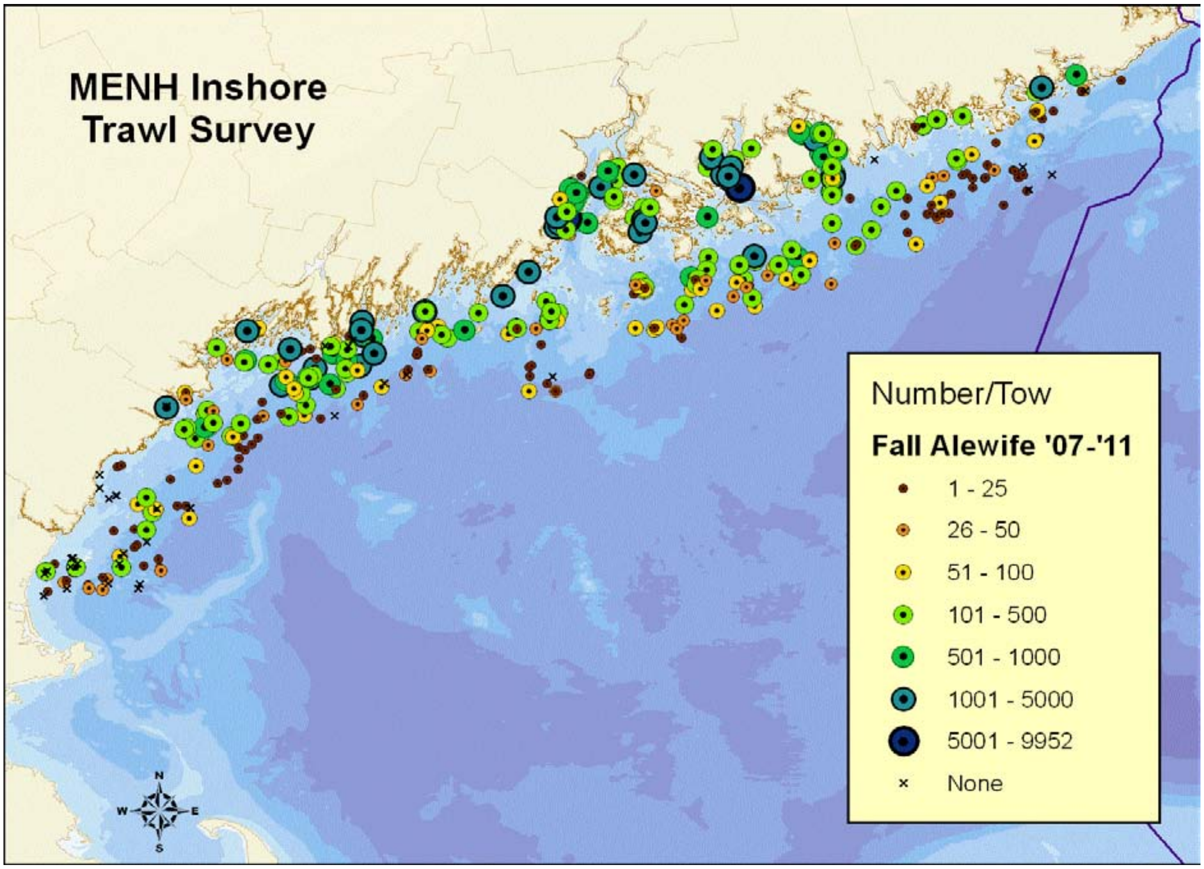


Figure 20. Aggregation of alewives observed during the fall 2007 – 2011 Maine/New Hampshire trawl survey *(from Cieri presentation on 6/22/2012 in Gloucester, MA).*

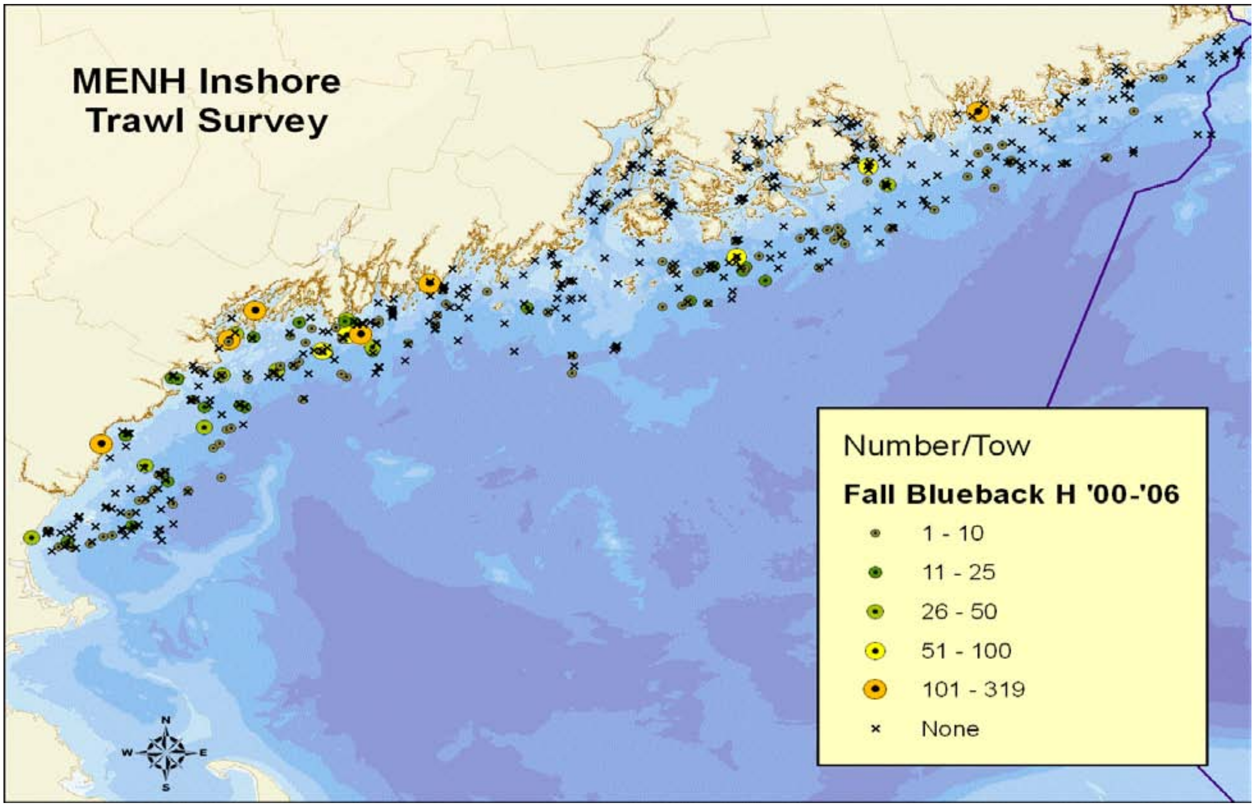


Figure 21. Aggregation of blueback herring observed during the fall 2000 – 2006 Maine/New Hampshire trawl survey *(from Cieri presentation on 6/22/2012 in Gloucester, MA).*

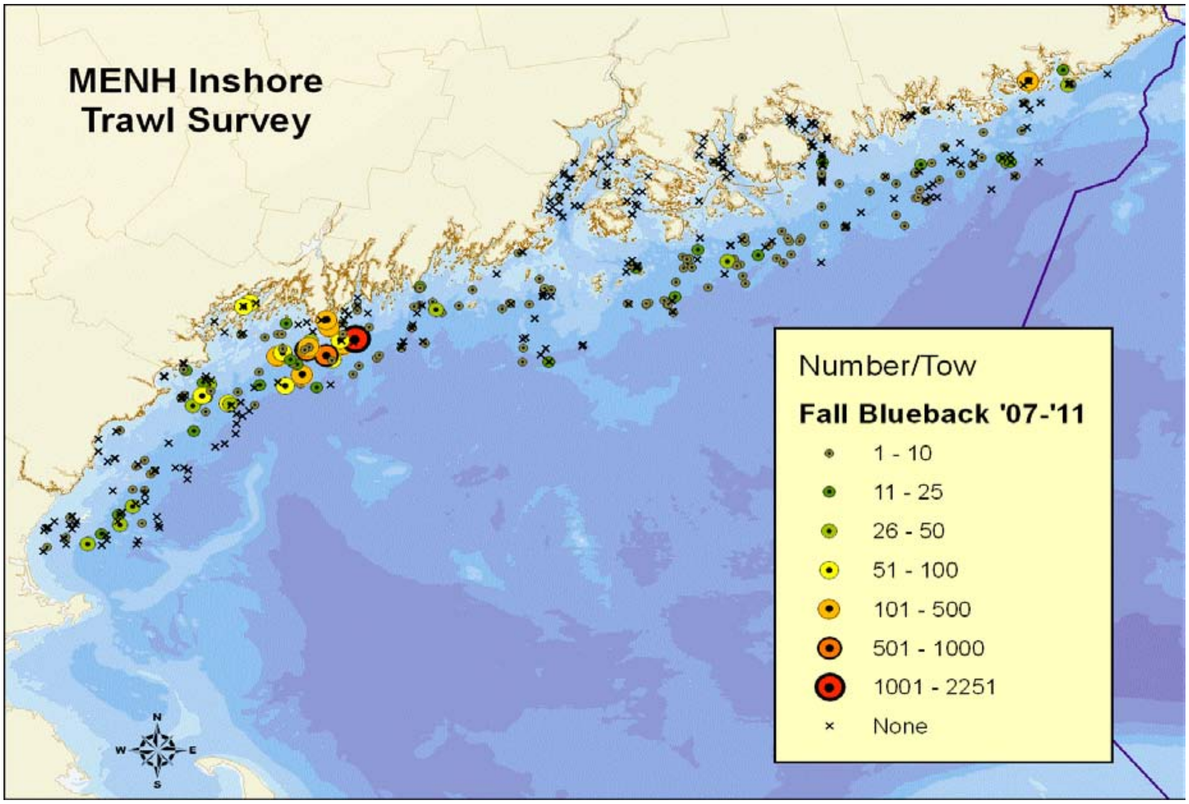


Figure 22. Aggregation of blueback herring observed during the fall 2007 – 2011 Maine/New Hampshire trawl survey *(from Cieri presentation on 6/22/2012 in Gloucester, MA).*

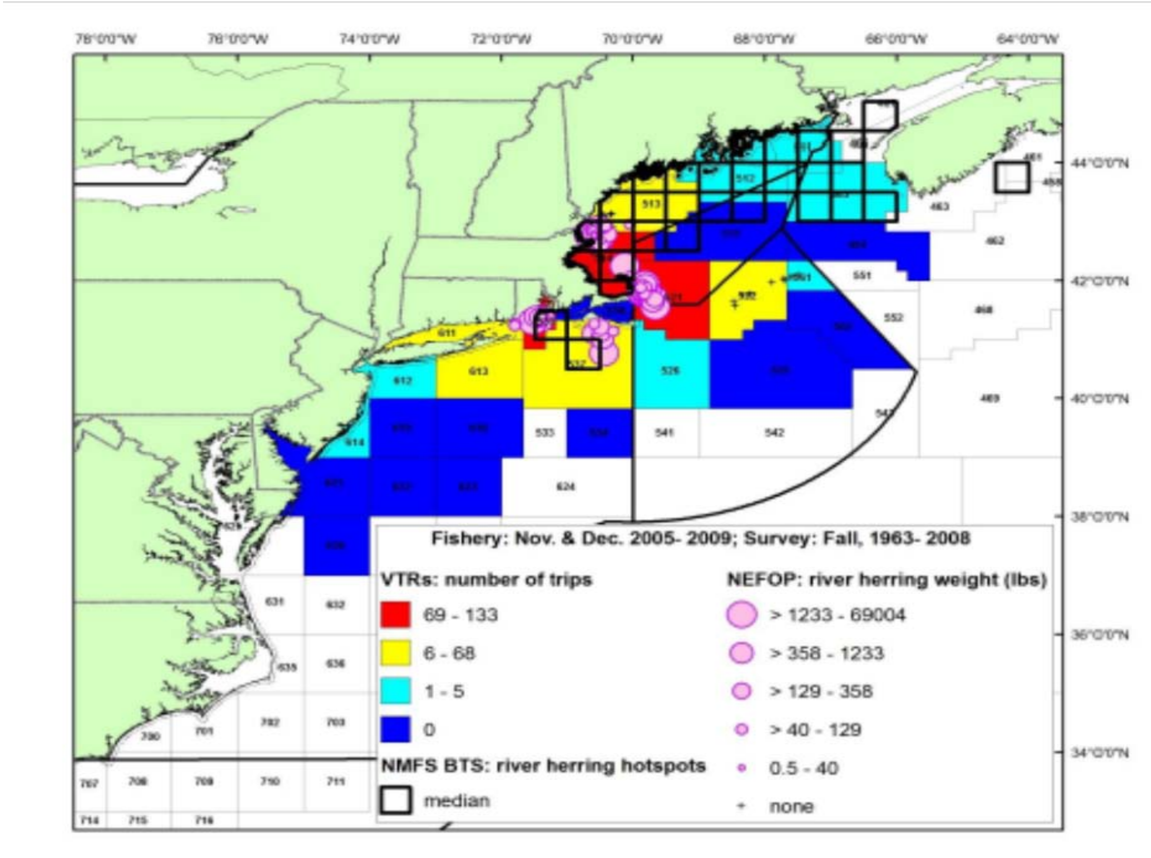


Figure 23. Reported trips and observed hauls and sets during November and December, 2005-2009 for directed Atlantic herring trips by bottom otter-trawls, purse seines, and mid-water trawls (single and paired). A "+" symbol signifies that an observed haul or set did not catch river herring. Directed herring trips are defined as 2,000 lbs of kept Atlantic herring trip. Fall candidate river herring "hot spot" quarter degree squares identified as squares with percent occurrence and median catch in number ≥ the 75th quantiles of both variables (bold outlined quarter degree squares (Sources: VTR Database 2005-2009, NEFOP Database 2005-2009, and Fall 1963 – 2008 NMFS bottom-trawl surveys). *(from Cieri presentation on 6/22/2012 in Gloucester, MA).*

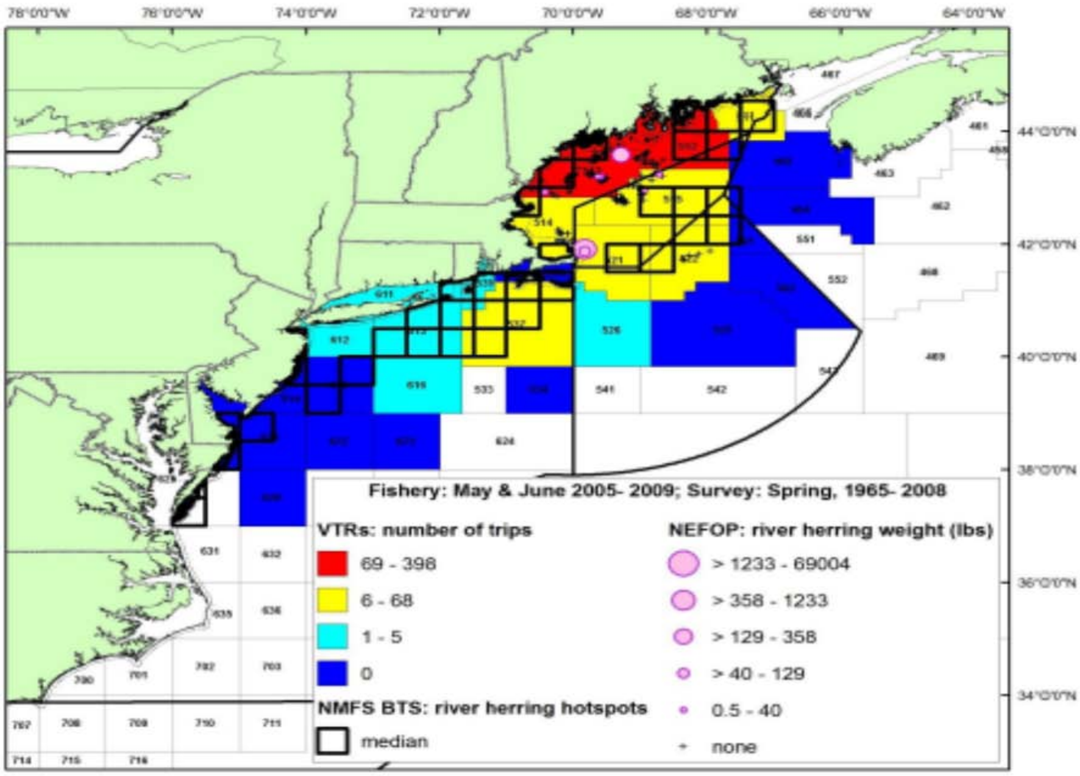


Figure 24. Reported trips and observed hauls and sets during May and June, 2005-2009 for directed Atlantic herring trips by bottom otter-trawls, purse seines, and mid-water trawls (single and paired). A "+" symbol signifies that an observed haul or set did not catch river herring. Directed herring trips are defined as 2,000 lbs of kept Atlantic herring trip. Fall candidate river herring "hot spot" quarter degree squares identified as squares with percent occurrence and median catch in number ≥ the 75th quantiles of both variables (bold outlined quarter degree squares (Sources: VTR Database 2005-2009, NEFOP Database 2005-2009, and Fall 1965 – 2008 NMFS bottom-trawl surveys). *(from Cieri presentation on 6/22/2012 in Gloucester, MA).*

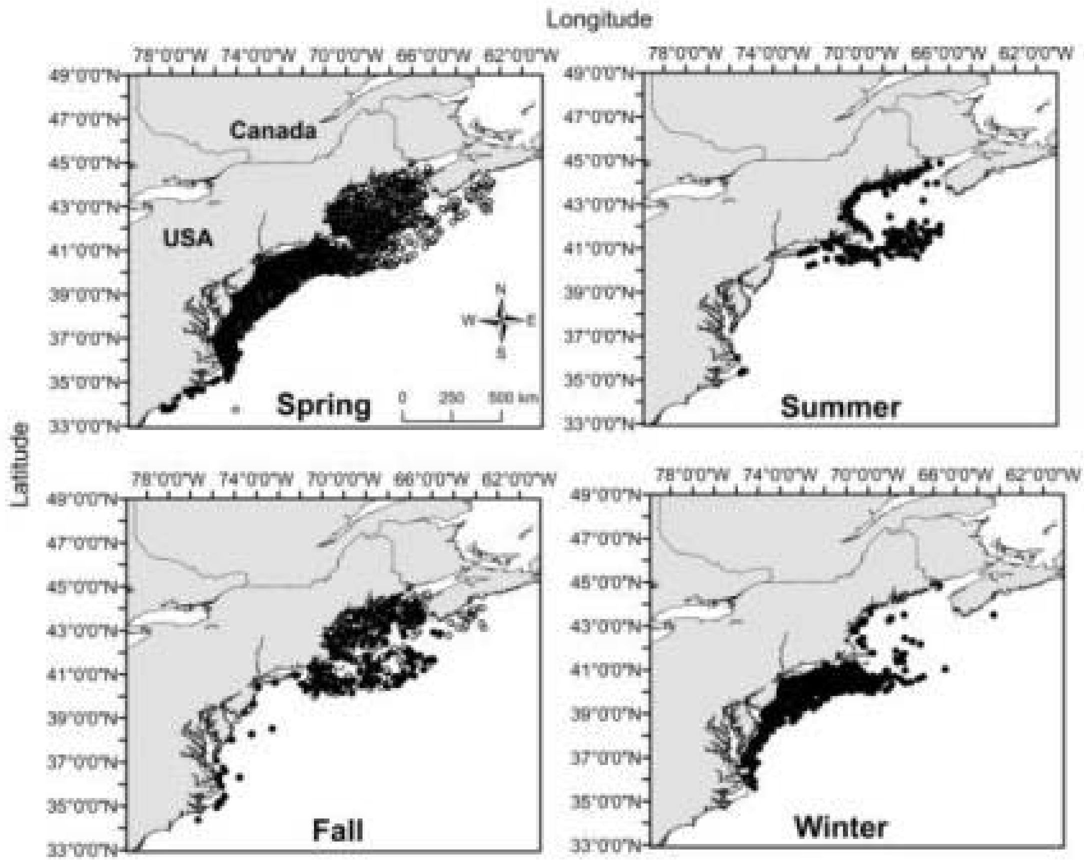


Figure 25. River herring distributions from National Marine Fisheries Service trawl surveys in spring, summer, fall and winter *(from Jordaan presentation on 06/22/12 in Gloucester, MA)*.

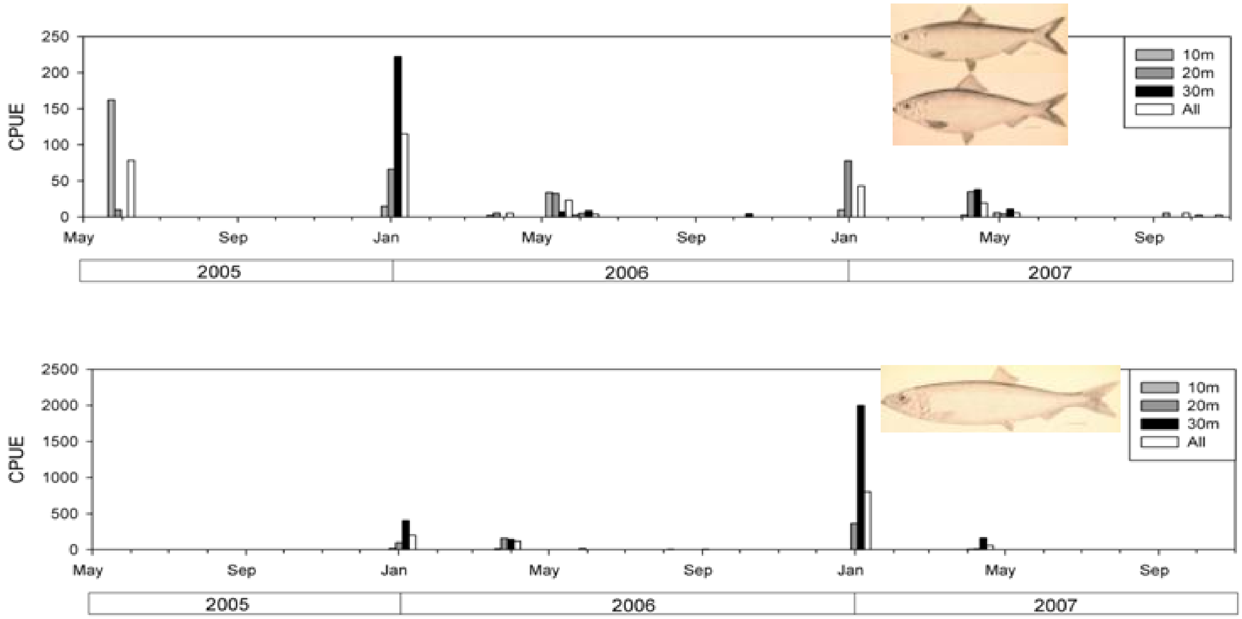
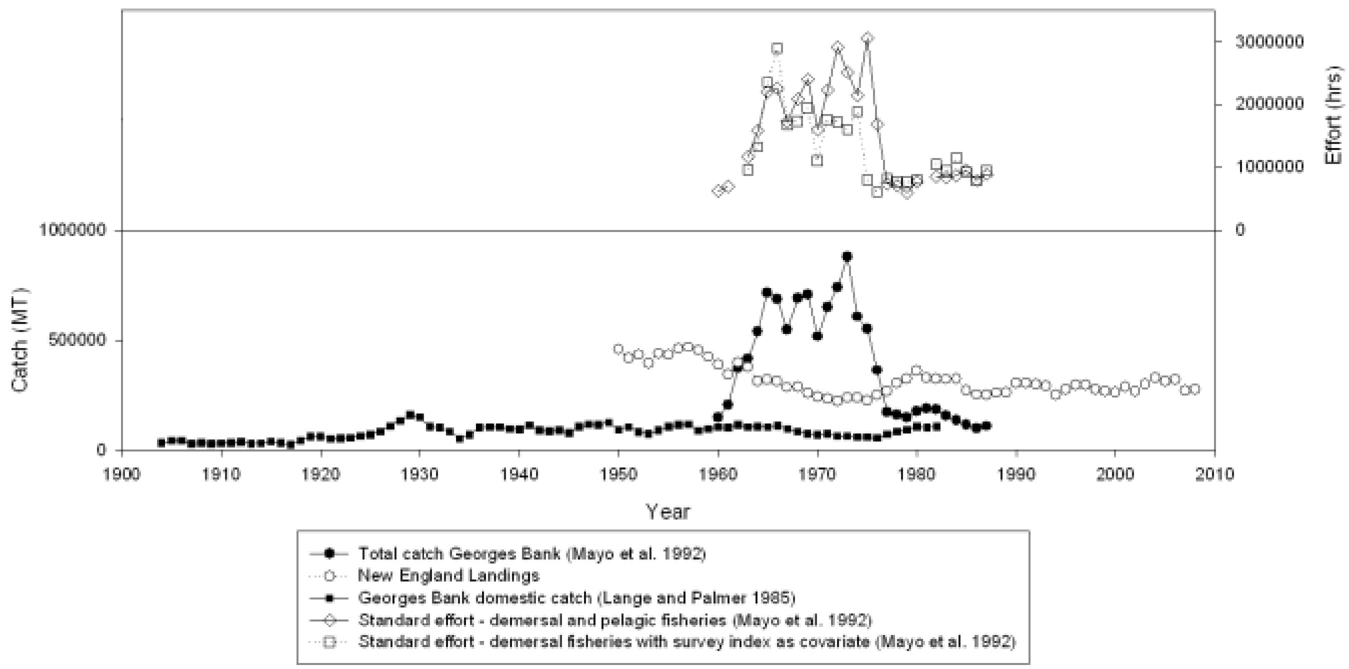


Figure 26. Seasonal catch per unit effort of river herring (upper panel) and Atlantic herring (lower panel) from Long Island Sound trawl surveys (Jordaan *et. al*, unpublished data) *from Jordaan presentation on 06/22/12 in Gloucester, MA.*



Jordaan, A., D.O. Conover and M.J. Fogarty. In Prep. Fisheries-induced juvenilization of northwest Atlantic ecosystems.

Figure 27. Fishing effort hours (upper panel) and catch in metric tons (lower panel) for fishing on Georges Bank from the early 1900's to 2009 (Jordaan *et. al*, unpublished data) *from Jordaan presentation on 06/22/12 in Gloucester, MA.*

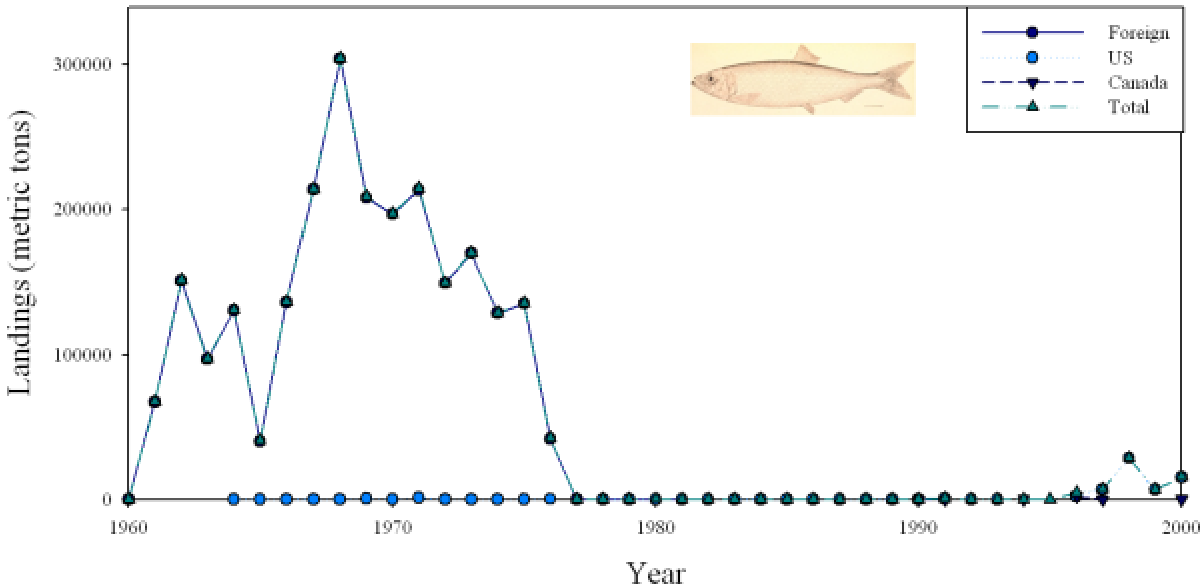


Figure 28. Landings (metric tons) of Atlantic herring in Georges Bank for Canada, U.S., and foreign fleets (Jordaan *et. al*, unpublished data) *from Jordaan presentation on 06/22/12 in Gloucester, MA.*

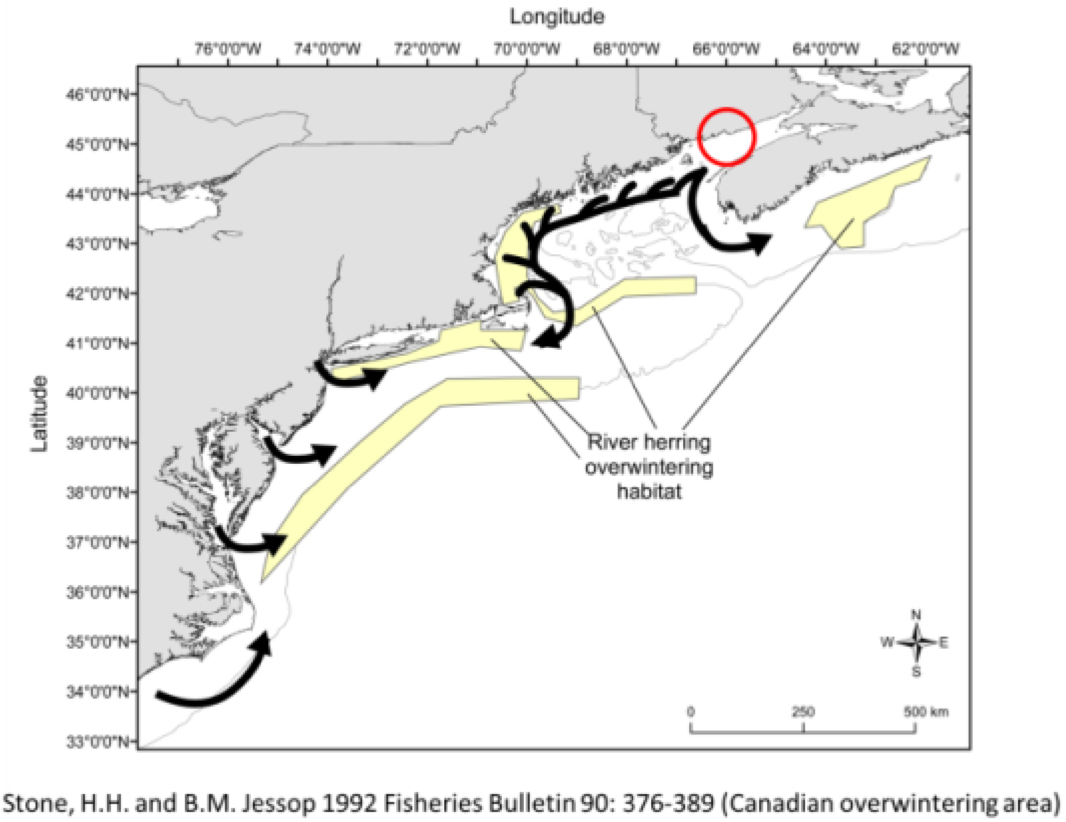


Figure 29. Hypothesized river herring overwintering areas and migration pathways. The Scotian shelf overwintering area was previously identified in Stone and Jessop (1992) *from Jordaan presentation on 06/22/12 in Gloucester, MA.*