# River Herring
# Spawning Stock Assessments
# in the
# Lower Connecticut River Basin 2013-2017

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**Introduction**

Alewife (*Alosa pseudoharengus*) and Blueback Herring (*Alosa aestivalis*) are anadromous fish species that are collectively referred to as river herring.  Blueback Herring are known to range from the southern Gulf of St. Lawrence (Canada) southward to the St. Johns River, Florida (Greene et al. 2009).  The range of Alewife is reported from the southern Gulf of St. Lawrence, including portions of Newfoundland southward to South Carolina (ICUN 2017).  A recent range contraction to the north has been observed for Alewife with the current southern extent of range for this species more accurately assigned to river basins north of Cape Fear, North Carolina (North Carolina Division of Marine Fisheries and South Carolina Department of Natural Resources unpublished data).  Both species are iteroperous (may spawn repeatedly), returning to freshwater systems in the spring when sexually mature to spawn.  Alewife are known to more commonly utilize lentic sites (i.e., pond) for spawning and nursery habitat and spawn in temperatures beginning to range from 5-10°C (Loesch 1987).  Blueback Herring are known to more commonly utilize lotic or riverine habitat for reproduction, but in the absence of co-occurring Alewife may use a wider range of habitats for spawning beginning in water temperatures ranging from 10-15°C (Loesch 1987; Greene et al. 2009).

The Connecticut River supports both Alewife and Blueback Herring populations that were impacted by restrictions to historic habitat (dams), water quality impairment, and harvest (inland and marine) over time.  The status of these species and other anadromous species concerns led in the mid-1960s to the development of the modern cooperative fish restoration program (Gephard and McMenemy 2004).  The Connecticut River Policy Committee to restore anadromous fishes, initiated in 1967 by the four basin states and federal fishery agencies, later led in 1983 to the Connecticut River Atlantic Salmon Commission (CRASC) approved by both Congress and the four State governments of the basin.  The CRASC has worked to improve the status of diadromous species and developed the Management Plan for River Herring in the Connecticut River Basin (2004) and the River Herring Restoration and Status Plans in the Connecticut River Basin (2015).

The Holyoke Dam, Massachusetts (river kilometer 139), provides a long-term data set for adult Blueback Herring (index of abundance). Following major fish passage improvements at the Holyoke Dam to its fish lift system in 1976, a dramatic increase in annual passage counts was observed four years later.  The record passage count of over 630,000 Blueback Herring occurred in 1985. However, the Blueback Herring population experienced later significant declines, based on these annual fish passage counts, beginning in the early 1990s (Figure 1).  Coupled with low Alewife adult returns as monitored by the Connecticut Department of Energy and Environment (CTDEEP) Fisheries Division, river herring fisheries were declared closed in Connecticut beginning in 2002, soon followed by the Commonwealth of Massachusetts.



Figure 1.  Annual Blueback Herring fish passage counts for the Holyoke Fish Lift for the period 1970 to 2017.
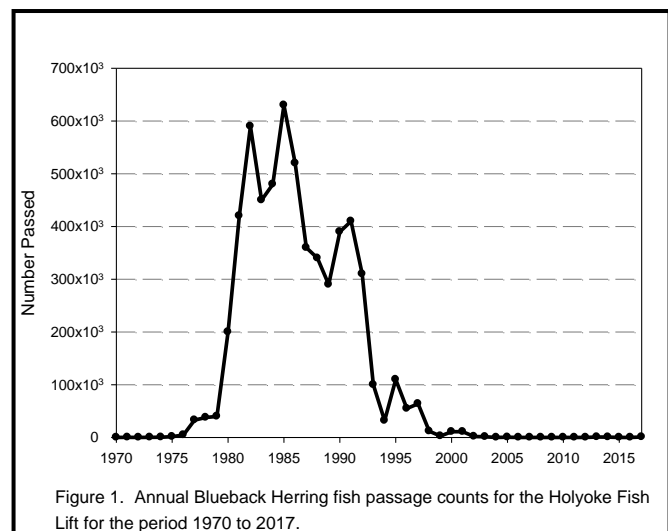
The Atlantic States Marine Fisheries Commission (ASMFC) also actively manages river herring as a species group, including the regulation of any recreational and/or commercial fisheries in State

jurisdictional waters, by state/federal legislation. The ASMFC completed a Coastwide Benchmark Stock Assessment (2012) that concluded river herring were "depleted," at all-time low level of abundance and impacted by a number of likely contributing factors including, freshwater habitat loss/degradation, dams, water quality/pollution, changing marine conditions, overharvest and bycatch. Findings of that assessment included recommendations to fill in substantial data gaps and improve monitoring efforts, including data for the Connecticut River. The National Marine Fisheries Service (NMFS) has been petitioned and has reviewed these species for consideration under the Endangered Species Act and determined a not warranted finding (2013) and is again (2017) in a review process for these species. The NMFS has identified the two species (defined as river herring) as "Species of Concern" since 2006. The Connecticut River basin states all also recognize Blueback Herring as a "Species of Greatest Conservation Need" with Connecticut also including Alewife in their respective USFWS Wildlife Action Plans. The recently completed ASMFC River Herring Stock Assessment Update (2017) examined updates of data sets from the 2012 Benchmark Assessment. The findings in this report maintain the conclusion that river herring stocks "…*continue to be depleted on a coastwide basis and near historic lows*."
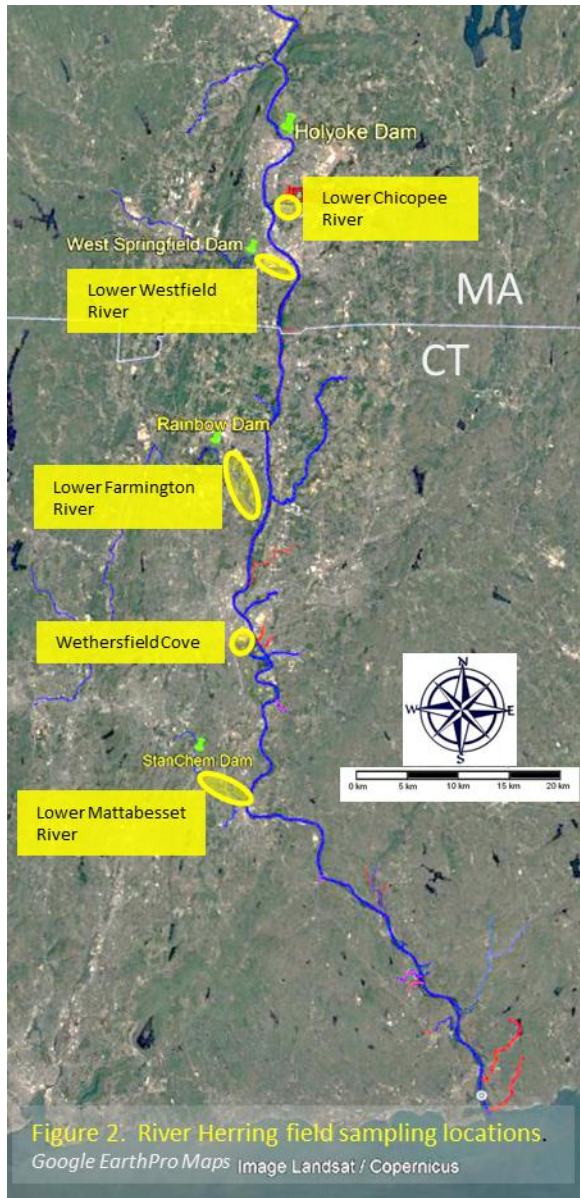
The objectives of this project were developed to address the defined data deficiencies described in the ASMFC River Herring Benchmark Stock Assessment (2012) for both adult Blueback Herring and Alewife during the spawning run for status and trends on: 1) relative abundance; 2) stock demographics length/weight/sex; 3) age structure; 4) spawning history; and 5) examine these data and other data/variables with appropriate statistical procedures. These data will be eligible for inclusion in the next planned ASMFC River Herring Benchmark Stock Assessment (anticipated in 2023) with the required minimum ten year data time-series.

**Methods**

A fixed site sampling design is used to sample primarily lower reaches of Connecticut River main stem tributaries downstream of Holyoke Dam (rkm 139), Holyoke, Massachusetts (Figure 2). A Smith Root (SR18) model electrofishing boat with a 5.0 GPP electrofisher, using two anode booms off the bow (~2m) with a Wisconsin style anode (six) dropper array off each boom, is used to survey study areas moving in a downstream direction at a rate slightly greater than stream flow (or 3-5 km/hr). Sampling was conducted in both the day and night time in 2013 but has been exclusively in the day since 2014. Electrofisher settings are based on measured water conductivity and observed responses of fish to the electrical field, to illicit a narcosis response in proximity to the anodes. Only pulse D.C. (90 hertz, at 200-400 volts) and 3-4 amps (as metered on console) are used with the boat hull as the cathode. Two netters are located at the bow and apply power at intervals of "on" for ~5 seconds, followed by "off" for ~5 seconds to reduce pushing fish in front of the electrical field. The electrofisher's time meter is used to standardize electrofishing effort to 500 seconds of "on time" for a sample run. In this manner, typically between 5-7 sampling runs are completed in a sample outing, dependent primarily on catch numbers and subsequent processing time. Using individual run catch totals and metered time, catch rates are determined for each run and expressed in fish/minute (f/min). At the end of each sample run, fish are processed for species assignment (visual relationship of eye diameter to head) biological data (total and fork length (mm), weight (g), and sex) by species and a subsample is randomly removed from the live well for each run, for additional processing in the laboratory. Subsampled laboratory fish are placed in uniquely marked bags that correspond to their field measurements on field data sheets. The initial laboratory target of n=50 fish per sample date, has been increased over the study period, with a current target of n=80 fish for each sample date. Beginning in 2016, spawning condition was also assigned (gravid, ripe/running, partially spent, and spent) based on expression of gametes. This

approach has the benefit of better describing spawning condition of fish during assessments and the context of fish weight data (spent vs. gravid weight fish).

Electrofish sampling is initiated between late March and early April, based on river discharge and water temperatures with the intent of sampling early Alewife arrivals prior to preferred spawning temperatures (<5°C). In the first several weeks of the survey, the lower Mattabesset River and Wethersfield Cove areas are sampled to obtain the less commonly observed Alewife that arrives prior to Blueback Herring in these areas (Figure 2). Once Blueback Herring are first observed sampling in these early sites, additional sampling of the lower Farmington River is initiated (Figure 2).



Figure 2. River Herring field sampling locations.
Google EarthPro Maps Image Landsat / Copernicus

Sampling is conducted on a weekly basis rotating among these areas. At the end of April, the Mattabesset River is dropped from the sampling rotation and the lower Westfield River and lower Chicopee River are added, also sampled weekly and on the same date given proximity to each other (Figure 2). There have been additional sporadic sampling efforts in other areas that were discontinued: in 2013 the main stem river downstream of Holyoke Dam (South Hadley, MA) and the main stem in the area of Glastonbury, CT; and 2015 Salmon River Cove (Haddam, CT).

As the Blueback Herring spawning run progresses in the spring, catch rates can on occasion become an issue for live well capacity, when too many fish are stunned and collected on a sample run. On sample runs where it is estimated >75 fish have been placed in the live well, the run is suspended and the reduced electrofisher time is noted for adjustment in catch rate determinations. On the occasions of large run sample sizes, once a minimum of 60 fish have been processed (length etc.), the remaining fish are identified to species, counted and released, with that number identified on the field data sheet for use in catch rate determinations. Field sampling is typically ended between early and mid-June, based on observed catch rates and spawning condition of collected fish.

Fish that are retained for laboratory processing are placed on ice and refrigerated for next day dissections. Fish are checked for peritoneal color (black for blueback, pale for Alewife) to confirm field species identification and sex. Fish that have been identified as possible hybrids based on intermediate eye diameter characteristics are confirmed for species or noted as a possible hybrid (intermediate color peritoneal tissue), based on lab examination. A scale sample is taken from left side of the fish ventral of the dorsal fin and anterior to the lateral line and placed in an envelope with the associated fish data for

tracking.  The otolith bones are extracted from the cranium, wiped and rinsed clean of all tissue fluid and placed in a labeled vial that is left open for air drying prior to being sealed (24 hrs).  The dissection process follows the protocols for these species developed by the Massachusetts Division of Marine Fisheries (MADMF) (Elzey et al. 2015).

Whole otoliths are examined in mineral oil using a digital imaging (camera) system and image analyses software to determine fish ages.  The MADMF has developed and refined fish aging techniques for adult river herring using the same digital imaging hardware and software system that we have adopted and been trained on by MADMF (Elzey et al. 2015). In addition, the ASMFC's River Herring Aging Workshop Report (2014) included a recommendation to adopt the MADMF protocols for river herring aging based on analyses of aging data comparisons.  Our office uses a single reader (same biologist) for otolith age determinations and includes a confidence measure for each assignment.  In addition we have on an ongoing basis maintained communication with MDMF on questionable otolith samples as well as reviews of assignments with otolith subsets to maintain a consistent approach and interpretation with MADMF.  In addition, we have developed our own reference collection of otolith samples that have been reviewed and determined consistent with MADMF interpretations for age assignments.

River herring scale samples are cleaned in warm water using brushes and eight scales (six prior to 2017) are placed on a glass slide, covered by another slide, and labeled with associated data.  Scales are examined with use of microfiche projectors.  The Connecticut Department of Energy and Environment (CTDEEP) Fisheries Division has an established protocol for the reading of river herring scales for both age and spawning mark determination using similar projectors.  Our staff is annually trained with CTDEEP in the identification of spawning marks to determine spawning history of sampled fish.  Scale reading effort has varied over time due to available staff, ranging from single readers (different staff) 2013 – 2016, to three independent readers (2017).  Only the 2017 data will be presented in this report.

**Results**

*Effort, Catch, Relative Abundance*
Sampling start and end dates and effort (both dates and electrofishing effort) have varied over time from the first survey year of 2013 to 2017.  A fairly consistent increase over the report period is observed in both the number of dates and electrofishing effort as reported in runs and seconds (Table 1). Note that differences among years between number of runs and electrofishing seconds is affected by the number of occasions that high catch rates resulted in the early termination of a run (<500 seconds).

Table 1.  Summary data on assessment number of sample dates, start and end dates, total sample runs, total electrofishing seconds by sample year.

|  | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|
| Number of sample dates | 21 | 21 | 20 | 25 | 26 |
| First sample date | 4/08/13 | 4/07/14 | 4/09/15 | 3/30/16 | 3/29/17 |
| Last sample date | 6/21/13 | 6/18/14 | 6/04/15 | 6/02/16 | 6/14/17 |
| Total sample runs | 81 | 124 | 114 | 145 | 145 |
| Total electrofishing seconds | 41,177 | 55,736 | 56,025 | 71,845 | 68,353 |

Catch rates and sample sizes for both Blueback Herring and Alewife vary substantially over time and among sample locations, reflected in terms of fish/min due to the patchiness of river herring and a number of other factors.  Catch rates may be affected by variables that also vary among sample area

within and among years.  Examples of these variables include: catchability of fish (affected by changes in electrical field range/setting/response); netter efficiency/skill; water transparency, water current velocity, water depth; wind (broken water surface); light levels and type (glare); and number of fish stunned (gear saturation).   For these reasons, relative abundance measures must be considered with caution.  In addition, examination of catch rate data should take into account sampling efforts in times when fish are not expected to be present (arrived) due to variables such as water temperatures or river discharge.   Summary results for annual sample totals and mean catch rates for Blueback Herring are presented with some censoring of data including: 1) for f/min - use of only catch data from four site areas (Wethersfield Cove, Farmington River, Westfield River and Chicopee River); 2) use of only sample dates beginning once BBH have been confirmed as present at any site;  and 3) catch data from the Westfield and Chicopee River are combined in calculating daily mean catch rates as those are sampled the same day and sample runs can be as few as one in the lower Chicopee River (Table 2).  There was no detectable correlation between annual mean f/min values and Holyoke Fish Lift counts.  In 2017, Holyoke Fish Lift accounted for 95% of the total Blueback Herring counted at first barriers in the basin. The other lower basin fish passage facilities that typically count bluebacks are; Moulson Pond (Eightmile R), StanChem (Mattabesset R), Rainbow (Farmington R), and West Springfield (Westfield R), which range from 5 to 13 rkm upstream from the main stem (CRASC 2015).

Table 2.  A summary of total annual Blueback Herring (BBH) catch, among all sampling locations, date of first BBH catch (in all years - sampling produced several weeks of zero BBH before a first capture), arithmetic mean catch rate by year, for BBH (Wethersfield Cove, Farmington River, Westfield River, and Chicopee River sites) with standard deviation (S.D.) and coefficient of variation (C.V.) using only dates after an initial BBH capture was documented (any site). Mean is calculated from sample date mean f/min (based on all runs of that date), which aggregates Westfield River and Chicopee River (1 or 2 runs not uncommon for this site) catch rates under a single date (date both are surveyed).

| Year | BBH captured (n) | Date of first BBH capture | Mean BBH f/min 4 primary areas | S.D. | C.V. (%) | Holyoke Fish Lift BBH Count |
|---|---|---|---|---|---|---|
| 2013[A] | 714 | 4/10/13 | 2.10 | 5.63 | 268 | 976 |
| 2014[B] | 2,593 | 4/23/14 | 8.51 | 12.96 | 152 | 647 |
| 2015 | 1,508 | 4/21/15 | 2.73 | 3.70 | 136 | 87 |
| 2016 | 1,586 | 4/21/16 | 2.18 | 2.57 | 118 | 137 |
| 2017 | 2,650 | 4/05/17 | 4.01 | 7.11 | 177 | 875 |
| Total | 9,051 | | | | | |

[A] includes 73 BBH collected in main stem sampling – discontinued sample area
[B] includes 7 BBH sampled in main stem sampling – discontinued sample area

Catch rates (relative abundance) for Blueback Herring vary substantially among sampling sites within a sampling year and over the season at individual sites.  In 2017, the mean f/min catch rates, with standard deviations, plotted against date, illustrate timing of measured blueback relative abundances (Figure 3).  The plotted water temperature, from USGS Thompsonville Gage (CT) is generally similar to slightly lower than sample site area water temperatures, which may warm at a faster rate in the spring (particularly Wethersfield Cove).  Changes in observed annual mean catch rates of Blueback Herring are illustrated in box plots using individual run catch rates for each year by sample area (Figure 4).
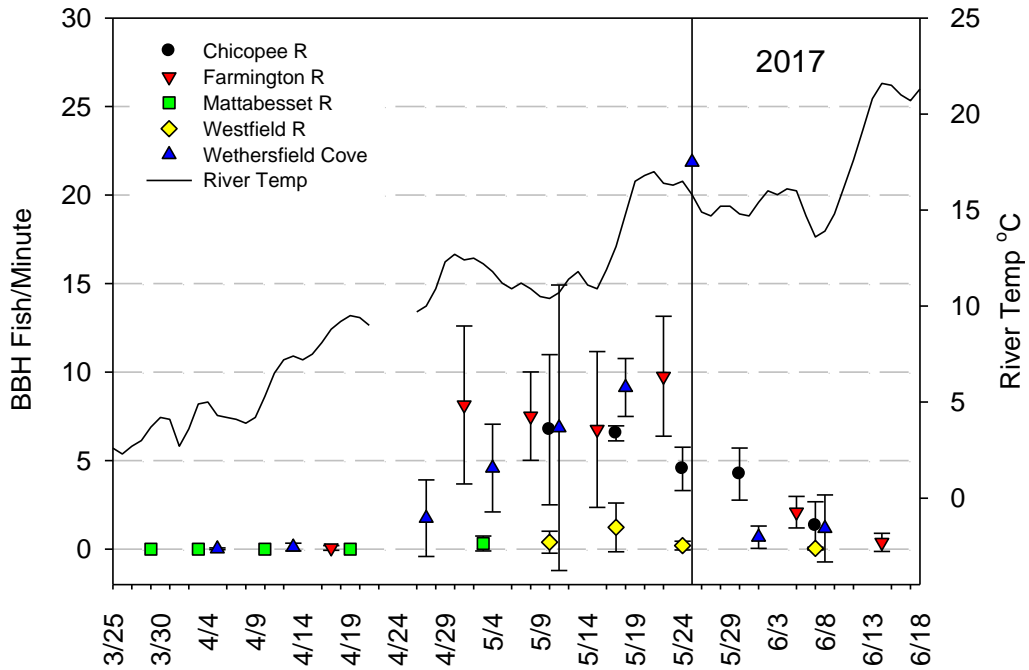
Figure 3. Blueback Herring CPUE expressed as mean fish/minute ± 1 standard deviation, by sample area and date for 2017 season. Reported water temperature is the daily mean, USGS Thompsonville, CT (main stem, old Enfield Dam site).
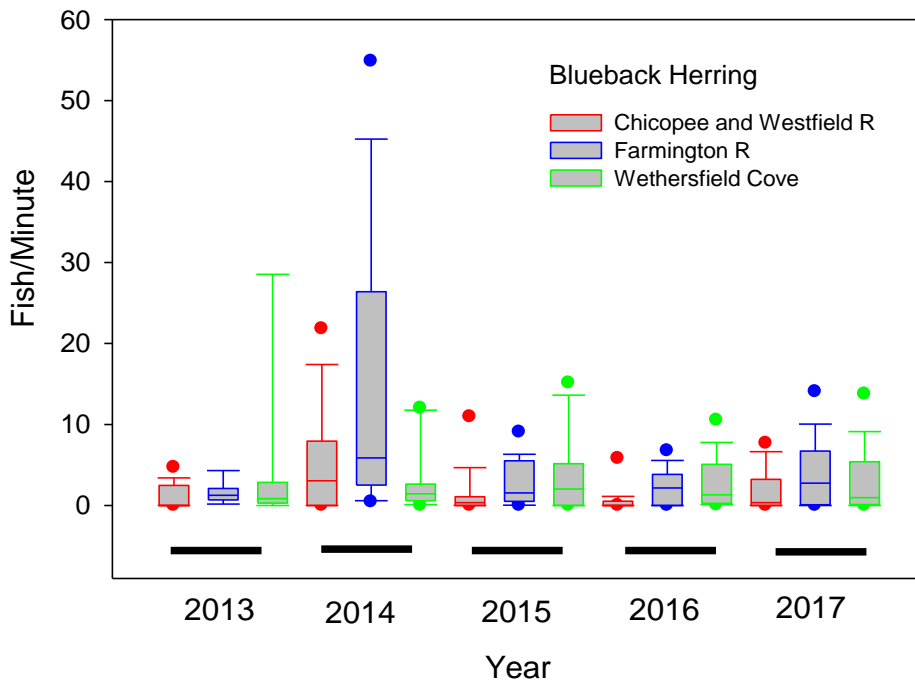


Figure 4. Blueback Herring annual catch rate summaries (using individual run f/min values) for the Chicopee and Westfield river sites combined, Farmington River, and Wethersfield Cove; bottom of box 25th percentile, line in box median, top of box 75th percentile, top line 95th percentile, bottom line 5th percentile.

Blueback Herring annual sample totals varied among sites over the report period but has generally been dominated by the Farmington River (Table 3). Sampling effort, as reported by number of sample runs is an important consideration along with timing of sampling given temporal shifts in run timing (ending Mattabesset River sampling by late April).

Table 3. The total number of Blueback Herring captured annually (n) at the four standard sampling areas with the total number of sample runs (n).

| Sample Area | 2013 Fish n (Run n) | 2014 Fish n (Run n) | 2015 Fish n (Run n) | 2016 Fish n (Run n) | 2017 Fish n (Run n) | Row Totals Fish n (Run ) |
|---|---|---|---|---|---|---|
| Mattabesset R. | 6 (9) | 19 (29) | 4 (23) | 5 (35) | 16 (33) | 50 (129) |
| Wethersfield Cove | 182 (19) | 332 (27) | 583 (28) | 592 (41) | 1,001 (48) | 2,690 (163) |
| Farmington R. | 182 (14) | 1,425 (31) | 722 (32) | 902 (47) | 1,190 (39) | 4,421 (163) |
| Westfield R. | 188 (12) | 310 (16) | 92 (16) | 18 (17) | 60 (14) | 668 (75) |
| Chicopee R. | 83 (14) | 500 (14) | 107 (5) | 69 (5) | 383 (11) | 1,142 (49) |
| Column totals | 641 (68)[A] | 2,586 (120)[B] | 1,508 (114) | 1,586 (145) | 2,650 (145) | 8,971 (589) |

[A] main stem S. Hadley, MA and Glastonbury, CT samples omitted (n=73 fish and 13 runs), not sampled after 2014
[B] main stem S. Hadley, MA sample omitted (n=7 fish and 7 runs), not sampled after 2014

Summary results for annual sample totals and mean catch rates for Alewife (ALW) are presented with some censoring of data including: 1) for f/min - use of only catch data from the Mattabesset and Wethersfield Cove; and 2) use of only sample dates beginning once ALW have been confirmed as present at any site (Table 4). Unlike BBH, the first sampling dates of the year have yielded catches of Alewife in all years, at low levels of abundance. The sole exception was in 2015, when the Salmon River Cove was sampled first on April 9, producing no fish, but on the following week the Mattabesset was first sampled and ALW were captured. As the Mattabesset River is sampled typically only to the end of April, all dates are used for catch rates of ALW. However, as the Wethersfield Cove site is sampled for the full season, ALW become rare (single individuals) and eventually absent in May. Accordingly, the catch data for ALW were also censored for Wethersfield Cove dates when "zero" ALW are captured in the month of May in all years (typically mid-May) in Table 3. Alewife were collected in differing percentages over the five years, summed among all study sites with the Mattabesset River (71%) contributing the largest samples followed by Wethersfield Cove (21%) (Figure 5). Only two Alewife were collected at one of the two most upstream sites (Chicopee River) over the report period.

Table 4. A summary of total annual Alewife (ALW) catch, among all sampling locations, date of first ALW catch, arithmetic mean catch rate by year for ALW (Mattabesset River and Wethersfield Cove sites) with standard deviation and coefficient of variation. Mean is calculated from sample date mean f/min (based on all runs of that date).

| Year | ALW captured (n) | Date of first ALW capture | Mean ALW f/min two primary areas | S.D. | C.V. (%) | Mean April Discharge[A] |
|---|---|---|---|---|---|---|
| 2013 | 107 | 4/08/13 | 0.41 | 0.48 | 117 | 33,360 |
| 2014 | 220 | 4/07/14 | 0.50 | 0.75 | 150 | 54,670 |
| 2015 | 257 | 4/15/15[B] | 0.68 | 1.06 | 156 | 43,350 |
| 2016 | 586 | 3/30/16 | 1.01 | 1.63 | 162 | 23,290 |
| 2017 | 200 | 3/29/17 | 0.37 | 0.59 | 160 | 31,650 |
| Total | 1,370 | | | | | |

[A] Mean discharge provided by USGS Thompsonville, CT Gage
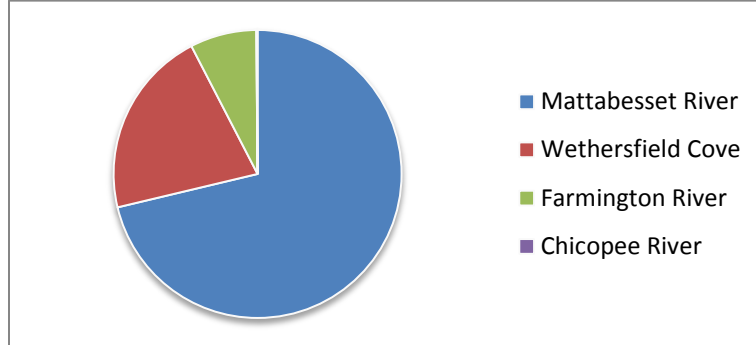[B] First sample date for Mattabesset that year, later than typical

Figure 5.  The relative percent contribution of the total number of Alewife sampled in surveys from 2013 to 2017 among four survey locations.

The Mattabesset River sample area, to a larger extent than other sites, may have catch rates affected by main stem river discharge in addition to its own discharge (Mattabesset is not USGS gaged).  The lower Mattabesset River has a large marsh and swamp floodplain component that is very low gradient in the sampled area.  As a result, when the main stem backwaters into the lower Mattabesset River, flooded habitat available to ALW increases dramatically and is believed to influence catch rates.  The highest annual catch rate and sample size obtained in April 2016, had the lowest mean monthly discharge of the study period, restricting fish over the sample period to a more defined stream channel and more limited cove areas (Table 3).  However, a log transformed regression analyses of mean river discharge versus mean f/min was determined not significant using the data in Table 3.

*Fish Length, Sex, Weight*
The number of Blueback Herring sampled for length, weight and sex over the report period total 8,444 fish among all sample locations.  This total is lower than the reported capture total (basis for CPUE) of 9,051 based on the subsampling approach for occasions of large sample sizes in a given run, described in Methods.  Length frequency distribution by year for all processed Blueback Herring (sexes combined) is shown in Figure 6.  The sex ratio for all years combined was skewed, with 2,307 females (27.9%) vs. 5,949 males (72.1%) sampled over the five year period (Table 5).  Among years, the annual proportions of females were fairly consistent, ranging from a low of 22.0% (2014) to a high of 33.4% (2016).
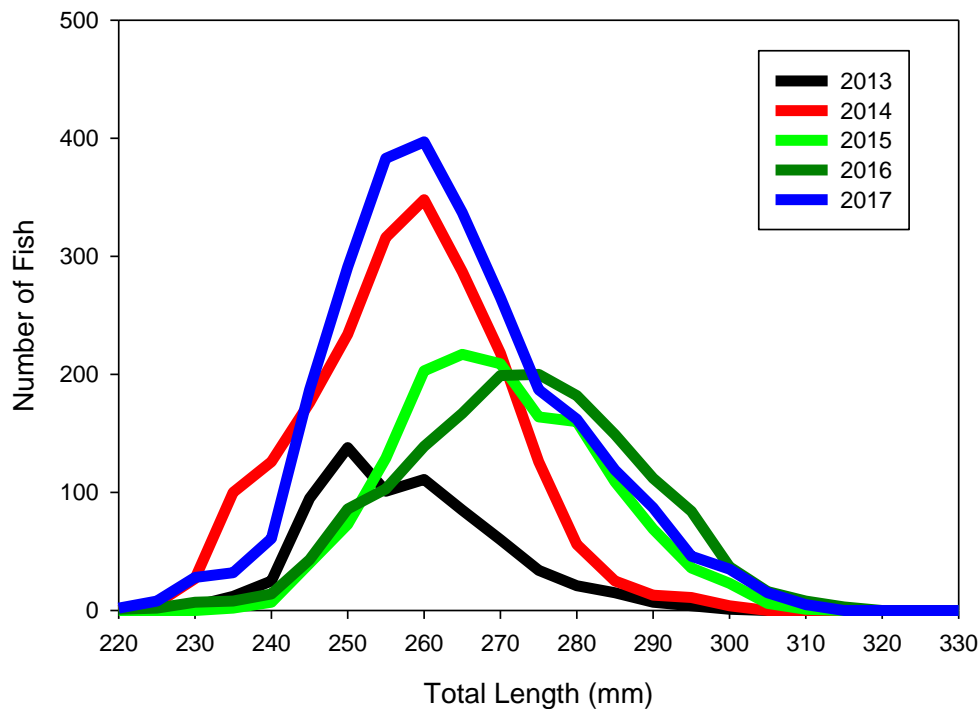
Figure 6. The cumulative length frequencies of all sampled Blueback Herring (sexes combined) by year.

The mean total length for Blueback Herring sampled at all sample locations by sex were examined for differences by sex (Table 5). There were a number of detected differences, for each sex, relating to increases in fish length in 2015 vs. 2014 followed by a smaller degree of increase in 2016 vs. 2015, followed by declines in both sizes for 2017 that were across all years, similar in their magnitude. These shifts in mean size will be explained in greater detail using age structure results that follow. As expected, based on differences in maturity rates, mean male total length was consistently smaller than female in all years (Loesch 1987). Mean annual total length, described by year, site and sex for Blueback Herring are described and were examined for statistical differences (Appendix A).

Table 5. The annual mean total length (mm) of all Blueback Herring sampled among all sampling areas by year and by sex. An ANOVA test, sex specific, was followed by pairwise comparisons with significant differences ($P < 0.05$) indicated by letter (year) assignments.

| | Male | | | Female | | |
|---|---|---|---|---|---|---|
| Year | n | Mean TL mm (± SD) | Signf. Diff. | n | Mean TL mm (± SD) | Signf. Diff. |
| 2013[A] | 412 | 253.8 (12.1) | C, D, E | 131 | 264.9 (12.6) | C, D, E |
| 2014[B] | 1,617 | 253.8 (11.4) | C, D, E | 456 | 264.9 (13.2) | C, D, E |
| 2015[C] | 984 | 263.0 (10.4) | A, B, D, E | 464 | 277.8 (11.7) | A, B, D, E |
| 2016[D] | 1,036 | 265.2 (13.3) | A, B, C, E | 519 | 281.3 (13.0) | A, B, C, E |
| 2017[E] | 1,900 | 257.5 (12.7) | A, B, C, D | 737 | 271.7 (14.9) | A, B, C, D |

Annual length frequency distribution of Blueback Herring sampled from the Farmington River, provide the largest sample size to explore shifts in distribution by sex at a single sample area (Figure 7). The Farmington River demonstrated a shift of increasing length distributions for both male and females from 2014 to 2016.



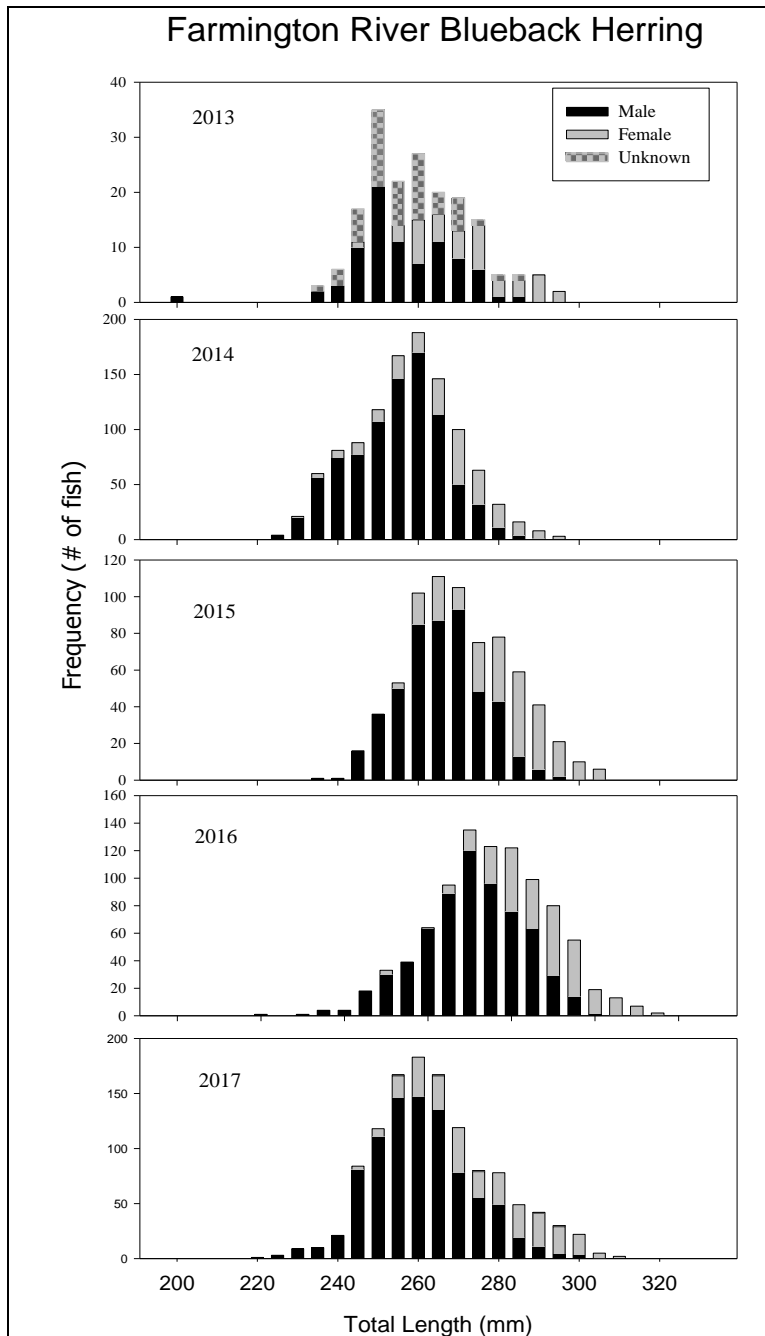Figure 7. Annual length frequency distributions (TL mm) for male and female Blueback Herring sampled from the Farmington River. Bars have values stacked, for each sex, the total number of fish is shown by the bar.

Blueback Herring length vs. weight data, by sex shows the expected increase in weight with fish length as well as greater weight at length for males vs. females (Figure 8). The mean weight (± SD) for Blueback

Herring males, all years and sites (n=5,880) is 148.5 g (± 25.6).  The mean weight for Blueback Herring females, all years and sites (n=2,283) is 181.7 g (± 36.4).  The 2017 data, utilizing a field assigned fish spawning condition (e.g., gravid, running, partial spent, spent) with weight and plotted by sex, provide improved resolution of length to weight relationships for females (Figure 9). However, for males, field spawning conditions assignments were nearly always determined ripe/running resulting in no discernible differences (Figure 10).
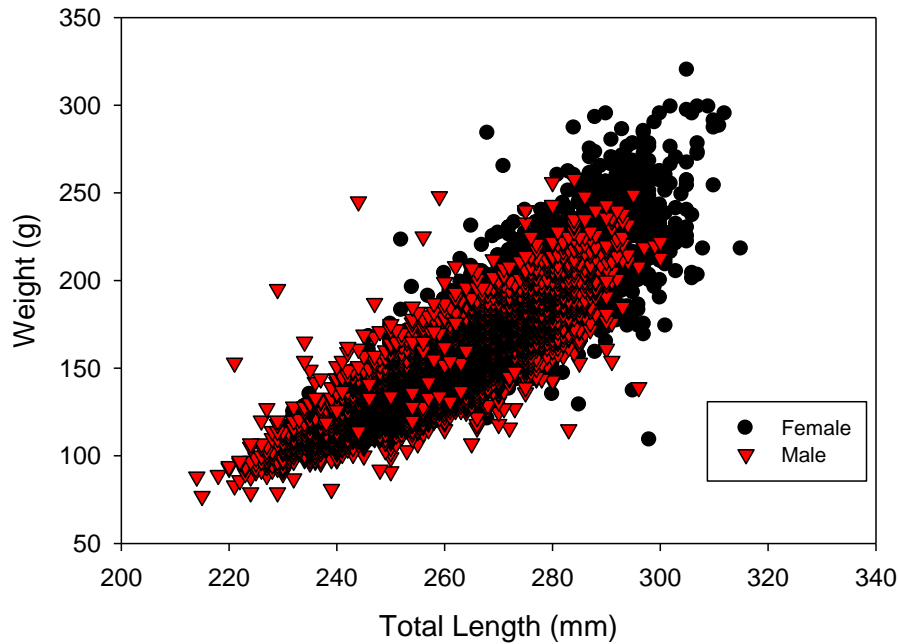


Figure 8.  Blueback Herring length to weight relationships for males and females, all years combined.
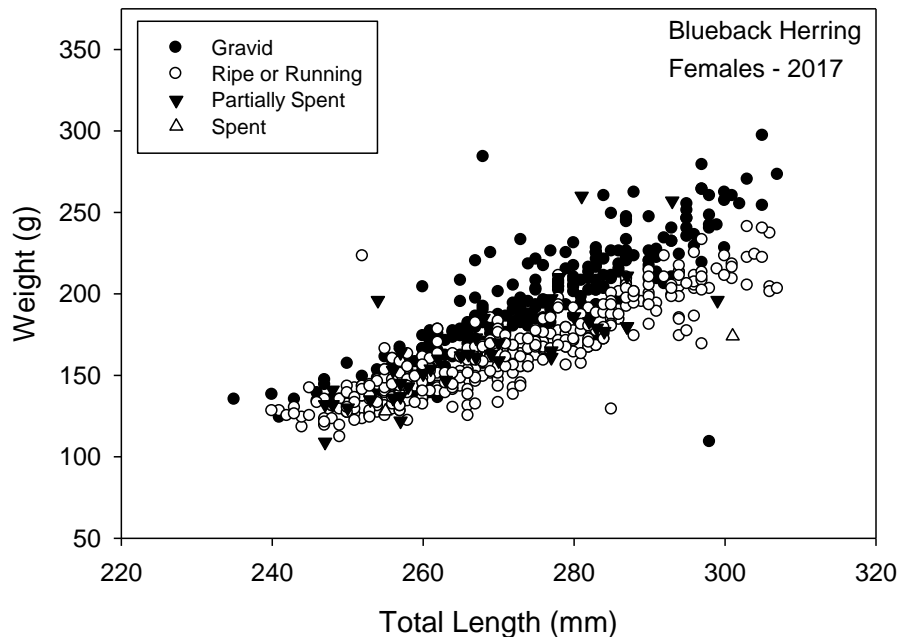


Figure 9.  Female Blueback Herring length to weight relationship, based on field spawning condition assignment, for fish sampled in 2017.
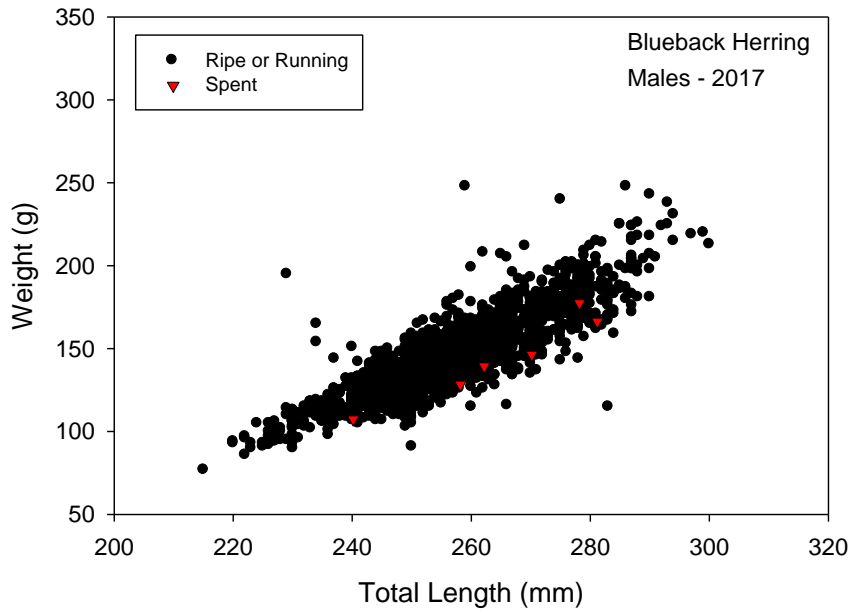
Figure 10. Male Blueback Herring length to weight relationship, based on field spawning condition assignment, for fish sampled in 2017.

The number of Alewife sampled for length, weight and sex over the report period total 1,372 fish among all sample locations.   Length frequency distribution by year for all processed Alewife (sexes combined) is shown in Figure 11.  The sex ratio for all years combined was skewed, with 426 females (31.2%) vs. 942 males (68.8%) sampled over the five year period (Table 6).  Among years, the annual proportions of females were more variable than observed with the Blueback Herring sample that had consistently greater sample sizes.  The proportion of Alewife females ranged from a low of 24.0% (2014) to a high of 62.1% (2013).  Removing the 2013 data, the smallest annual sample, n=103 of known sex fish, the mean proportion of annual sampled females is 29.3% for 2014-2017 that is very similar to the annual mean reported for Blueback Herring (27.9%).
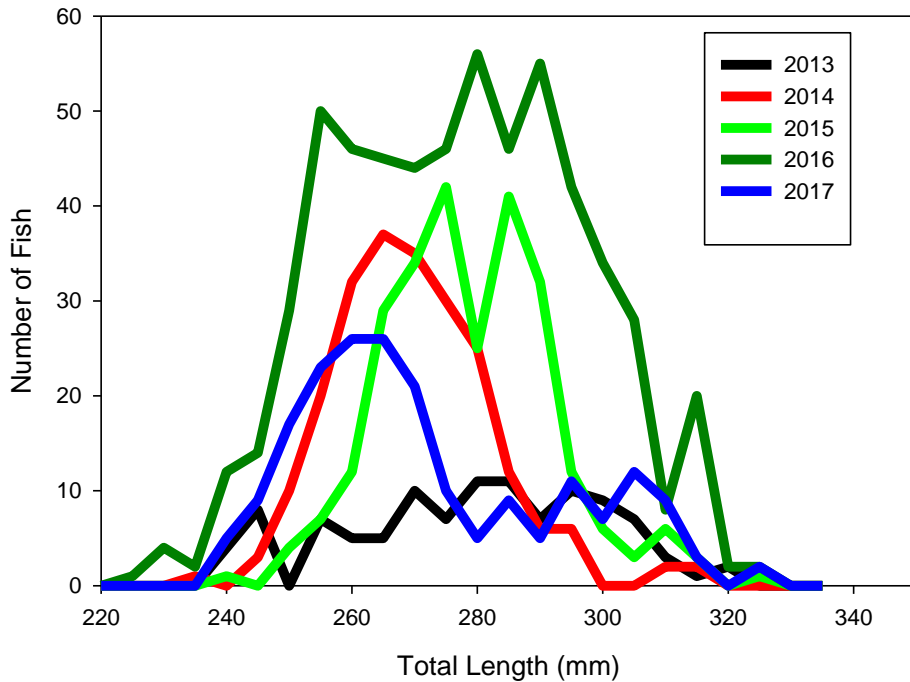
Figure 11. The cumulative length frequencies of all sampled Alewife (sexes combined) by year.

The mean annual total length for Alewife sampled at all sample locations, by sex were examined for differences by sex (Table 6). There were a number of detected significant differences, for each sex, between years. These shifts in mean size will be explained in greater detail using age structure results that follow. As expected, based on differences in maturity rates, mean male total length was consistently smaller than female in all years (Loesch 1987). Alewife mean length sizes by sex were greater in all between year comparisons with Blueback Herring. Mean annual total length, described by year, site and sex for Alewife are reported (Appendix B). Differences in reported mean lengths, among sites within year, were not tested for significance given the variability in timing and duration of sampling effort among areas, which may bias results of such a comparison.

Table 6.  The annual mean total length (mm) of all Alewife sampled among all areas by year and by sex.  An ANOVA test (by sex) was followed by pairwise comparisons with significant differences (P <0.05) indicated by letter (year) assignments.

| Year | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | n | Mean TL mm (± SD) | Signf. Diff. | n | Mean TL mm (± SD) | Signf. Diff. |
| 2013[A] | 39 | 261.6 (15.8) | C, D | 64 | 287.7 (16.2) | B, E |
| 2014[B] | 168 | 266.2 (10.8) | C, D | 53 | 276.1 (15.5) | A, C, D |
| 2015[C] | 188 | 273.1 (11.7) | A, B, E | 70 | 287.9 (12.4) | B, D |
| 2016[D] | 424 | 270.7 (18.0) | A, B, E | 162 | 286.4 (19.0) | B, E |
| 2017[E] | 123 | 265.0 (18.3) | C, D | 77 | 278.4 (21.4) | A, C, D |

*Age Structure*

Over the five year period (2013-2017), a total of 3,699 Blueback Herring (all sample areas) were laboratory processed for otoliths extractions, resulting in otolith based age assignments for 3,679 fish samples.  Fish ages ranged from age-2 (males only) to age-9 (both male and female, Table 7).   Percent contribution by age, for combined sexes, was influenced by the disproportionate contribution of male fish.  The greatest contribution (both sexes) was age-3 (30.1%) in a steadily declining rate to the oldest age-9 assignment that was only 0.2% of the total sample.  Length frequency comparisons between fish that were randomly sub-sampled in the field, for laboratory processing and aging from all captured fish by year, were developed (Appendix D).

Table 7. Blueback Herring age structure, all sites combined, combined sexes and by sex, for the years 2013 to 2017 inclusive.

| Age | Both Sexes | | Male | | Female | |
|---|---|---|---|---|---|---|
| | n | % | n | % | n | % |
| 2 | 34 | 0.9 | 34 | 1.3 | 0 | 0 |
| 3 | 1,107 | 30.1 | 870 | 32.5 | 237 | 23.6 |
| 4 | 988 | 26.9 | 734 | 27.4 | 254 | 25.3 |
| 5 | 798 | 21.7 | 546 | 20.4 | 252 | 25.1 |
| 6 | 555 | 15.1 | 366 | 13.7 | 189 | 18.8 |
| 7 | 164 | 4.5 | 110 | 4.1 | 54 | 5.4 |
| 8 | 24 | 0.7 | 11 | 0.4 | 13 | 1.3 |
| 9 | 9 | 0.2 | 5 | 0.2 | 4 | 0.4 |
| Totals | 3,679 | | 2,676 | | 1,003 | |

Shifts in length frequency distributions over time, reported earlier, are partially explained by observed shifts in the age structure for Blueback Herring.  In 2014, the proportional contribution of age-4 fish, both male and female was prominent and represented the 2010 cohort or year class (Figure 12).  The 2010 cohort has had an ongoing dominate overall contribution (relative to our data time series) in proportion age contribution starting in 2014 through the most current 2017 year as age-7.  The 2010 cohort had a relatively high juvenile index (JI) value 12.8 (geometric mean) determined from the annual CTDEEP juvenile main stem alosine seine survey (Roberts 2017).  To place the 2010 JI value in context, the CTDEEP mean annual geometric mean for the preceding 15 years is 4.6 with a standard deviation of

2.0 (Roberts 2017). CTDEEP reports annual geometric mean values have been variable in subsequent years; 2.9 (2011), 2.2 (2012), 6.9 (2013), 3.7 (2014), 8.63 (2015), and 1.55 (2016). Note that the 1.55 value is the lowest value in the complete time series. The data time-series remains relatively short at only five years, limiting many statistical examinations that will be more appropriately considered with ten years of data.
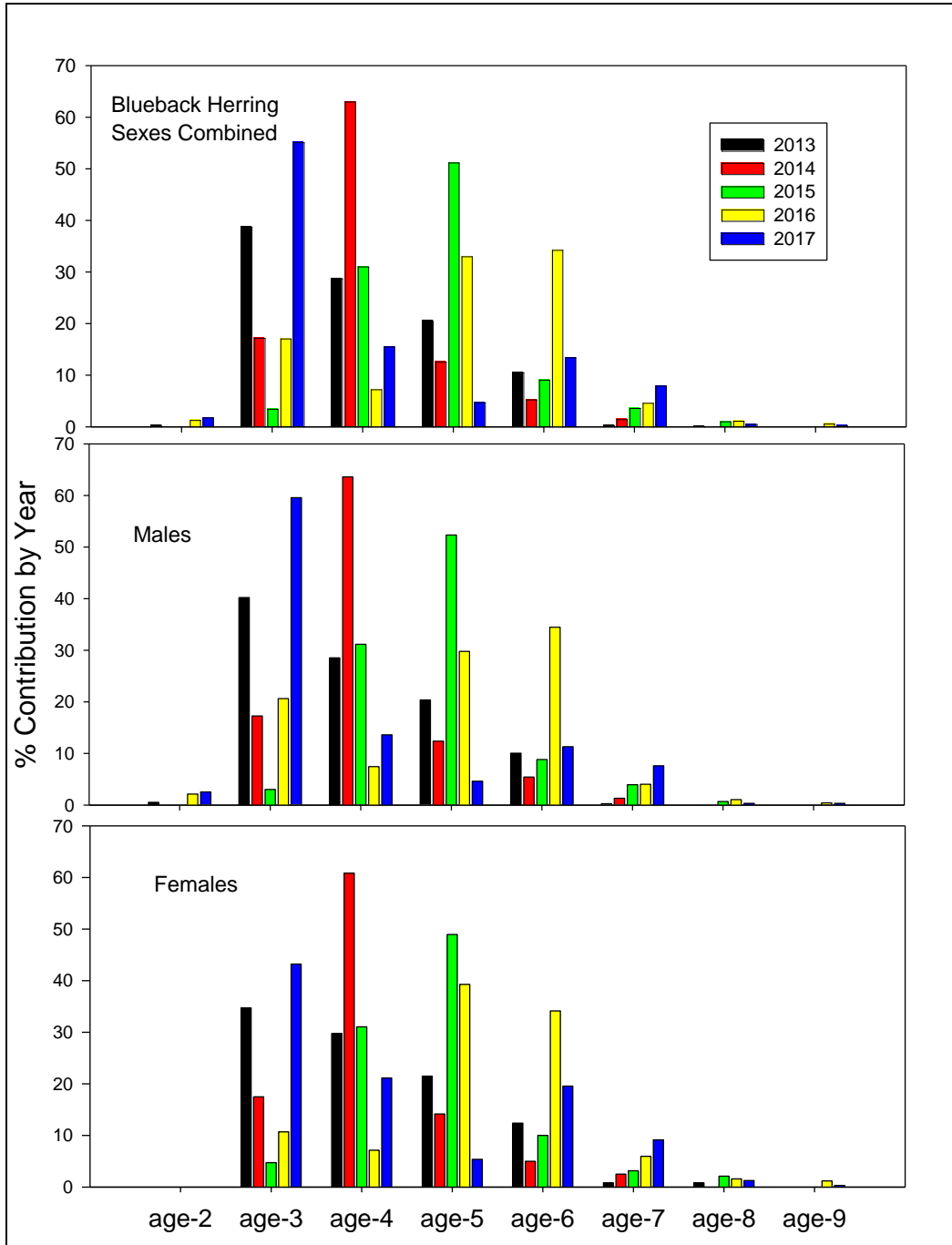


Figure 12. Top panel - annual age distribution, expressed as a frequency percentage (sum to 100%), for all Blueback Herring sexes combined, all sample sites 2013 – 2017 inclusive. Middle panel – annual age distribution for males only and bottom panel – annual age distribution for females only.

The annual cumulative percent of age for Blueback Herring has varied considerably over the five year period, tied with the presence of the 2010 cohort through time and the initial contribution of the 2014 cohort in 2017 as age-3 fish (Figure 13 and 14).
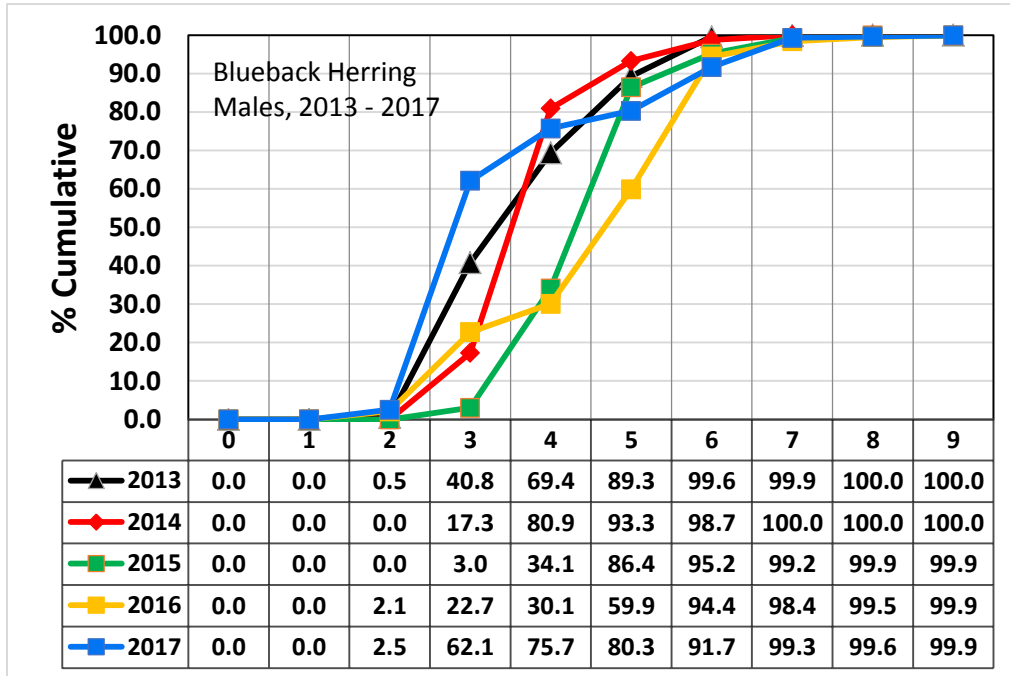


| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 0.0 | 0.0 | 0.5 | 40.8 | 69.4 | 89.3 | 99.6 | 99.9 | 100.0 | 100.0 |
| 2014 | 0.0 | 0.0 | 0.0 | 17.3 | 80.9 | 93.3 | 98.7 | 100.0 | 100.0 | 100.0 |
| 2015 | 0.0 | 0.0 | 0.0 | 3.0 | 34.1 | 86.4 | 95.2 | 99.2 | 99.9 | 99.9 |
| 2016 | 0.0 | 0.0 | 2.1 | 22.7 | 30.1 | 59.9 | 94.4 | 98.4 | 99.5 | 99.9 |
| 2017 | 0.0 | 0.0 | 2.5 | 62.1 | 75.7 | 80.3 | 91.7 | 99.3 | 99.6 | 99.9 |

Figure 13. Annual cumulative percentage frequency – age of male Blueback Herring.



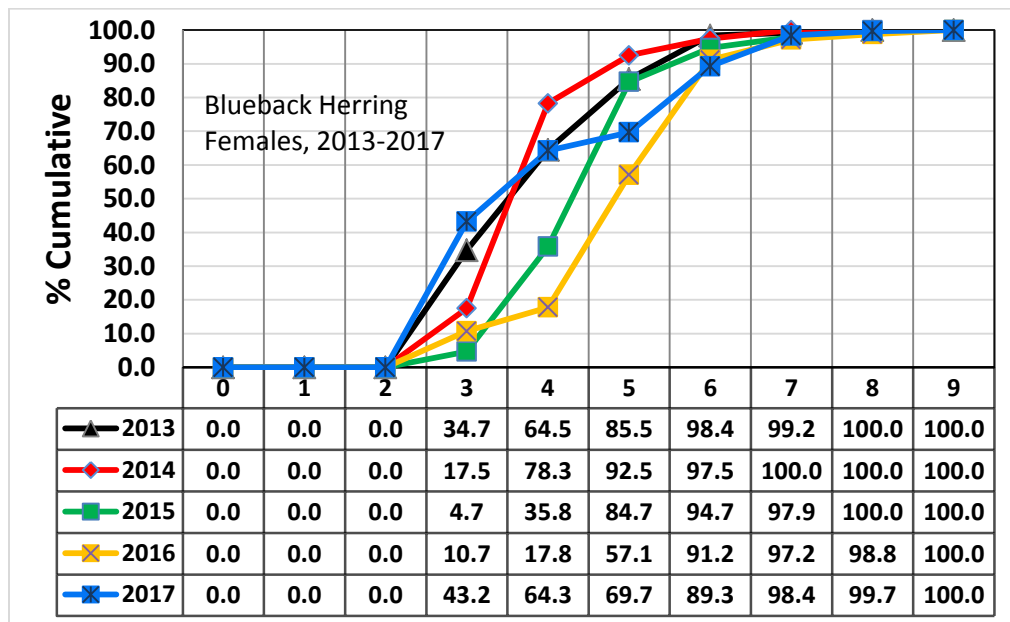| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 0.0 | 0.0 | 0.0 | 34.7 | 64.5 | 85.5 | 98.4 | 99.2 | 100.0 | 100.0 |
| 2014 | 0.0 | 0.0 | 0.0 | 17.5 | 78.3 | 92.5 | 97.5 | 100.0 | 100.0 | 100.0 |
| 2015 | 0.0 | 0.0 | 0.0 | 4.7 | 35.8 | 84.7 | 94.7 | 97.9 | 100.0 | 100.0 |
| 2016 | 0.0 | 0.0 | 0.0 | 10.7 | 17.8 | 57.1 | 91.2 | 97.2 | 98.8 | 100.0 |
| 2017 | 0.0 | 0.0 | 0.0 | 43.2 | 64.3 | 69.7 | 89.3 | 98.4 | 99.7 | 100.0 |

Figure 14. Annual cumulative percent frequency – age of female Blueback Herring.

The sample size contributions from different sample areas has varied within year and among year and should be recognized when considering data presented or analyzed in an annual summary context

(Table 3).  Appendix D includes figures showing the annual age frequencies (as actual sample size) for each sample area that show variability in age structure for Blueback Herring.  A breakout of the contributions of lab processed fish that determine age structure shows that 70% of the Blueback Herring age data is attributed to samples obtained from the Farmington River and Wethersfield Cove (Table 8).  This may be attributed to several factors including; 1) sampling effort (refer to Table 3), and 2) quantity and quality of habitat for fish and boat efishing access (e.g., Chicopee River site may be limited to a single 500 second run in lower flow conditions and Westfield River has broad shallow sandy shoals).

Table 8.  Summary sample sizes of Blueback Herring for otolith age assignments by sample area, for combined sexes and by sex for all sample years 2013 to 2017 inclusive.

| Site | Both Sexes | | Male | | Female | |
|---|---|---|---|---|---|---|
| | n | % | n | % | n | % |
| Connecticut River - S. Hadley[A] | 53 | 1.4 | 34 | 1.3 | 19 | 1.9 |
| Chicopee River | 562 | 15.3 | 444 | 16.6 | 118 | 11.8 |
| Westfield River | 450 | 12.2 | 371 | 13.9 | 79 | 7.9 |
| Farmington River | 1,373 | 37.3 | 1,007 | 37.6 | 366 | 36.5 |
| Wethersfield Cove | 1,199 | 32.6 | 795 | 29.7 | 404 | 40.3 |
| Mattabesset River | 42 | 1.1 | 25 | 0.9 | 17 | 1.7 |
| Column Totals | 3,679 | 100.0 | 2,676 | 100.0 | 1,003 | 100.0 |

[A] Area only sampled in 2013

Comparisons for within year difference in age structure, proportions of observations in contingency table arrangement, among sample sites (Wethersfield, Farmington, Westfield and Chicopee) were made with Chi square tests using only males (given the larger sample sizes).  In 2013 a significant difference (P < 0.001) was detected among male age structure for all four sites (age bins of 3, 4, 5 and ≥6).  The removal of Wethersfield Cove, with fewer age-3 males, yielded a Chi square value of no significant difference (P = 0.276) difference for the remaining three sites age structures.  In 2014, a significance difference (P <0.001) among male age structure for all four sites was again detected and once again the removal of Wethersfield Cove yielded a no detectable difference (P = 0.474) among the other sites age structures.  Comparisons in 2015 were affected by smaller sample sizes.  We combined the males by age for the Westfield and the Chicopee and with that approach, a significance difference (P <0.001) among the three groups was detected.  A comparison of Wethersfield and Farmington also yielded a significant difference (P < 0.001).

Comparisons for 2016 males, with larger sample sizes of older age fish, permitted an additional age bin of ≥ age-7 in tests, but also required the combination of the Westfield and Chicopee samples due to smaller overall sample sizes in those areas.  A significance difference among the three group/sites age structures were detected in 2016.  A comparison of only Wethersfield and the Farmington was significantly different (P <0.001), as was a comparison between the Farmington and the grouped Westfield/Chicopee sites.  The 2017 male age comparisons, (age bins of 3, 4, 5, 6 and ≥ 7) among sites had significant differences (P <0.001).  Sites were removed from the analyses for comparisons among smaller groups (removed, 1st Wethersfield, 2nd Westfield, and 3rd both Westfield and Chicopee) in all three cases the remaining sites were significantly different (P < 0.001).

Alewife samples have been noted throughout this report to comprise a smaller component (14%) of the river herring assessment data over the study period (n = 1,372) compared with Blueback Herring (n = 8,444). The smaller sample sizes have subsequent effects in data summaries and analyses from increased variability, partially attributed to timing of sampling effort. Over the five year period (2013-2017), a total of 1,037 Alewife were lab processed for otolith extraction, resulting in otolith based age assignments for 1,032 fish. Fish ranged from age-2 (males only) to age-8 (Table 9). The greatest contribution (both sexes) was age-3 (40.5%), as well as by sex, for both male and female.

Table 9. Alewife age structure, all sites combined, combined sexes and by sex, for years 2013 to 2017 inclusive.

| Age | Both Sexes | | Male | | Female | |
|---|---|---|---|---|---|---|
| | n | % | n | % | n | % |
| 2 | 14 | 1.4 | 14 | 2.0 | 0 | 0.0 |
| 3 | 418 | 40.5 | 314 | 43.9 | 104 | 32.9 |
| 4 | 292 | 28.3 | 201 | 28.1 | 91 | 28.8 |
| 5 | 216 | 20.9 | 144 | 20.1 | 72 | 22.8 |
| 6 | 78 | 7.6 | 40 | 5.6 | 38 | 12.0 |
| 7 | 12 | 1.2 | 3 | 0.4 | 9 | 2.8 |
| 8 | 2 | 0.2 | 0 | 0.0 | 2 | 0.6 |
| Totals | 1,032 | | 716 | | 316 | |

Shifts in length frequencies over time (year to year) are also partially explained by the contribution of shifting age structures of the sampled Alewife population (Figure 15). The 2011 cohort's prominent contribution to annual age structure continued in 2015, 2016 and 2017. In 2014, the proportion of age-3 fish, both male and female was also prominent and represented the 2011 cohort (Figure 15). The CTDEEP Juvenile Alosine Survey does not report Alewife JI catch values, so it is unclear what level of juvenile production may have occurred in 2011 in relation to other years for that species. It is reasoned that a substantial, but unknown proportion of the 2014 cohort remained at sea in 2017 and are expected to contribute as age-4 samples in 2018 in addition to any "repeat spawners" (i.e., males). As noted earlier, the 2010 Blueback Herring cohort is similarly prominent in successive years contributions to the annual age structure.
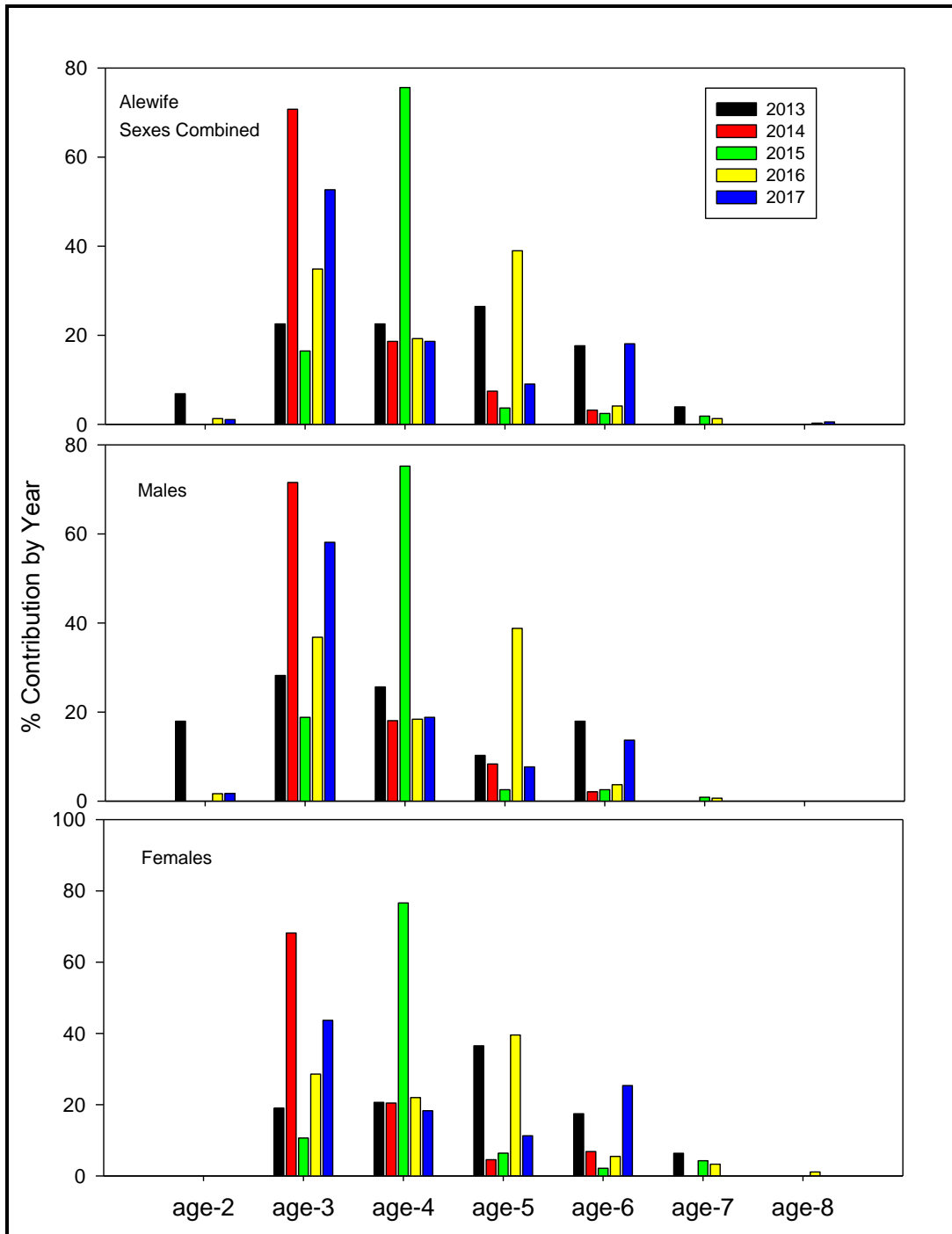
Figure 15.  Top - Annual age distribution, expressed as a frequency percentage (sum to 100%), for all Alewife, sexes combined, all sample sites 2013 – 2017 inclusive. Middle – Annual age distribution for males only. Bottom – Annual age distribution for females only

The annual cumulative percent of age for Alewife has varied over the five year period, tied with the presence of the 2011 cohort through time and the initial contribution of the 2014 cohort in 2017 as age-3 fish (Figure 16 and 17).
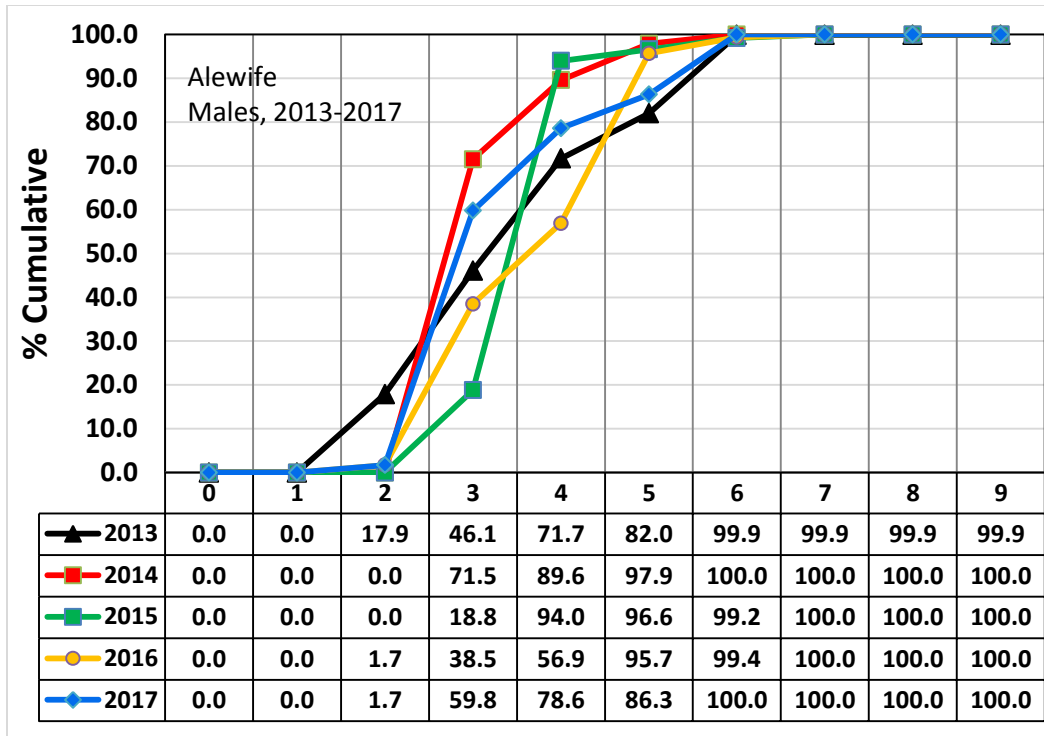
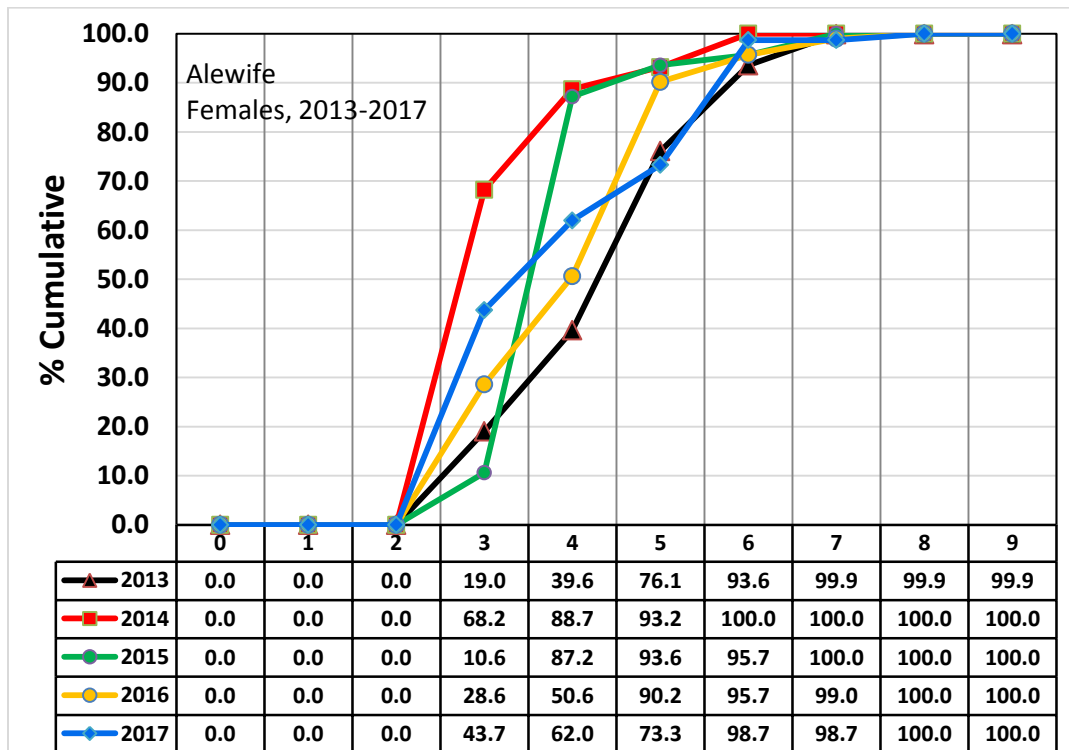Figure 16.  Annual cumulative percent frequency – age of male Alewife.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 0.0 | 0.0 | 17.9 | 46.1 | 71.7 | 82.0 | 99.9 | 99.9 | 99.9 | 99.9 |
| 2014 | 0.0 | 0.0 | 0.0 | 71.5 | 89.6 | 97.9 | 100.0 | 100.0 | 100.0 | 100.0 |
| 2015 | 0.0 | 0.0 | 0.0 | 18.8 | 94.0 | 96.6 | 99.2 | 100.0 | 100.0 | 100.0 |
| 2016 | 0.0 | 0.0 | 1.7 | 38.5 | 56.9 | 95.7 | 99.4 | 100.0 | 100.0 | 100.0 |
| 2017 | 0.0 | 0.0 | 1.7 | 59.8 | 78.6 | 86.3 | 100.0 | 100.0 | 100.0 | 100.0 |



Figure 17. Annual cumulative percent frequency – age of female Alewife.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | 0.0 | 0.0 | 0.0 | 19.0 | 39.6 | 76.1 | 93.6 | 99.9 | 99.9 | 99.9 |
| 2014 | 0.0 | 0.0 | 0.0 | 68.2 | 88.7 | 93.2 | 100.0 | 100.0 | 100.0 | 100.0 |
| 2015 | 0.0 | 0.0 | 0.0 | 10.6 | 87.2 | 93.6 | 95.7 | 100.0 | 100.0 | 100.0 |
| 2016 | 0.0 | 0.0 | 0.0 | 28.6 | 50.6 | 90.2 | 95.7 | 99.0 | 100.0 | 100.0 |
| 2017 | 0.0 | 0.0 | 0.0 | 43.7 | 62.0 | 73.3 | 98.7 | 98.7 | 100.0 | 100.0 |

*Length at Age*
Blueback Herring length at age data were developed using otolith aged fish with associated standard deviations by age (Figure 18).  Alewife length at age data were developed using otolith aged fish with associated standard deviations by age (Figure 19).
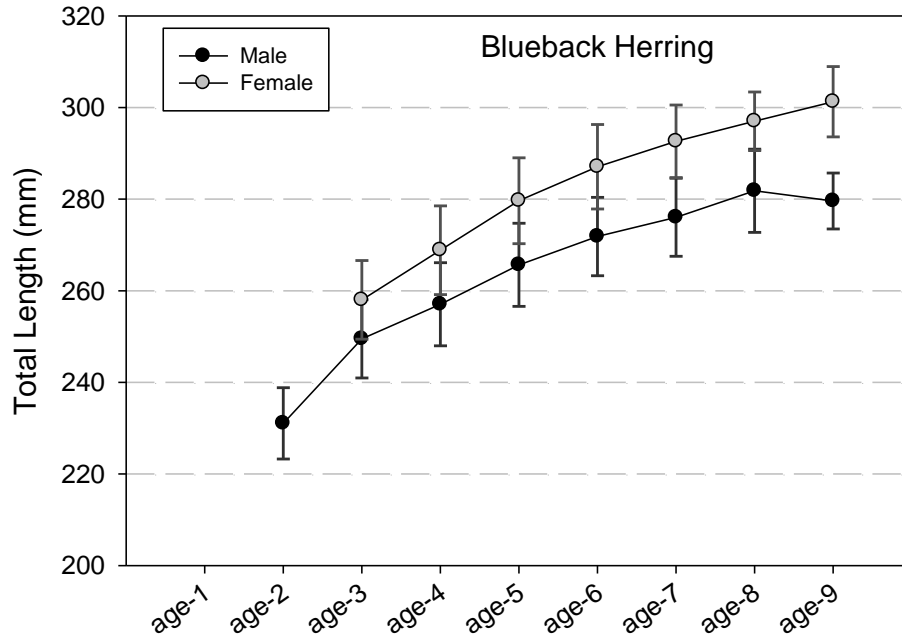


Figure 18.  Mean total length (mm) for otolith aged Blueback Herring male and females by age, using all data (all sites, all years).  Error bars are +/- one standard deviation.
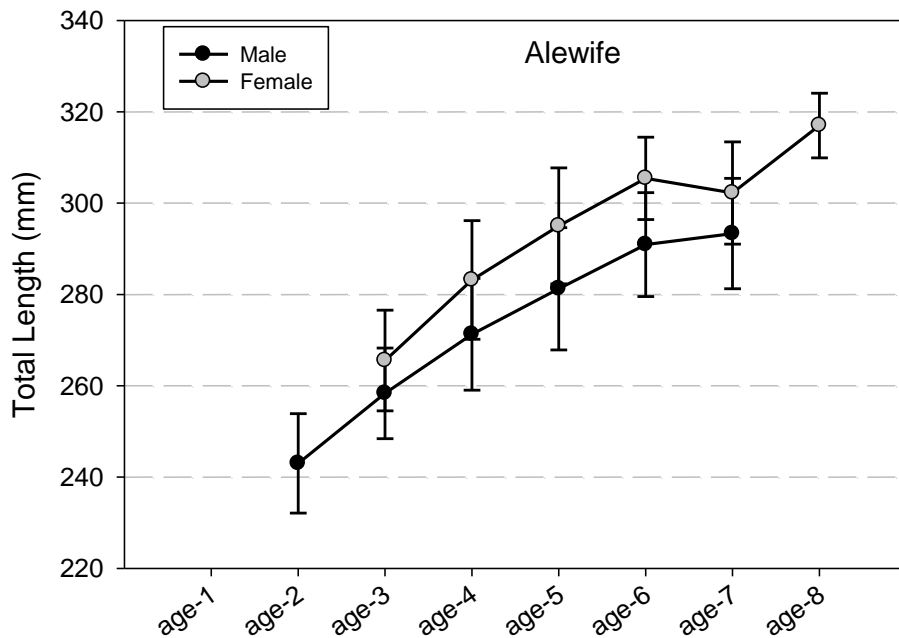


Figure 19.  Mean total length (mm) for otolith aged Alewife male and females by age, using all data (all sites, all years).  Error bars are +/- one standard deviation.

*Component of Virgin and Repeat Spawners*

Results from scale reading to determine subsampled fish spawning history were completed by several different readers for the years 2013 through 2016 (single sample read).  Those data require some additional review and are not provided in this report.  However, the 2017 scale spawning mark assignment data were determined by three readers, who each completed examination of the full sample set.  Scale readers worked independently allowing examination by level of agreement.  For Blueback Herring, the summary data on fish spawning history, by age, for three-of-three reader (100%) agreement consisted of combined sample size of 698 males and 233 females for all sites combined in 2017 (Table 10).  The 2017 spawning history assignments (all sites) were influenced by the relatively high contributions of age-3 fish for males and age-3 and age-4 contributions for females (Figure 12).

Table 10.  Spawning history assignments for all Blueback Herring, by age and sex, from all sample sites in 2017 that had three reader independent agreement.

**MALE**

| Age | n | Virgin (n) | % | One Repeat (n) | % | Two Repeat (n) | % | Three Repeat (n) | % |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 21 | 21 | 100.0 | 0 | - | 0 | - | 0 | - |
| 3 | 483 | 478 | 99.0 | 5 | 1.0 | 0 | - | 0 | - |
| 4 | 82 | 55 | 67.1 | 27 | 32.9 | 0 | - | 0 | - |
| 5 | 26 | 6 | 23.1 | 18 | 69.2 | 2 | 7.7 | 0 | - |
| 6 | 50 | 7 | 14.0 | 36 | 72.0 | 7 | 14.0 | 0 | - |
| 7 | 33 | 2 | 6.1 | 20 | 60.6 | 10 | 30.3 | 1 | 3.0 |
| 8 | 2 | 0 | - | 2 | 100.0 | 0 | - | 0 | - |
| 9 | 1 | 0 | - | 1 | 100.0 | 0 | - | 0 | - |
| | 698 | 569 | | 109 | | 19 | | 1 | |
| Column % (of total) | | 81.5 | | 15.6 | | 2.7 | | 0.1 | |

**FEMALE**

| Age | n | Virgin (n) | % | One Repeat (n) | % | Two Repeat (n) | % | Three Repeat (n) | % |
|---|---|---|---|---|---|---|---|---|---|
| 2 | 0 | 0 | - | 0 | - | 0 | - | 0 | - |
| 3 | 129 | 129 | 100.0 | 0 | - | 0 | - | 0 | - |
| 4 | 47 | 31 | 66.0 | 16 | 34.0 | 0 | - | 0 | - |
| 5 | 12 | 5 | 41.7 | 6 | 50.0 | 1 | 8.3 | 0 | - |
| 6 | 27 | 2 | 7.4 | 17 | 63.0 | 7 | 25.9 | 1 | 3.7 |
| 7 | 16 | 0 | - | 9 | 56.3 | 4 | 25.0 | 3 | 18.8 |
| 8 | 1 | 0 | - | 1 | 100.0 | 0 | - | 0 | - |
| 9 | 1 | 0 | - | 0 | - | 0 | - | 1 | 100.0 |
| | 233 | 167 | | 49 | | 12 | | 5 | |
| Column % (of total) | | 71.7 | | 21.0 | | 5.2 | | 2.1 | |

*Restoration Stockings*
Active restoration measures in the form of wild captured adult Blueback Herring was initiated in 2010 from Wethersfield Cove. Annual captures and transfers have varied from 2010 to 2016, dependent on fish abundance and available resources to complete this work (Table 11). In 2010, working with CTDEEP, we captured and released a total of 4,575 blueback into the Farmington River, approximately 40 river kilometers upstream of the Rainbow Dam (Farmington, CT). Also in 2010, we captured and released a total of 2,920 Blueback Herring into the Westfield River approximately 30 river kilometers upstream of the West Springfield Dam (Agawam, MA). In 2013 and 2014, restoration stockings only occurred into habitats upstream of Holyoke Dam in the Oxbow (Northampton, MA) and the Manhan River (Easthampton, MA) that empties into the Oxbow. In 2015, the Oxbow and Manhan were stocked with fewer fish than the preceding years and the Farmington River was also collaboratively stocked with CTDEEP. Only the Oxbow was stocked in 2016, making it the fourth consecutive year of stocking in that area. In the late summer and fall, the Oxbow has been electrofish surveyed and juvenile Blueback Herring have been sampled. Transfers were ceased in 2017 with the intention of determining whether a "response" in terms of Holyoke passage counts occurs with the progeny from these stockings. In 2018 and 2019 we would expect increased cohort contributions, compounding from the progeny of these stockings.

This stocking effort was intended to increased juvenile production in under and un-utilized habitats, upstream of dams with fishways and produce returning adults that may exhibit some level of natal habitat fidelity. This may present a confounding factor in examining our monitoring data time-series. However, the CTDEEP main stem juvenile alosine survey, as noted earlier in this report, demonstrated a high level of juvenile production in 2010. In addition, the 2010 year class was observed among all adult sample areas (Wethersfield Cove the least magnitude) starting as age-4 fish in 2014 and in subsequent years, suggesting the 2010 stocked fish progeny were either masked, or swamped by higher magnitude main stem habitat production.

Table 11. Annual summary of Blueback herring captured at Wethersfield Cove, trucked, and released into identified waters.

| Year | Release Site | Number Released |
|------|--------------|-----------------|
| 2010 | Farmington River (Farmington, CT), upstream of Rainbow Dam Reservoir | 4,575 |
| 2010 | Westfield River (Westfield, MA), upstream of West Springfield Dam | 2,920 |
| 2013 | Oxbow (Northampton, MA), upstream of Holyoke Dam | 2,364 |
| 2013 | Manhan River (Easthampton, MA), upstream of Manhan fish ladder | 517 |
| 2014 | Oxbow (Northampton, MA), upstream of Holyoke Dam | 3,270 |
| 2014 | Manhan River (Easthampton, MA), upstream of Manhan fish ladder | 1,460 |
| 2015 | Oxbow (Northampton, MA), upstream of Holyoke Dam | 920 |
| 2015 | Farmington River (Farmington, CT), upstream of Rainbow Dam Reservoir | 1,360 |
| 2015 | Manhan River (Easthampton, MA), upstream of Manhan fish ladder | 490 |
| 2016 | Oxbow (Northampton, MA), upstream of Holyoke Dam | 1,010 |

*Farmington River restoration stockings done cooperatively with CTDEEP*

**Discussion**

The river herring population assessment program has provided information noted as missing and a priority management need by the ASMFC as well as CRASC, primarily for Blueback Herring.  Alewife monitoring data remain limited in both spatial and temporal context for this program and reflect limited contribution (currently) for this species in the study areas.  This observation may be a function of overall available habitat, habitat sampling area/effort, and depressed population size.  The existing study design, methods and techniques has shown very high levels of within year variability for relative abundance among sites for both species.  Given the extent of this variability as currently reported and analyzed, differences in statistical levels of abundance are not possible, but as presented are still informative.  The development of additional analytical approaches to standardize for some variables of influence in catch rates may help to reduce variability that is not unique to our assessment program.  The assessment program's ability to determine information on fish size and age structure among areas has demonstrated consistencies that suggest these data are reliable measures for status and trends in the monitored areas.  These data also demonstrated in a five year period substantial variability in measures that included agreement with the CTDEEP JI Survey high index value for juvenile production in 2010 that we identified as subsequent adult returns and tracked through 2017.

The Holyoke Fish Fish Lifts (HFL), at rkm 139 (Figure 2), provides the most consistent long-term source of fishery independent data on adult Blueback Herring for the Connecticut River, in the form of passage counts (Figure 1).  Importantly, as with all fishways, numerous factors can affect annual passage counts including but not limited to; structural and operational changes (dam and fishways) and environmental conditions (discharge, spill, water temp) both within and among years. The dramatic declines in Blueback Herring counts at HFL, from >100,000 annually passed (1980-1993 without break and a peak of 632,000 in 1985) has remained consistently under 1,000 annually from 2004 to the present.  This monitoring and assessment project was initiated at these species' all-time low level of abundance and must be considered in that context.

Possible causal factors for the observed decline in Blueback Herring passage counts at Holyoke in the 1990s were examined by Savoy and Creeco (2004).  The researchers tested three hypotheses: 1) overharvest by in-river and offshore commercial fisheries, 2) stock displacement or enhanced ocean mortality due to colder water temperatures, and 3) increased predation on adult and juvenile alosines.  They were able to show evidence to reject the first two hypotheses and provided indirect evidence to support the predation hypothesis, with increased abundances of the coastal migratory stock of striped bass.  However, at this time, the level of bycatch in the Atlantic Herring offshore fishery was not understood.  The authors only acknowledged the Atlantic Mackerel fishery and noted that its mixed stock bycatch could not approach accounting for the level of observed adult fish losses.

More recent river herring stock structure research on spring adult Blueback Herring in the Connecticut River occurred in 2003 and 2004 in Roaring Brook, a tributary to the Connecticut River in Glastonbury, CT (Davis and Shultz 2006).  Only 2003 data were examined for Roaring Brook due to sample size issues in 2004.  The researchers noted that the 2003 Blueback Herring run was dominated by 1998 (age-5) and 1999 (age-4) year classes and that "the majority were repeat spawners".  They also noted that fish older than age-5 were largely absent.  In the 2005, the CTDEEP funded a three year research study by the University of Connecticut (UConn) that was designed to provide more specific data on the abundance of striped bass and their feeding habits primarily in the main stem river, below Holyoke Dam, over time and space (Davis et al. 2009).  Study results pertaining to river herring include a predominance of Blueback Herring vs. Alewife (<3%) in total boat electrofish samples; blueback run was comprised primarily of age-3 to age-6 fish; the 2005 run had relatively large numbers of fish ≥ age-5, and

approximately 30% of fish were repeat spawners. The 2006 and 2007 runs were dominated by a strong 2003 year class, with a combined sex average of 16% and then 15% repeat spawner component respectively.   Davis et al. (2012) concluded using these data and their applied models, that striped bass consumed 400,000 Blueback Herring (95% CI 200,000 – 800,000) annually in their study area during the spring migration.  Management recommendation based on their research led to the implementation of less restrictive size limits in the Connecticut River by the CTDEEP to in part, reduce in-river mortality on Blueback Herring.

Similar to our study, the UConn researchers in a period of only three years also observed a dominant blueback cohort that was observed in their last two successive study years.  They also detected a decrease in blueback relative abundance on a south to north gradient (Glastonbury to Holyoke) on the main stem river, inverse to observed striper densities.  Sampling areas between the UConn study and our study are not directly comparable (only the Wethersfield Cove area sampled in both) given differences in habitat types and other factors.  Differences in abundances among our sampled tributaries may be related to variability in habitats and unique hydrologic features (e.g., Chicopee River and its lowermost dam position) that do not allow for such comparisons with the Davis et al. (2009) study that focused on main stem sample reaches.  However, some differences to varying extents, of mean fish lengths among sites were sporadically detected in comparisons, within our study years (Appendix A).  Overall, we observed some relative consistency in the subsampled age structure determinations among sample areas, which as noted earlier, has direct implication to reported mean annual fish lengths for each sex (Appendix D).

The Davis et al. (2009) study conclusions for Blueback Herring included; population structure has changed over recent decades and that contemporary runs feature younger, smaller fish, and reduced occurrence of iteroparity.  These statements on comparisons over time were based on the only previous study to examine Blueback Herring demographics cited as Loesch (1987).  However, the actual data reported by Loesch is taken from Marcy (1969) that provides no distinction between his sample areas of the Thames and Connecticut rivers in 1966 and 1967.  We have three concerns with historical comparisons to the Marcy work. First, scale reading was used for aging and utilized the transverse groove method of Cating (1953) that for American Shad has been shown to both overestimate the age of younger fish and underestimate the age of older fish (McBride et al. 2005; Elzey et al. 2015).  Davis et al. identified issues with their comparison of scale and otolith readings for blueback ages (scale under aging) resulting in their use of otoliths for age assignments.  This concern would potentially bias comparisons of mean length at age with Marcy (scale approach) who reported values that were greater for each age (potentially related to this bias).  However, other longer term stock structure monitoring programs in many East Coast stocks do report similar declines in length at age measures as well as in repeat spawner component and overall reduced age structure (ASMFC 2012 and 2017).

A second concern with Marcy (1969) comparisons regard the omission of any comparisons between the Thames and Connecticut River samples, data and results are only in the aggregate and we have no way of knowing whether there were or were not any differences between the two sample areas and two sample years in the reported measures.  The third concern with Marcy is as only a two-year study, the extent to which year class strength variability did or did not occur cannot be adequately considered relative to adult stock structure for a factor in the observed metrics.  Blueback Herring juvenile year class abundance has been monitored by CTDEEP continuously since 1979 at seven main stem sites on the Connecticut River downstream of Holyoke Dam.  These data are the only long-term fishery independent data for juveniles and demonstrate declines in catch rate values (fish per net haul) over the data time series (Figure 20).  The decline of both the adult spawning stock, based on the Holyoke Fish

Lift counts in relation to the CTDEEP juvenile index suggest a relationship (poorly explained variability $R^2=0.268$), but requires extreme caution in interpretation given the many other factors expected to interact with JI value development (e.g., within and between year river discharge) that are beyond the scope of this exploratory plot (Figure 21).
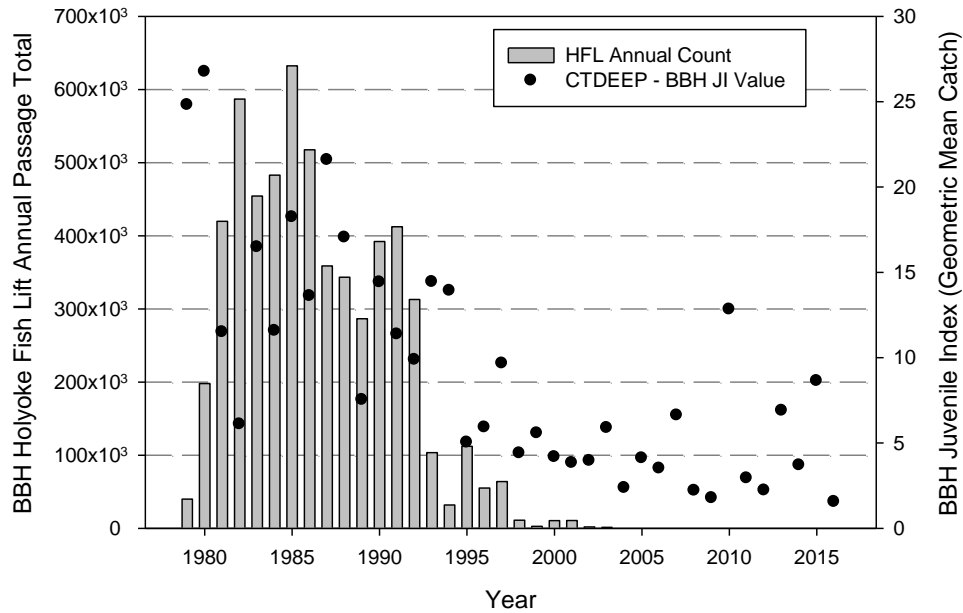


Figure 20.  Annual total Blueback Herring counted passing Holyoke Fish Lifts from 1979 through 2016, with annual CTDEEP, BBH Juvenile Index value (geometric mean) for the same time period.
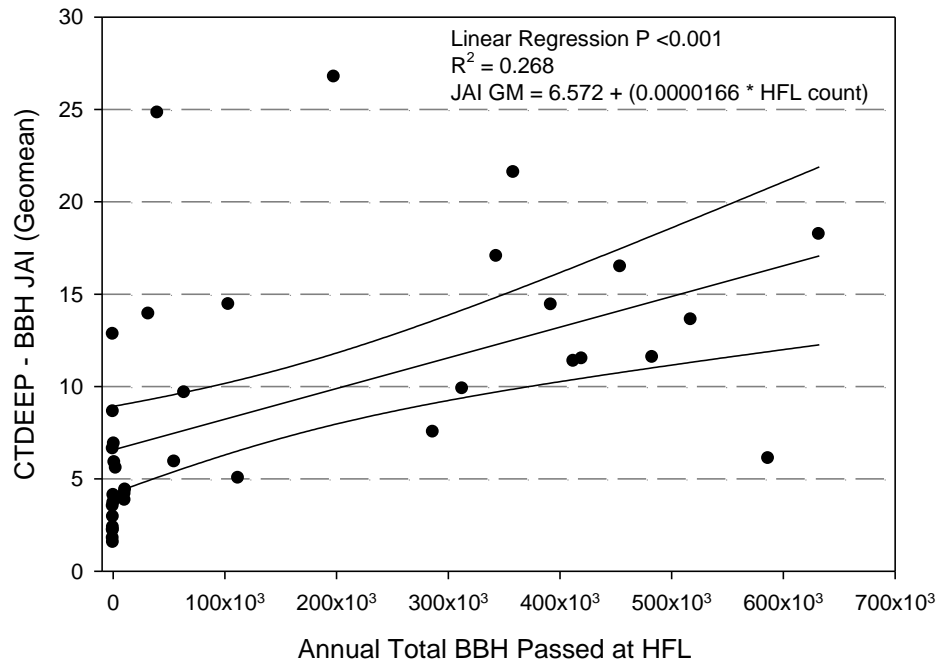


Figure 21.  Linear regression of BBH annual HFL passage counts and same year CTDEEP Juvenile Index for BBH for the period 1979 - 2016.

Additional research into possible causal factors to help explain the observed wide-spread declines in river herring has included marine fisheries bycatch, an area that was poorly monitored and understood. Spatial and temporal patterns of alosine bycatch were examined for the Atlantic Herring fishery for the period 2005-2009 (Cournane et al. 2013). This research provided a detailed synthesis describing how alosine bycatch varied over time and space in defined offshore management zones and by gear type. Paired midwater trawls were the dominant gear type for interaction with near shore areas also having greater interaction. Time period interactions were variable, with winter and fall having notably greater levels of alosine bycatch.

Bethoney et al. (2014) expanded on the details of the bycatch topic, but only focused on the midwater trawl fisheries targeting Atlantic Herring and Atlantic Mackerel in the Northwest Atlantic, during 2011 and 2012. Both portside and at-sea observation data specific to river herring were obtained and examined in a number of ways to better quantify and explore these interactions. Differences in the sizes of river herring in bycatch among fishing areas (e.g., Gulf of Maine vs. Southern New England) are noted. Provided length frequency plots of bycatch among fishing areas show fish ranging modally in the 190mm to 210mm fork length, or primarily sub- adult. This information is of interest given concerns for declines in repeat spawners that would be in the "tails" of the size distributions reported in this study. Catches in 2011 for all areas and fisheries summed to ~516,000 Alewife and ~538,0000 Blueback Herring. In 2012, the same summaries were ~502,000 Alewife and 1.55 million Blueback Herring. The researchers conclude that the estimated bycatch could not account for the overall decline but noted the need for better stock assignments to be able to discriminate stock contributions.

Tissue samples for both river herring species were obtained in 2008-2012 from East Coast Rivers and populations that were used by Palkovacs et al. (2014) to examine population genetic structure with microsatellite markers. The researchers reported differences among stocks best described at regional scales and subsequently developed stock groupings for each species at the coastwide scale. Relative to the Connecticut River, Blueback Herring were assigned to the Middle Atlantic Stock (MAT), one of four regional groups for this species. The Connecticut is the most northern stock component for this MAT group that extends southward to the Nuese River (North Carolina), a large geographic range. For Alewife, three stock groupings were identified, with Long Island Sound runs assigned to the Southern New England Stock (SNE). The SNE stock complex also has a large geographical scale, spanning from Boston to the Hudson River.

Following on results reported in Palkovacs et al. (2014), a companion study was published that examined the genetic stock composition of marine bycatch of river herring (Hasselman et al. 2016). Using the 15 microsatellite markers from Palkovacs et al. (2014), bycatch samples from the southern New England Atlantic Herring Fishery were estimated for both 2012 and 2013, with over 4.95 million river herring (95% CI: 4.11 – 5.79 million) estimated as bycatch losses. Blueback Herring of MAT assignments (includes the Connecticut River) comprised a high proportion of the total (80%) blueback bycatch for both years, with the remaining 20% partitioned among the three other regional stock areas (e.g., Southern New England and Northern New England). Differences in bycatch were shown between years and gear type. For MAT Blueback Herring, the estimated bycatch was 633,600 (midwater trawl) and 78,200 (bottom trawl) in 2012. In 2013, this shifted to 32,400 (midwater trawl) and 324,800 (bottom trawl). Genetic stock composition of blueback bycatch did not differ significantly between gear types or between years. Notably, different species dominated the bycatch in 2012 (Blueback Herring) vs. 2013 (Alewife). Bycatch in the commercial fisheries was shown to be not evenly distributed among genetic stocks, but was disproportionately assigned to the most depleted genetic stocks (Southern New England Alewife and MAT Blueback Herring). A large proportion of this study's sample was obtained

from the Southern New England Atlantic Herring fishery that was noted to occur in areas adjacent to Long Island Sound, suggesting this interaction is a likely contributing factor to Long Island Sound stock declines.

Bycatch limits for river herring and American Shad were instituted for the Atlantic Herring fishery starting in late 2014 (Framework 3) by the New England Fishery Management Council. In addition, the Atlantic Herring midwater bycatch avoidance program run by MA Division of Marine Fisheries, UMass Dartmouth and the fishing industry also remains in operation (Bethoney et al. 2017). An evaluation of "pre" and "during" program interactions of the mid-water trawl fishery are detailed in Bethoney et al. (2017) that show an influence in fishing behavior that contributed to an overall (alosine) decrease in bycatch with some exceptions at finer scales (zones and by species). The goal of a 50% reduction in total bycatch (metric ton, mt) was met in overall aggregate, but is complicated by reductions in fishing effort from reduced target fish quotas. Bycatch ratios were another monitored metric which varied among areas over time "pre" and "during" program (e.g., down in Zone 1 but up in Zone 2). Near shore areas in Zone 1 (Gulf of Maine – MA Northshore and NH coastal area) showed the most dramatic declines in "pre" (2007-2010) vs. "during" (2011-2014) program for Alewife measures (225 mt to 6 mt), shifting to more offshore areas. In Zone 2, more equivocal results were shown with "pre" program bycatch total for Alewife 154 mt vs. "during" 240 mt and for blueback "pre" 285 mt vs. "during" 142 mt.

Bycatch limits for river herring and shad by the Middle Atlantic Fishery Management Council, for the Atlantic Mackerel, Squid and Butterfish Fishery Plan was addressed for the first time with Amendment 14 in 2014. A bycatch cap of 236 mt was initially selected (with a 33,821 mt quota) and has since evolved to include a tiered system based on harvest of mackerel that currently is set at 89 mt (for a reduced quota of 10,000 mt). That value was based on a median bycatch rate estimate from vessels that landed over 20,000 lbs. of mackerel in 2015. A decrease in the federal mackerel quota (2016-2018) from 10,000 mt to 9,177 mt, was used to adjust the bycatch cap (82 mt).

**Management and Research Recommendations**
This program is planned to continue with the same study design, objectives, and methods through at least 2023, to fully develop a ten-year data series for use by the ASMFC and CRASC in ongoing management and restoration assessment and monitoring efforts. ASMFC has established a minimum ten-year data series for these species for "Benchmark Assessment" analyses (Benchmark Assessments are required to introduce new data). Future recommendations include:

- Based on ASMFC Shad and River Herring Technical Committee meeting discussions, additional analyses to standardize metrics (fish/min) with field environmental measures (water transparency/secchi, water temp, river discharge, water conductivity should be explored using General Linear Model(s) or Generalized Additive Model(s).
- Evaluation of juvenile production measurements of river herring (CTDEEP) and possible exploration of other approaches should be considered and validated with other suitable data. Examination of factors that may influence or explain variability in juvenile production should be explored.
- Blueback Herring population dynamics in large rivers remains poorly understood with limited monitoring for status and trends necessary for management. The Hudson River Fisheries Unit (State of New York) has a number of fishery independent studies and programs in place with Blueback Herring, but habitat differences between the Hudson River and larger New England rivers (e.g., high dam densities) make many comparisons challenging at best. More research to answer basic questions on in-river spawning migration, timing, habitat use, and sources, extent,

timing of mortality is required.  In addition information on spawning success among habitats/areas, juvenile production, growth, and survival are also needed, in relation to variables/factors of influence.  In the estuarine and marine environments survival, migration, movements, timing, mortality sources, and interaction with fisheries also require further study.

- Biological sampling data obtained over the complete temporal span of the spawning run should be adjusted to account for shifts in spawning stock abundance to more accurately reflect population measures that are under examination.  A suitable approach for this adjustment needs to be developed and then comparisons can be made between unadjusted versus adjusted measures for sensitivity and any directional biases.
- Otolith annuli measurements and back-calculations for length-at-age should be developed from samples for both sexes and species to develop Von Bertalanffy growth equations.  Once the three Von Bertalanffy parameters are derived, additional fishery population models can be developed.  This work is currently in progress using our Blueback Herring aged otolith set.
- The current CRASC River Herring Management Plan that was approved in 2004 should be updated.

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Appendix A. Mean annual total length, described by sex, year and site for Blueback Herring. Sample size and standard deviation are provided. Within year comparisons of mean total length, by sex, were performed with a one way analysis of variance. Significant difference detection was followed by all pairwise comparison (Holm-Sidak method) with an overall significance level set = 0.05.

| Year | Sample Area | Code | Sex | N | Mean TL (mm) | S.D. | Significant Differences by Sex |
|------|-------------|------|-----|---|--------------|------|-------------------------------|
| 2013 | Chicopee River | A | f | 11 | 259.0 | 15.5 | C |
| 2013 | Connecticut River - S. Hadley | B | f | 19 | 255.9 | 5.5 | C, F |
| 2013 | Farmington River | C | f | 43 | 270.3 | 12.7 | A, B, E |
| 2013 | Mattabesset River | D | f | 6 | 270.5 | 12.0 | - |
| 2013 | Westfield River | E | f | 34 | 261.5 | 11.1 | C |
| 2013 | Wethersfield Cove | F | f | 18 | 269.4 | 10.8 | B |
| 2013 | Chicopee River | G | m | 72 | 252.2 | 8.9 | H, K |
| 2013 | Connecticut River - S. Hadley | H | m | 34 | 246.5 | 8.3 | G, I, J, K |
| 2013 | Farmington River | I | m | 82 | 254.9 | 11.2 | H, K |
| 2013 | Westfield River | J | m | 132 | 252.7 | 10.5 | H, K |
| 2013 | Wethersfield Cove | K | m | 92 | 259.3 | 10.9 | G, H, I, K |
| | | | | | | | |
| 2014 | Chicopee River | A | f | 67 | 261.7 | 12.1 | - |
| 2014 | Farmington River | B | f | 230 | 264.8 | 13.0 | - |
| 2014 | Mattabesset River | C | f | 7 | 271.1 | 7.8 | - |
| 2014 | Westfield River | D | f | 41 | 267.2 | 14.9 | - |
| 2014 | Wethersfield Cove | E | f | 111 | 265.7 | 13.6 | - |
| 2014 | Chicopee River | F | m | 297 | 255.1 | 11.0 | G |
| 2014 | Farmington River | G | m | 865 | 252.8 | 11.5 | F, I |
| 2014 | Mattabesset River | H | m | 12 | 253.2 | 11.4 | - |
| 2014 | Westfield River | I | m | 216 | 255.8 | 10.6 | G |
| 2014 | Wethersfield Cove | J | m | 227 | 254.0 | 11.6 | - |
| | | | | | | | |
| 2015 | Chicopee River | A | f | 40 | 277.4 | 7.9 | - |
| 2015 | CT River- Westfield River mouth | B | f | 7 | 276.7 | 10.3 | - |
| 2015 | Wethersfield Cove entrance | C | f | 38 | 277.8 | 11.4 | - |
| 2015 | Farmington River | D | f | 234 | 278.9 | 11.6 | - |
| 2015 | Mattabesset River | E | f | 2 | 282.0 | 7.1 | - |
| 2015 | Westfield River | F | f | 5 | 282.2 | 5.8 | - |
| 2015 | Wethersfield Cove | G | f | 138 | 275.7 | 12.9 | - |
| 2015 | Chicopee River | H | m | 67 | 266.9 | 8.6 | N |
| 2015 | CT River- Westfield River mouth | I | m | 49 | 267.6 | 7.6 | J, N |
| 2015 | Wethersfield Cove entrance | J | m | 48 | 261.3 | 11.6 | I |
| 2015 | Farmington River | K | m | 481 | 263.6 | 10.2 | N |
| 2015 | Mattabesset River | L | m | 2 | 251.0 | 1.4 | - |
| 2015 | Westfield River | M | m | 31 | 267.4 | 10.1 | N |
| 2015 | Wethersfield Cove | N | m | 306 | 260.3 | 10.6 | H, I, K, M |

Appendix A. Continued.

| Year | Sample Area | | Sex | n | Mean TL (mm) | S.D. | Significant Differences by Sex |
|------|-------------|---|-----|---|--------------|------|--------------------------------|
| 2016 | Chicopee River | A | f | 26 | 272.3 | 15.1 | B, D |
| 2016 | Farmington River | B | f | 266 | 284.7 | 11.2 | A, E |
| 2016 | Mattabesset River | C | f | 1 | 283.0 | | - |
| 2016 | Westfield River | D | f | 3 | 294.3 | 5.1 | A |
| 2016 | Wethersfield Cove | E | f | 223 | 278.0 | 13.4 | B |
| 2016 | Chicopee River | F | m | 43 | 261.5 | 13.1 | G |
| 2016 | Farmington River | G | m | 648 | 268.3 | 12.2 | F, J |
| 2016 | Mattabesset River | H | m | 4 | 270.8 | 12.2 | - |
| 2016 | Westfield River | I | m | 15 | 267.9 | 9.8 | - |
| 2016 | Wethersfield Cove | J | m | 326 | 259.3 | 13.4 | G |
| | | | | | | | |
| 2017 | Chicopee River | A | f | 73 | 266.9 | 16.5 | B |
| 2017 | Farmington River | B | f | 302 | 274.2 | 14.8 | A, E |
| 2017 | Mattabesset River | C | f | 3 | 284.3 | 2.5 | - |
| 2017 | Westfield River | D | f | 12 | 278.3 | 19.4 | - |
| 2017 | Wethersfield Cove | E | f | 347 | 270.2 | 14.0 | B |
| 2017 | Chicopee River | F | m | 310 | 257.4 | 13.6 | I |
| 2017 | Farmington River | G | m | 883 | 258.4 | 12.3 | I, J |
| 2017 | Mattabesset River | H | m | 13 | 257.5 | 8.6 | - |
| 2017 | Westfield River | I | m | 48 | 266.0 | 11.9 | F, G, J |
| 2017 | Wethersfield Cove | J | m | 646 | 255.8 | 12.5 | G, I |

Appendix B. Mean annual total length of Alewife, by year, sex, and site with sample size and standard deviation.

| Year | Sample Area | Sex | n | Mean TL (mm) | S.D. |
|------|-------------|-----|---|--------------|------|
| 2013 | Farmington River | f | 5 | 262.8 | 5.7 |
| 2013 | Mattabesset River | f | 35 | 290.0 | 14.7 |
| 2013 | Wethersfield Cove | f | 24 | 289.6 | 15.7 |
| 2013 | Farmington River | m | 5 | 262.0 | 14.8 |
| 2013 | Mattabesset River | m | 15 | 266.7 | 17.3 |
| 2013 | Wethersfield Cove | m | 19 | 257.5 | 14.4 |
|  |  |  |  |  |  |
| 2014 | Farmington River | f | 5 | 278.0 | 21.6 |
| 2014 | Mattabesset River | f | 24 | 280.4 | 14.8 |
| 2014 | Wethersfield Cove | f | 24 | 271.4 | 14.1 |
| 2014 | Farmington River | m | 16 | 265.6 | 8.0 |
| 2014 | Mattabesset River | m | 128 | 266.5 | 11.3 |
| 2014 | Wethersfield Cove | m | 24 | 265.3 | 9.8 |
|  |  |  |  |  |  |
| 2015 | Farmington River | f | 12 | 286.3 | 11.7 |
| 2015 | Mattabesset River | f | 46 | 289.5 | 13.2 |
| 2015 | Wethersfield Cove | f | 12 | 283.3 | 9.1 |
| 2015 | Chicopee River | m | 1 | 251.0 |  |
| 2015 | Farmington River | m | 8 | 270.4 | 11.1 |
| 2015 | Mattabesset River | m | 161 | 273.8 | 11.7 |
| 2015 | Wethersfield Cove | m | 18 | 269.1 | 10.6 |
|  |  |  |  |  |  |
| 2016 | Chicopee River | f | 1 | 265.0 |  |
| 2016 | Farmington River | f | 30 | 274.5 | 16.8 |
| 2016 | Mattabesset River | f | 102 | 292.3 | 17.6 |
| 2016 | Wethersfield Cove | f | 29 | 278.8 | 17.9 |
| 2016 | Farmington River | m | 14 | 256.6 | 17.0 |
| 2016 | Mattabesset River | m | 308 | 274.2 | 17.2 |
| 2016 | Wethersfield Cove | m | 102 | 262.1 | 16.7 |
|  |  |  |  |  |  |
| 2017 | Farmington River | f | 4 | 260.3 | 11.7 |
| 2017 | Mattabesset River | f | 52 | 283.3 | 22.0 |
| 2017 | Wethersfield Cove | f | 21 | 269.6 | 17.3 |
| 2017 | Farmington River | m | 1 | 262.0 |  |
| 2017 | Mattabesset River | m | 105 | 266.2 | 19.0 |
| 2017 | Wethersfield Cove | m | 17 | 257.1 | 12.3 |

Appendix C. Length frequency distributions for Blueback Herring sampled at all sites in noted year. The distributions of the total sampled (processed in the field) in relation to those that were sub-sampled and retained for laboratory processing are shown.
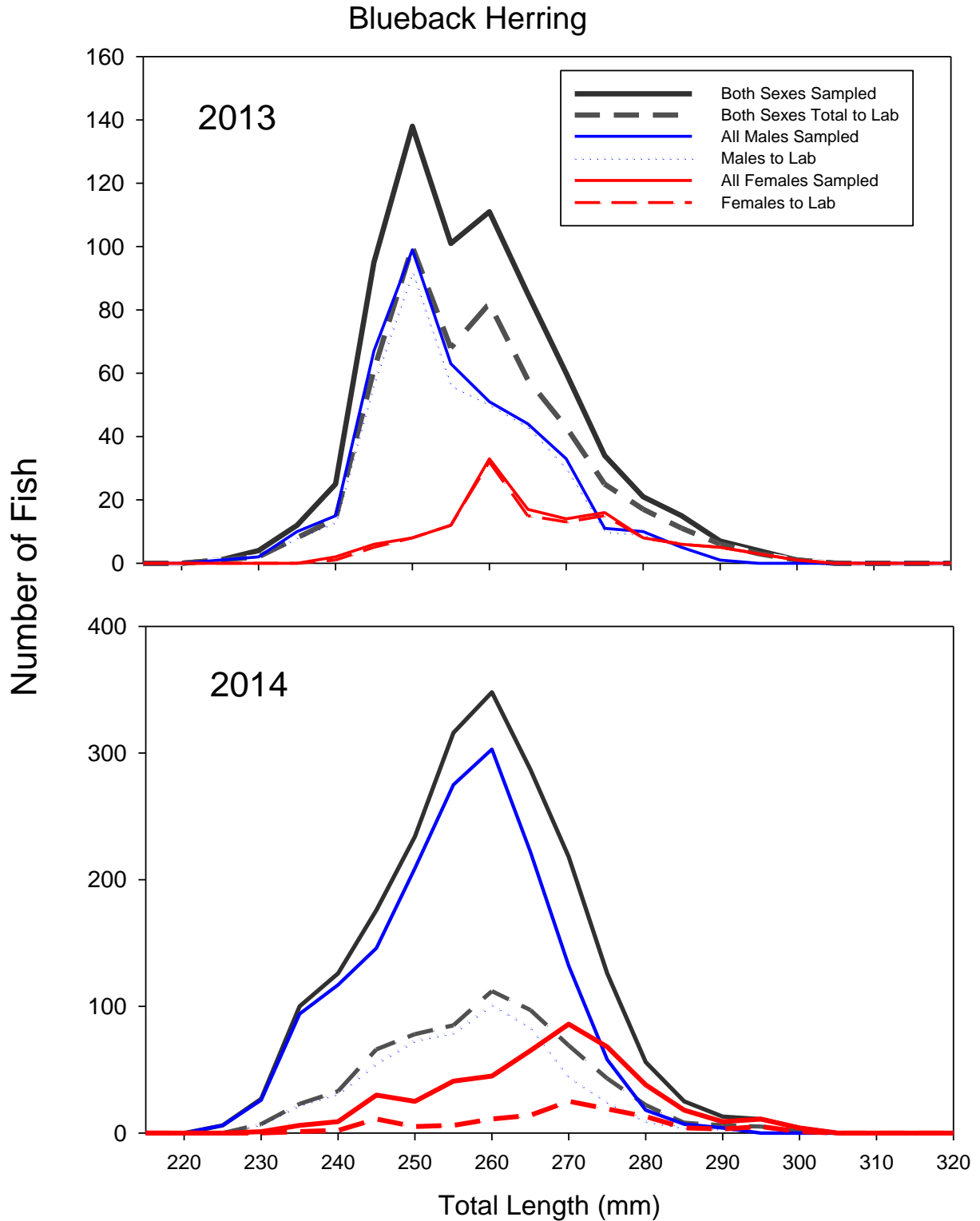


Blueback Herring
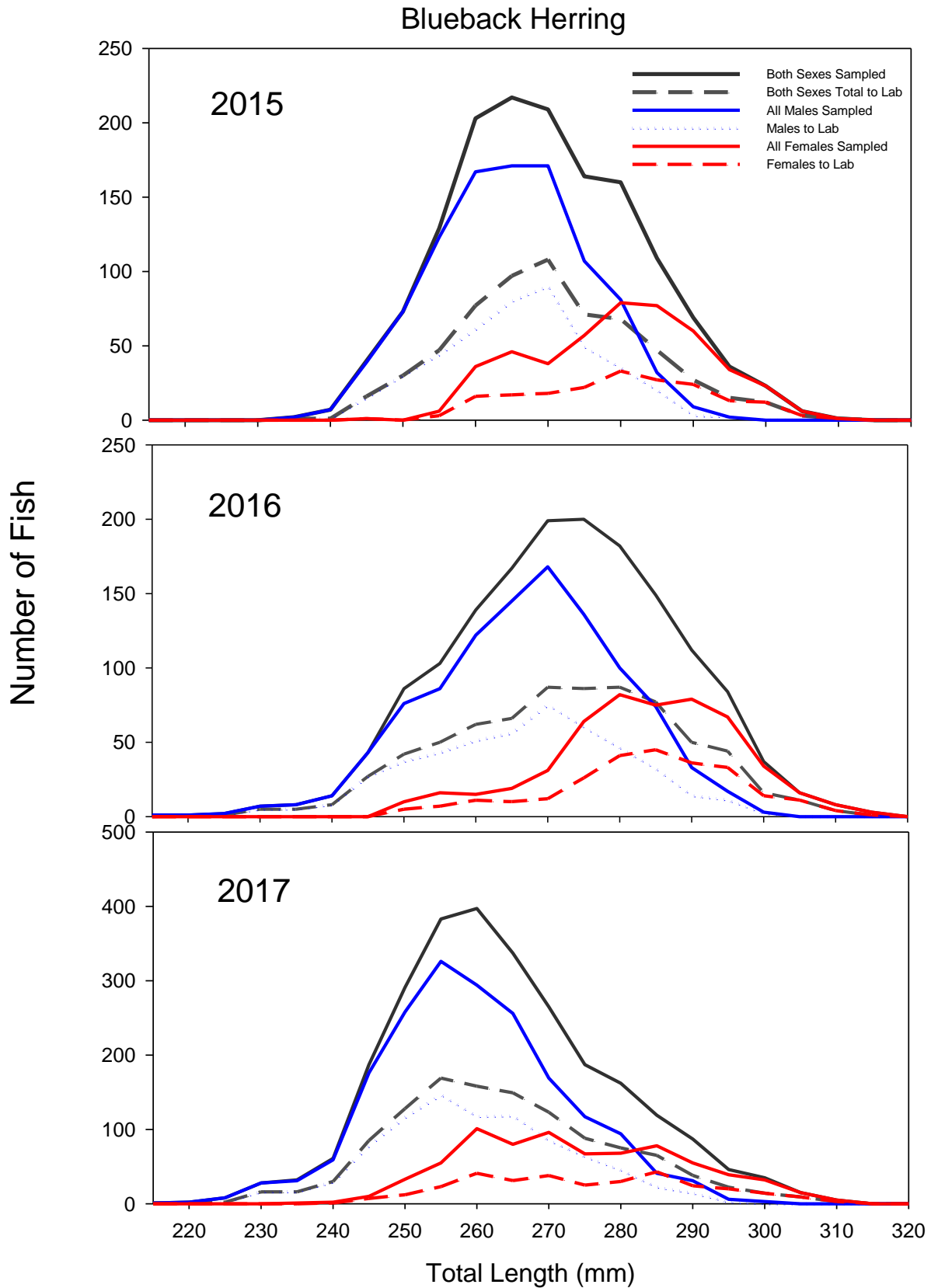
## Blueback Herring

Appendix D. Blueback Herring annual age structure at all sample areas.
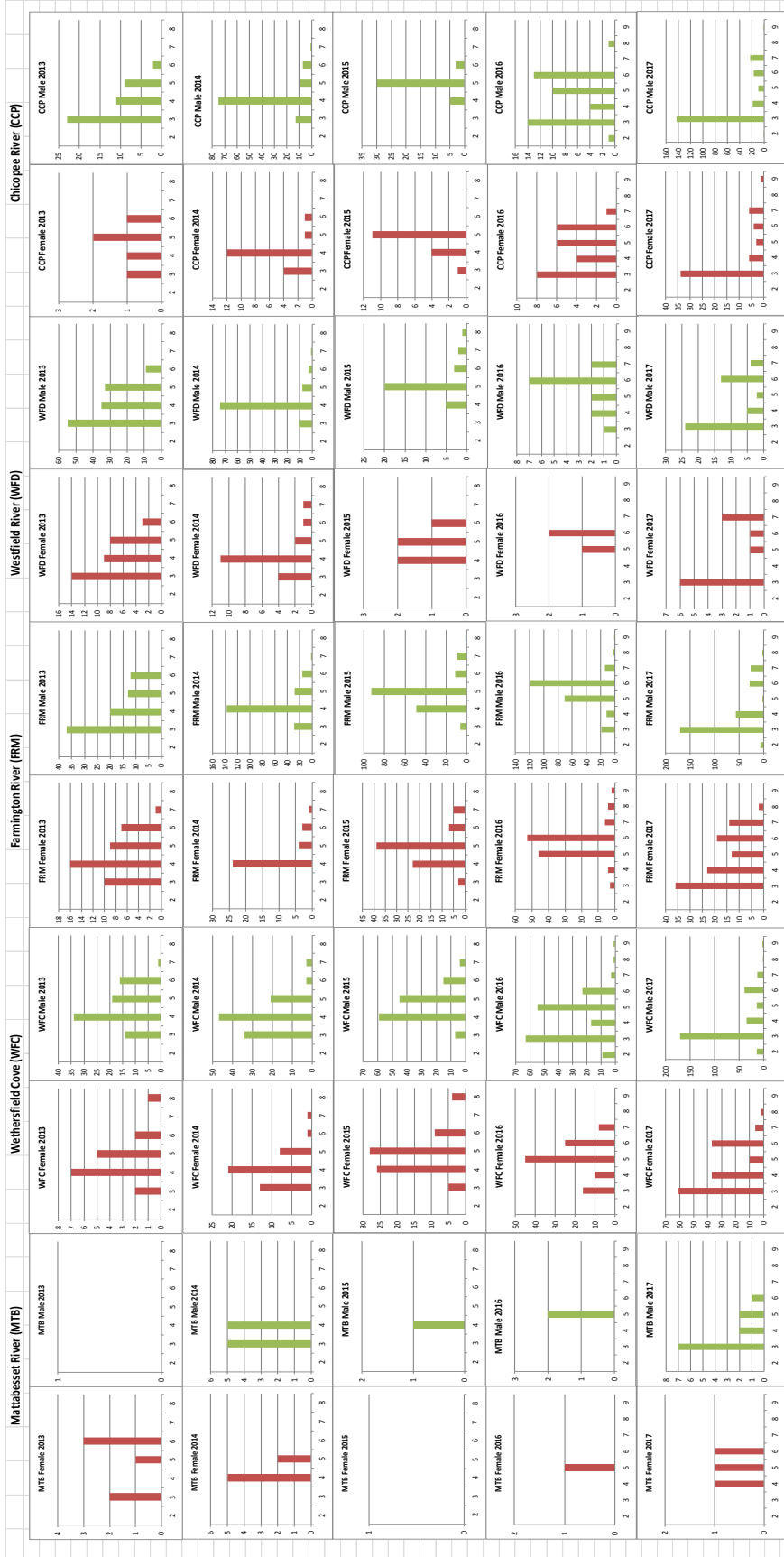


X Axis is age

Red = Females
Green = Males