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Assessment of River Herring and Striped Bass in the Connecticut River: Abundance, Population Structure, and Predator/Prey Interactions

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Executive Summary

Purposes of the Project

- Populations of anadromous alewife *Alosa pseudoharengus* and blueback herring *Alosa aestivalis*, collectively referred to as river herring, have declined in the Connecticut River. The number of blueback herring passing Holyoke Dam, the most downstream dam on the mainstem Connecticut River, has declined from 630,000 in 1985 to a recent low of 21 in 2006.
- An hypothesis for why river herring have declined in the Connecticut River is that predation pressures have increased, particularly associated with recent increases in abundance of striped bass *Morone saxatilis.* This study was designed to test this hypothesis. It will serve as a starting point for the formulation of river herring conservation plans, the collection of long-term datasets, and the development of future research directions.

Objectives

- Assess abundance, temporal/spatial distribution, and population structure of river herring in the Connecticut River below Holyoke Dam
- Assess abundance, temporal/spatial distribution, and size structure of striped bass in the Connecticut River below Holyoke Dam
- Characterize predator/prey interactions between striped bass and river herring in the Connecticut River below Holyoke Dam

Methods

- The river stretch from Wethersfield, CT to Holyoke, MA was selected as the study region. This region was selected because its along-river length, depth and width were conducive to sampling, and because prior information indicated that striped bass and river herring congregate there.
- The region was sampled in 2005-2008. Sampling occurred during mid-April to June, which is the spring migratory season for river herring and striped bass in the Connecticut River (Savoy and Crecco 2004).
- Experimental sampling in April-early May of 2005 focused on identification of effective sampling techniques for river herring and striped bass, as well as selection of standardized sample sites within the study region.
- Initial sampling in 2005 employed several gears, including anchored and drifting gill nets, beach seines, controlled angling, and night-time boat electrofishing. Boat electrofishing was most efficient, and was used in conjunction with anchored gill-nets and controlled angling for the remainder of 2005. Boat electrofishing was used exclusively in 2006-2008.
- Five sample sites were selected in 2005: Wethersfield, the lower Farmington River, Windsor Locks, Enfield, and Holyoke, MA. These sites were selected based on criteria including relative spacing along the study stretch, catch rates of target species, navigation safety, and ease of access. The five standard sample sites accounted for the majority of 2005 sampling and were used exclusively in 2006-2007. Sampling in 2008 was restricted to Windsor Locks to support striped bass mark-recapture efforts (see below).

- Sample sites were visited once per calendar week during the 2005, 2006 and 2007 sampling seasons, river conditions and equipment permitting. Fixed electrofishing transects were sampled in a systematic fashion on each sample night.
- All river herring captured in 2005-2007 were enumerated and measured for total length (TL, in mm). Up to five herring per 5-mm size class were euthanized on each sample night. Fish in these sub-samples were returned to the lab for sex, species, age, and spawning history determination. No river herring were collected in 2008 as sampling focused on striped bass mark-recapture efforts (see below).
- All striped bass captured in 2005-2008 were enumerated and measured. In 2005 and 2006, all striped bass were weighed (kg), and diet samples were collected from all striped bass ≥ 300 mm TL via gastric lavage. In 2007, striped bass were weighed and lavaged on a subset of sample nights (see below). In 2006-2008, all striped bass ≥ 300 mm TL were tagged (see below). No striped bass were weighed or lavaged in 2008. The majority of striped bass (> 99%) collected were released.
- A striped bass mark-recapture study was initiated in 2006 to provide estimates of population size in the study region during the spring migratory season. All striped bass ≥ 300 mm TL were tagged with uniquely-coded internal anchor FLOY tags. Tags featured a phone number that anglers could call to report recapture of tagged fish. Tagging was conducted during normal sampling operations in 2006. In 2007, additional funding was obtained to field an independent sampling crew devoted solely to the mark-recapture study. The mark-recapture crew sampled Windsor Locks exclusively, and did not lavage or weigh striped bass (enumeration, measuring, and tagging only). Field sampling in 2008 was restricted to mark-recapture efforts (enumeration, measuring, and tagging of striped bass in Windsor Locks).
- Spatiotemporal patterns of striped bass and river herring abundance were assessed using electrofishing catch rates in 2005, 2006 and 2007. Distributions of the two species were assessed for degree of overlap.
- Otoliths and scales were removed from all sub-sampled herring for age and spawning history analysis. An age-length key approach (Devries and Frie 1996) was used to determine population structure with respect to age and spawning history. Contemporary data were compared to historic data (Loesch 1987) to assess decadal shifts in population structure.
- Striped bass diet samples were sorted by prey category. Prey items were enumerated, weighed (g), and measured for length (TL, mm) when possible. Diet composition was summarized as percent frequency of occurrence, percent composition by mass, and percent composition by number (Bowen 1996).
- A meal turnover model (Adams and Breck 1990) was used to estimate striped bass per-capita consumption rates for river herring and American shad prey.
- Striped bass mark-recapture data were used to estimate population size using a Schnabel mark-recapture model (Hayes et al. 2007).
- Estimates of striped bass per-capita consumption rates and population size were used to estimate population-level consumption of river herring and American shad prey (Tabor et al. 2007).

Key Findings

- Over 100 sampling trips were completed in four field seasons. Sampling began in April, but was sporadic until early May due to river flooding. Field operations were generally terminated in mid-late June due to persistently low catch rates of target species and low river flows.
- Over 3,000 river herring were collected in 2005-2007.
- Almost all river herring collected were blueback herring; alewives comprised < 3% of sub-sampled fish.
- Over 2,000 striped bass were collected in 2005-2008. Approximately 700 of these fish were subjected to gastric lavage, and approximately 1,400 were tagged.
- Blueback herring were most abundant in the downstream end of the study region and lowest at upstream sites. Herring catch rates varied more than an order of magnitude between the upstream and downstream ends of the region.
- Blueback herring abundance varied over the sample season. Herring were generally most abundant in early-mid May, and several subsequent waves of abundance were often observed.
- Blueback herring averaged 244 – 265 mm TL. Size structure differed among years. Sample site did not have a significant effect on herring size. Herring size decreased as the season progressed.
- Otolith and scales did not yield concordant estimates of blueback herring age, despite similar levels of between-reader agreement. Otoliths were selected as the preferred structure for age estimation. Scales were used to estimate spawning history as otoliths do not contain information on previous spawning activity.
- The blueback herring spawning run was composed primarily of age 3 – 6 fish. The 2005 run contained a relatively large number of fish age 5 and older, and approximately 30% of fish were repeat spawners. The 2006 and 2007 runs were dominated by a strong 2003 year class, and 15% of fish were repeat-spawners.
- Comparisons of contemporary blueback herring population structure to historical data from Connecticut (Loesch 1987) indicate significant decadal shifts. Blueback herring in 1960's spawning runs were 6 – 16% larger than recent fish. The blueback herring run in 1966 was dominated by fish age 5 and older, fish younger than age 4 were relatively rare, and approximately 82% of fish were repeat-spawners.
- A wide size range of striped bass was captured (min = 156 mm, max = 1224 mm, median = 430 mm). Striped bass were classified by size into two groups, divided at a size close to the median of the distribution: "Small" (≤ 500 mm TL) and "Large" (> 500 mm TL).
- Seasonally-averaged abundance of Small striped bass was highest in Windsor Locks in all years.
- Seasonally-averaged abundance of Large striped bass increased upriver, being lowest in Wethersfield and greatest in Holyoke. Variation in along-river abundance of Large striped bass approached or exceeded an order of magnitude in all years.
- River-wide abundance of Small striped bass varied temporally in some years but did not display a consistent pattern.
- There was no temporal variation in river-wide abundance of Large striped bass in any year.
- Average striped bass size consistently increased along-river in each year, such that striped bass were largest in Holyoke.

- Striped bass size structure differed among years. Average size gradually declined across the time period of this study.
- Large striped bass and river herring displayed similar seasonal patterns of abundance. Both species were most abundant in the study region in May and early June.
- Large striped bass and river herring showed inverse patterns of along-river distribution.
- Recapture rates of tagged striped bass within the study region during the sampling season were 2.7% and 3.3% in 2007 and 2008, respectively.
- Low recapture rates and lack of multiple recaptures of the same tagged fish precluded use of open population mark-recapture models. A closed population model (Schnabel) was used to estimate striped bass population size in the river stretch from Hartford, CT to the MA/CT border in May 2008.
- Population size was estimated as 65,744 striped bass ≥ 300 mm TL (95% confidence interval = 2,434 – 109,573).
- Diet samples were obtained from 389 striped bass in 2005-2007. Smaller striped bass consumed a variety of fish and invertebrate prey. Larger striped bass diets were more specialized and contained mostly fish.
- River herring were a prominent item in diets of 600 – 900 mm TL striped bass. 74 striped bass diet samples contained river herring.
- American shad were the most prevalent diet item in ≥ 900 mm TL striped bass. 45 striped bass diet samples contained shad. A small portion of the striped bass population (< 4%) feeds on American shad.
- Striped bass capture of herring differed among sites. Striped bass capture success was concordant with the along-river distribution of Large striped bass but not with the abundance of herring.
- Striped bass ≥ 400 mm TL consumed 0 – 2% body mass day^{-1} of river herring and American shad. Striped bass ≥ 1000 mm TL consumed 3 – 7 % body mass day^{-1} of shad. Daily ration estimates were multiplied by the mean mass of striped bass within each size class to estimate daily prey biomass consumption. Consumption of herring was 13 – 43 g day^{-1}, and consumption of shad was 0 – 968 g day^{-1}.
- We estimate that striped bass consumed over 200,000 herring (95% CI = 8,187 – 368,351) and almost 100,000 American shad (95% CI = 3,541 – 159,688) between Hartford, CT and the MA/CT border in May 2008.

Conclusions

- Blueback herring population structure has changed over recent decades. Contemporary runs feature younger, smaller fish that are less likely to complete multiple spawning runs over their lifetime. These findings are consistent with our previous studies of river herring populations in Connecticut (Davis and Schultz in press).
- The Connecticut River blueback herring population is more vulnerable to stressors as a result of changes in demography and life history. Decreases in iteroparity will result in larger variations in adult population size because years of poor juvenile survival and poor subsequent recruitment will be followed by years of depleted spawning migrations. Younger, smaller spawners produce fewer eggs and possibly lower-quality larvae, reducing the reproductive potential of the population.

- The changes in the Connecticut River blueback herring population indicate that mortality has increased among older, larger individuals, caused by factors such as predation or fisheries.
- Striped bass predation in the Connecticut River is a significant source of mortality for adult blueback herring. River herring represent a significant portion of striped bass diets in the Connecticut River during May – June, and striped bass congregate in locations where they are successful in capturing herring. The estimated seasonal consumption of river herring is substantial; it far exceeds the number of herring that are passed at the Holyoke fish lift, and is comparable to the number that passed in years before a sharp decline in the early 1990's.
- Modeling currently underway will allow us to better interpret the significance of our findings with respect to blueback herring population dynamics. Such models can be used to hindcast the impact of striped bass predation on river herring run size in recent decades, and examine potential impacts of changes in striped bass management.
- Future studies could significantly improve our understanding of the complex and inter-related dynamics of river herring and striped bass. These studies should focus on providing more robust estimates of local striped bass population size and consumption rates, as well as greater understanding of movements and spawning behavior of both species within the Connecticut River.

Recommendations

- Continue ongoing population modeling efforts designed to hindcast the contribution of striped bass predation to river herring declines in the Connecticut River in recent decades. Assess the potential for striped bass management changes to alleviate predatory pressure on blueback herring populations.
- Develop validated aging protocols for blueback herring in the Connecticut River. These efforts will require acquisition of scales and otoliths from known-age fish, and may incorporate a "total evidence" approach that relies on age estimates from both structures.
- Conduct diet studies of coastal striped bass populations during May-June to assess differences in capture success and consumption of river herring prey.
- Use either bioenergetics or gastric evacuation models to provide more precise estimates of striped bass consumption. Bioenergetics models will require detailed data on striped bass growth during Connecticut River residence, as well as information on activity rates. Gastric evacuation models will require laboratory experiments to measure the thermal-dependency of gastric evacuation rate for large striped bass feeding on large piscine prey.
- Conduct ichthyoplankton studies designed to assess along-river trends in river herring larval densities. Such studies will test the hypothesis that striped bass predation effects the along-river distribution of river herring spawning activity. If high abundance of large striped bass in the upper river truncates river herring spawning migrations, the Holyoke time series may over-estimate declines in annual run size. In addition, ichthyoplankton surveys may also confirm striped bass spawning activity in the Connecticut River.
- Conduct studies of juvenile blueback herring growth and survival in different portions of the Connecticut River. These studies will provide insight into the potential benefits river herring accrue by risking striped bass predation to reach upriver spawning grounds and the relative importance of spawning habitat above Holyoke Dam.

- Consider establishing a long-term monitoring program to establish a time series of river herring and striped bass abundance in the Connecticut River. Programs such as these have been established in other areas (e.g. Hudson River, Chesapeake Bay) and have provided great benefits to fishery managers. The sampling protocol used for our study could serve as a template for such a long-term monitoring program.
- Develop more robust estimates of striped bass population size in the Connecticut River. These studies should seek to employ open population models, and will require more extensive tagging and recapture efforts. Coordinated creel surveys will be required if anglers are relied on as the primary means of tag recapture. Telemetry studies may also provide better insight into relative rates of movement into and out of the study area.
- Assess the predatory impact of striped bass on juvenile alosines in the Connecticut River during the late summer – fall. Large numbers of small striped bass are present in the Connecticut River year-round, and may consume a considerable number of juvenile river herring. Studies assessing this predator-prey interaction should focus on the southern portion of the Connecticut River, and may need to employ different gears than our study.

Table of Contents

Project Report: Assessment of River Herring and Striped Bass in the Connecticut River: Abundance, Population Structure, and Predator/Prey Interactions

Rationale

Populations of anadromous alewife *Alosa pseudoharengus* and blueback herring *Alosa aestivalis*, collectively referred to as river herring, have declined in the Connecticut River. The number of blueback herring passing Holyoke Dam, the most downstream dam on the mainstem Connecticut River, has declined from 630,000 in 1985 to a recent low of 21 in 2006 (U.S. Fish and Wildlife Service, migratory fish count data at http://www.fws.gov/r5crc/fish/fish.html). A comparable time series is not available for alewife in Connecticut; evidence for this species decline is provided in a recent review of commercial landings data and in observations by Connecticut Department of Environmental Protection (CDEP) personnel (Davis and Schultz in press). In response to these apparent crashes of local populations, the Connecticut Department of Environmental Protection enacted an emergency closure of the river herring fishery in the Connecticut River in 2002. This emergency closure remains in place. Similar closures were instituted in the neighboring states of Massachusetts and Rhode Island in 2005. The closures apply to both coastal and ocean-intercept fisheries, and therefore constitute a moratorium on directed fisheries for river herring in southern New England.

An hypothesis for why river herring have declined in the Connecticut River is that predation pressures have increased, particularly associated with recent increases in abundance of striped bass *Morone saxatilis* (Savoy and Crecco 2004). Adult striped bass are large, piscivorous fish that are known to consume menhaden, shad and river herring (Walter et al. 2003). Striped bass populations in the Atlantic coastal region have risen to historically high levels over the last two decades (Richards and Rago 1999). The increase in striped bass abundance has resulted in a predictable increase in predatory pressure exerted by striped bass throughout their range (Walter et al. 2003). A temporal correspondence between increasing striped bass populations and declining river herring population within the Connecticut River suggests a causal relationship that bears more detailed study (Savoy and Crecco 2004). Unfortunately, despite wide knowledge that striped bass are seasonally abundant in the River, virtually nothing is known of their spatiotemporal distribution, size structure, or prey use. Such data are needed for a full assessment of the role these predators may have played in driving declines of river herring.

Prior to this project there has been no quantitative sampling for river herring in the lower Connecticut River aside from the long-term dataset on blueback herring abundance at Holyoke Dam. Information on river herring abundance was limited to anecdotal reports by members of the public and qualitative observations by CDEP personnel. The spatial and temporal characteristics of upstream migration by river herring over the course of the spawning season were poorly understood. There was no information on the current size structure, age structure, or growth characteristics of Connecticut River herring. Previous study of alewife spawning in a CT coastal stream with a headpond (Bride Brook) suggested that age structure and life history have shifted dramatically in the last 40 years; fish on the spawning run are now younger, and are more likely to be first-time spawners or 'virgins' (Davis and Schultz in press). This shift is symptomatic of high exploitation or predation pressure and increases the vulnerability of the population to further stressors.

This study was designed to test the hypothesis that local populations of herring have been subject to top-down control by striped bass. Several predictions of this hypothesis were tested. One prediction is that the populations of presumptive predator and prey come into close contact. Both species are known to concentrate in the river during their seasonal migrations; we sampled to determine if the spatial and temporal patterns of relative herring and striped bass abundance correspond. Another prediction is that adult striped bass in the River are large enough to consume adult river herring. We quantified the size dependence of striped bass predation on river herring. Size dependence is of particular interest because fishery management tools such as size limits can have a direct impact on the size structure of the predator population (if harvest or hooking mortality is substantial), and therefore could have an indirect effect on recovery prospects for prey species. A third prediction is that the striped bass are capable of consuming an appreciable proportion of river herring. To address this prediction, we will model an estimated predation rate using data on population size, size structure and consumption rates.

Information gathered by this study is necessary to more precisely characterize the decline of river herring populations within the Connecticut River, and will inform the debate over the mechanisms driving these declines. This study will serve as a starting point for the formulation of river herring conservation plans, the collection of long-term datasets, and the development of future research directions.

Species Background

Anadromous alewife and blueback herring have a largely sympatric distribution along the Atlantic coast of North America, from the maritime provinces of Canada to the southeastern US (Mullen et al. 1986). The species are quite similar, and are often referred to generically as river herring throughout their range. Adults inhabit relatively shallow (<100m) waters along the continental shelf (Neves 1981). The timing of return to freshwater spawning habitats in spring varies with species (Mullen et al. 1986) and is cued by temperature (Kissil 1974; Loesch 1987): alewives generally spawn earlier in the season at colder water temperatures than blueback herring. Juvenile river herring complete a period of freshwater residence before migrating to estuarine or marine environments during the period of June –November (Loesch 1987). During periods of freshwater and estuarine residence, both adult and juvenile river herring provide forage for numerous aquatic, terrestrial, and avian predators (Loesch 1987). Post-spawn mortality of adult river herring also provides an important addition to the nutrient budget of many aquatic systems (Durbin et al. 1979).

Striped bass are an economically-important recreational species native to the Atlantic coast of North America, from the St. Lawrence to northern Florida, and along the northern shore of the Gulf of Mexico (Collette and Klein-MacPhee 2002). Landlocked populations have been established in southeastern reservoirs, and the species has also been introduced well outside its native range in the US (Fuller et al. 1999). The fish is highly prized for food and sport. Commercial landings of the species peaked at almost 15 million pounds in 1973 and then declined by more than 75% over the next decade (Atlantic States Marine Fisheries Commission 1999). Following imposition of strict limits on commercial and recreational fishers, the stock was declared fully recovered by the Atlantic States Marine Fisheries Commission in 1995; landings have continued to climb since then. The migratory behavior of this fish is complex and remains poorly understood. Some individuals overwinter in southern New England, but most appear to arrive in the region in the springtime after migrating from the mid-Atlantic coast.

Vernal migrations into fresh waters may not represent spawning migrations in all locations, and spawning of striped bass in the Connecticut River has not been confirmed.

Objectives

Our goal was to test the hypothesis that recent increases in striped bass populations are suppressing the abundance of river herring populations. The specific objectives of the proposed research were to:

1) Assess abundance, temporal/spatial distribution, and population dynamics of river herring in a portion of the Connecticut River between Hartford and the Holyoke Dam (referred to henceforth as the “study region”);
2) Assess abundance, temporal/spatial distribution, and size structure of striped bass in the study region;
3) Characterize predator/prey interactions between striped bass and river herring.

Summary of Field Sampling Operations 2005 – 2008

Project field sampling began in spring of 2005. The goals of the 2005 sampling season were to a) identify a standardized sampling approach for assessment of spatial and temporal distribution of striped bass and river herring in the study region during spring months (April – June); b) identify sampling techniques effective for the capture of these target species; and c) obtain sample sizes of these target species large enough to permit effective analysis of population structure. The study region was selected due to its relative narrowness, shallow depth, and the need to constrain sampling activities to an area small enough to permit comprehensive weekly sampling. The prototype sampling plan was stratified random, with calendar weeks serving as strata (hereafter referred to as “periods”). Five sampling trips were planned on randomly-selected days within each period. On each sampling trip a randomly selected site within the study region would be sampled. Potential sample sites were selected *a priori* based on relative location within the study region and feasibility of sampling during a normal workday (i.e. travel time from boat launches).

Sampling began on 16 April 2005 and continued sporadically throughout the rest of April and early May 2005 when river conditions allowed for safe navigation. During this early portion of the 2005 field season (4/16/05 – 5/9/05), 8 sampling trips were conducted. Anchored gill nets served as the primary sampling gear. Two experimental monofilament gill net configurations that had proven successful for herring and striped bass capture in the Hudson River were used (Mark Mattson, Normandeau Associates, personal communication): 300’ long by 8’ deep, 3 x 100’ panels of 4”, 5” and 6” bar mesh (targeting striped bass, hereafter referred to as the “striper net”); 150’ long by 8’ deep, 3 x 50’ panels of 1.75”, 2.25”, and 2.75” bar mesh (targeting river herring, hereafter referred to as the “herring net”). Gill-nets were deployed for 90-120 minute sets during daylight hours at random locations within the sample site. Nets were set from shore at an angle oblique to river flow and at the top of the water column. We experimented with additional gears, including drifting gill-nets, controlled angling, and beach seining. Gill net drifts used the same nets as the anchored gill-nets described above. A beach seine configuration that had proven successful for herring and striped bass capture on the Hudson River was used (K. Hattala, NYDEC, personal communication: 300’ long by 12’ deep, 2” stretch mesh).

No herring were captured during the early weeks of the 2005 sampling season, and catch of striped bass was sporadic. It was often difficult to effectively deploy anchored gill-nets due to high river flows, and nets quickly became heavily fouled. Beach seine sets and gill-net drifts

were also unproductive, largely owing to a dearth of locations conducive to these approaches (multiple snags on river bottom, lack of beaches large enough to land beach seine).

A decision was made on 10 May 2005 to adopt boat electrofishing as the primary sampling method, and to move sampling operations to night-time hours. A Coffelt electrofishing boat (owned by the University of Connecticut – hereafter referred to as the “UConn boat”) equipped with a single, “Wisconsin ring” style electrode was used for boat electrofishing operations. Five standard sample sites were selected (Table 1, Fig. 1): Wethersfield (WF), the mouth of the Farmington River (FR), Windsor Locks (WL), Enfield (EF), and Holyoke, MA (HK). Each site was sampled on a randomly-selected night within a calendar week, river conditions permitting. Occasional electrofishing was conducted at locations other than the standard sites. Fixed electrofishing transects were defined within each sample site. Transects were generally located in near-shore, shallow habitat (≤ 6 ft. water depth) and ran parallel to the shoreline. Transects were set to a length that corresponded to approximately 650 seconds of shocking time. These transects were sampled via boat electrofishing in identical fashion during every sampling night. We used fixed, rather than randomized, transect locations for several reasons. Fixing locations enabled us to separate transects by habitat (e.g. cove mouths, tributary mouths, mainstem, tailrace), and to sample multiple habitats. Fixed locations also probably furnished us with greater sample size for analysis of striped bass diet and population size than would have been realized with a completely randomized design; transects were established in places that were known to hold fish. The consequence of this decision is that abundance estimates are biased to an unknown degree. Anchored gill-nets and controlled angling were also used in concert with electrofishing, primarily as a means of increasing sample sizes for the purpose of population structure analyses. Sampling began approximately 2 hours before dark. Anchored gill-nets were deployed in fixed locations that had been identified by trial and error as having the appropriate depth and current. Gill-nets were marked with lighted buoys in order to avoid boating mishaps. Once the anchored gill-nets had been deployed, controlled angling was performed by traveling to the upstream end of the sample site and then drifting downstream with the ambient current. Artificial lures 7 – 22 cm in length were used during controlled angling. After dark, controlled angling was discontinued and fixed electrofishing transects were sampled. Anchored gill-nets were retrieved once electrofishing was complete.

Fish were collected with all three sampling methods in 2005. Over five week-long periods, sampling was conducted on 27 nights, and 82 electrofishing transects were completed (Table 2). Electrofishing effort was distributed fairly equitably over the five periods (Table 3). Electrofishing effort was distributed unevenly among sites because nonstandard sites were visited on some nights, in addition to or in lieu of sampling a standard site in that period (Table 2, Table 4). Bycatch was recorded for gill net sets: fifteen species were captured (Table 5). Gill net effort was distributed unevenly among sites (Table 6) because of differences in visit number and also because suitable locations for anchored gill-nets were not available at each site. The herring net was more effective than the striper net (Table 7, Table 8). The herring net captured primarily striped bass (Table 7, Table 9). Neither gill net configuration captured river herring. The striper net was discontinued on 18 May 2005, and the two herring nets were joined together to create a 300’ long, 8’deep net consisting of 6 alternating panels. Controlled angling effort was distributed unevenly among sites because of differences in visit number, and catch per unit effort also varied among sites (Table 10). Sampling was discontinued on 15 June 2005 in response to consistently low catch rates of target species.

In subsequent years of field sampling (2006-2008) we used a modified version of the method used in the latter part of the 2005 field season. We discontinued use of anchored gill-nets and controlled angling, because of low catch rates. Electrofishing efficiency improved via the use of a different electrofishing boat, a Smith-Root Model SR-18 electrofishing boat (hereafter referred to as the "Smith-Root boat") loaned to us under contractual agreement with the USFWS CT River Coordinator's Office in Sunderland, MA. The Smith-Root boat (Fig. 2) was equipped with two "spider" electrode arrays that were more conducive to sampling in the lotic environment of the Connecticut River. The five standard sample sites identified in 2005 (Fig. 1) were used exclusively in subsequent years (i.e. there was no experimental sampling in other areas) and the timing of site visits was systematic within a period. Each site was sampled on the same day within each calendar week, such that the interval between sampling events at a site was fixed at seven days.

The first sampling trip of 2006 took place on 27 April. Thirty sampling trips were completed before the final trip on 30 June (Table 11). All five sites were sampled in four periods in May and June; in other periods fewer than five sites were sampled because of flooding, limited availability of personnel or equipment malfunction (Table 11, Table 12). Sixteen to 30 electrofishing transects were completed at each site (Table 13).

Field sampling operations in 2007 were expanded to incorporate both the standard project sampling conducted in 2005-2006 (hereafter referred to as the "SWG Project") and a striped bass mark-recapture study funded through a grant from the State of Connecticut Long Island Sound License Plate Fund (hereafter referred to as the "Mark-Recapture Project"). The objective of the Mark-Recapture project was to provide more detailed estimates of striped bass abundance during spring months (May-June) in the study region, information that is complementary to the SWG Project (see Objectives 2 - 3).

The simultaneous execution of these two projects required multiple crews to operate independently in different portions of the river on the same night. To meet this need, the UConn boat was designated for use on the Mark-Recapture Project, while the Smith-Root boat was designated for use on the SWG Project. The UConn boat was re-fitted with two "spider" electrode arrays, which markedly improved its sampling efficiency. Mark-Recapture Project procedure called for 3 nights each week of night-time boat electrofishing at the Windsor Locks (WL) site. Hence the sampling schedule for both projects required sampling at WL 4 nights each week (Tue-Fri), with Tuesday nights serving as a dual purpose SWG Project and Mark-Recapture Project sample night (i.e. data collected on this night would be used for both projects). On SWG Project and dual purpose nights, the SWG project sampling protocol was followed (methods are described in sections Objectives 1-3). In contrast, Mark-Recapture Project sample nights entailed only collection, measurement (TL), and tagging of striped bass. Decreased fish handling times on Mark-Recapture Project sample nights allowed for a greater spatial coverage and greater numbers of tagged striped bass. Mark-Recapture Project sample nights also provided additional data on striped bass size structure in Windsor Locks (see Objective 2).

In 2007, field sampling began on 10 April and ended on 15 June. We conducted sampling on 42 nights (Table 14; 22 SWG Project, 14 Mark Recapture Project, 6 dual purpose) and completed 169 electrofishing transects (Table 14, Table 15, Table 16). Equipment failure on the UConn boat necessitated a change in sampling schedule from 24 May to the end of the season: SWG Project sampling was conducted Sunday through Tuesday (EF site dropped from sampling schedule), dual purpose WL sampling was done on Wednesday, and Mark-Recapture Project sampling was done Thursday and Friday at WL. The modified schedule therefore

contained one fewer Mark-Recapture Project sample night per week for the final 3 weeks of the sampling season and elimination of EF from the sampling rotation (Table 15). The number of transects completed at EF was lower than at other sites (Table 16). Sampling was discontinued after 15 June because of additional equipment failure, consistent low catch rates, and poor navigability stemming from low water levels at WL.

Field sampling in 2008 was devoted entirely to the Mark-Recapture Project. Sampling began on 6 May and ended on 11 June; 14 sampling trips and 56 transects were completed (Table 17, Table 18). All sampling occurred at the Windsor Locks site. As in 2007, Mark-Recapture Project sampling entailed only collection, measurement (TL), and tagging of striped bass (see Objective 2). The Smith-Root boat was used until 27 May, when mechanical failure necessitated a switch to the UConn boat. Sampling was discontinued after 11 June because of mechanical failure, low river flows, and persistent low catch rates.

Objective 1: Assess Abundance, Temporal/Spatial Distribution, and Population Structure of River Herring

Distribution and abundance

All captured river herring were enumerated and measured for total length (TL). All river herring were captured via boat electrofishing, with the exception of 4 fish that were collected from anglers on 5/6/05. A maximum of five herring per 5 mm size class were euthanized and retained as sub-samples for analysis of demographic variables (sex, species, age, and spawning history). Subsampled herring were placed on ice and subsequently dissected within 24 h. Species determinations were made based on peritoneal color (Loesch 1987). Sex determinations were made based on examination of the gonads.

Totals of 555, 1,523, and 1,326 river herring were collected in the years 2005-07, respectively (Table 19). Of these fish, 432, 777, and 634 were retained as sub-samples. Alewives comprised approximately 1-3% (n = 5 in 2005, n = 21 in 2006 and 2007) of subsampled herring, and were generally collected during the early portion of the sample season (on or prior to 5/11) in the southern sample sites (Wethersfield and lower Farmington River). The lone exception was an alewife collected on 5/29/06 in Enfield. Hence, virtually all captured river herring were blueback herring; analyses of relative abundance and size structure described herein are referred to as pertaining to blueback herring. Analyses of age and spawning history structure excluded the relatively few subsampled alewives. Differences between 2005 results and those of subsequent years should be considered with caution because of changes in gear (UConn boat vs. Smith-Root boat) and sampling plans (see Summary of Field Sampling Operations).

We analyzed spatiotemporal effects on herring abundance via analysis of variance (ANOVA). We first analyzed the combined effects of site and period, including tests for the site-period interactions (Table 20). Because we were interested in the patterns of fish abundance with regards to the main effects, we tested for differences among means using a multiple testing method (Tukey Studentized Range Test) that controls the experimentwise error rate. We view these tests as broadly informative; however it should be noted that they should be viewed with caution in datasets in which the site-period interaction was significant, because the difference between means of one main effect depends on the level of the other main effect.

Location had a consistent influence on the catch rate (expressed as catch per hour of shocking time) of herring in every year. In all three years, blueback herring abundance was highest in downriver sites. In 2005, seasonally-averaged herring abundance was lowest at

Enfield and Holyoke and varied more than an order of magnitude along the river (Fig. 3). In 2006, seasonally-averaged herring abundance was also lowest at Enfield and Holyoke and again varied more than an order of magnitude along the river (Fig. 4). In 2007, seasonally-averaged herring abundance was lowest at Enfield, and varied more than an order of magnitude along the river (Fig. 5). Results from Enfield in 2007 should be viewed with caution due to relatively low sampling effort at this site (Table 16).

There was a strong effect of date on river-wide abundance of herring. In 2005, river-wide herring abundance was highest in the earliest sampling period (Fig. 6). Several waves of river-wide herring abundance were evident in 2006 (Fig. 7). In 2007, herring were abundant for a three week period in the middle of the season (Fig. 8). Seasonal peak rates of catch exceeded 100 herring per hour in 2006 and 2007. Mean herring catch rates had declined below 10 fish per hour in the last sampling period of every year.

Size and age structure

Mean herring size varied significantly among years ($F_{2,3401} = 370$, $p < 0.0001$). Multiple comparisons tests (Tukey) revealed that size distribution in each of the three years was significantly different from that of other years. Mean herring size was largest in 2005 (265 mm $\pm$ 17 SD; Fig. 8), smallest in 2006 (244 mm $\pm$ 19 SD; Fig. 10), intermediate in 2007 (256 mm $\pm$ 13 SD; Fig. 11).

Herring size varied within a season, and there was no consistent effect of location. In ANOVA, site was not significant as a main effect in any year (Table 21). In contrast, herring size varied over the season each year. In 2005 (Fig. 12) and 2006 (Fig. 13), herring were smallest late in the season. In 2007 herring were smallest in late May (Fig. 14).

Scale samples and sagittal otoliths were collected from all lethally subsampled blueback herring in 2005-2007 for age and spawning history analysis. Scales were taken from the area above the lateral line and anterior to the dorsal fin (Hattala 1999). Annuli and spawning marks were counted from projections of scales that were mounted between glass microscope slides and placed in a microfiche reader (Davis and Schultz in press). Sagittae were placed in immersion oil and examined using a dissecting scope at 12x magnification. Otolith age estimates were made in accordance with the methods of Libby (1985). In the case of both scales and sagittae, age was estimated by adding 1 to the annulus count (i.e. edge of structure considered to be final annulus) (Marcy 1969; Libby 1985; Davis and Schultz in press).

Initial analyses focused on comparisons of age estimates derived from otoliths and scales, with the goal of deciding which structure would be used as the primary structure for estimation of population age structure. A stratified random sample (maximum of 5 fish from each year/sex/cm TL stratum) of subsampled blueback herring were chosen for this analysis (n = 247). Scale samples and otoliths from these fish were read independently by three readers. The mean standard deviation of age estimates for individual fish was calculated as a measure of inter-reader precision. Ages were then assigned to each sample using the following rules: in cases in which two readers agreed on age but the third disagreed by 1 year, the majority age was assigned to the sample; in all other disagreement cases (three-way disagreement or two-way agreement in which the third reader disagreed by more than 1 year), the sample was removed from further analysis. Once ages had been assigned, log-transformed length was regressed on age for both otoliths and scale age estimates to examine differences in age-length relationships produced by the two methods. The agreement between otolith and scale age estimates for individual fish was also examined.

The mean standard deviation of age estimates was 0.56 years for otoliths and 0.47 years for scales, indicating higher levels of inter-reader precision in scales. The frequency distribution of standard deviations for both structures shows a strong mode at 0.5 years for scales, while the distribution for otoliths is flatter and has a longer tail (Fig. 15). This result indicates that the relatively lower levels of inter-reader precision for otoliths may be driven by a small number of extremely "noisy" otoliths that produced highly variable age estimates. The slopes of the age-log length regressions produced by the two structures were similar (Fig. 16, Fig. 17; slope = 0.02 for otoliths, slope = 0.03 for scales, $R^2 = 0.32$ for both relationships). However, otolith age estimates were higher than scale age estimates (Fig. 18).

These analyses indicate that otoliths and scales, while producing comparable levels of inter-reader precision, do not agree well on the age of individual fish. We decided to proceed with otoliths as the primary structure for population structure analyses, because otoliths are widely considered to be more reliable estimators of age than scales for most fish species, especially in older fish (Maceina et al. 2007). Otolith age estimates for older fish may nonetheless be erroneously high. Readers consistently reported difficulties in interpreting the edge of otoliths from larger fish, and estimates greater than 7 years exceed published values for river herring longevity (Marcy 1969; Loesch 1987; Jessop 2003; Davis and Schultz in press). In order to minimize the uncertainty associated with age estimates for larger fish, we designated all individuals producing age estimates > 5 yrs as age 6. Because information concerning spawning history can not be derived from otoliths, scales were used to estimate spawning history via counts of spawning marks.

To characterize population age structure, additional fish (5 fish from each year/sex/cm TL stratum) were randomly selected and added to the initial age subsample (n = 439 for the combined subsample). The entire subsample of otoliths was examined by one reader for age estimation. A portion (n = 245) was screened by a second reader to assess inter-reader agreement. The two readers agreed on age for 82% (n = 200) of the samples, and disagreed by more than one year in < 2% (n = 4). A portion of scales in the subsample (n = 322) was examined by one reader for spawning history estimation. Agreement in spawning history estimation was not assessed due to high rates of agreement (> 99% agreement or difference of one previous spawn) found in our previous studies of river herring scale aging (Davis and Schultz in press).

We used age-length keys to estimate age structures for each year (Devries and Frie 1996). We used a separate key for each sex because of previously-demonstrated differences in growth and age at first spawn (Loesch 1987). Sex and age composition of each 10 mm size class for each year was determined from dissection and scale analysis. These sex-specific age keys were then used to estimate the sex and age composition of the size structure sample for each year:

$$F_{i(a,b)} = F_i * P_{i(a,b)}, \qquad \text{(equation 1)}$$

where: $F_{i(a,b)}$ = estimated number of fish of sex a and age b in size class i; F_i = number of fish measured in size class i; and $P_{i(a,b)}$ = proportion of fish of sex a, and age b in size class i (from dissection and scale analysis). The total estimated number of fish of each sex and age within the size structure sample was then calculated as:

$$F_{(a,b)} = \sum_i F_{i(a,b)}, \qquad \text{(equation 2)}$$

A spawning history/age key was developed for each sex. These keys were then applied to the estimated age structures for each sex to estimate the frequency of each spawning class within each age class:

$F_{a,b(r)} = F_{(a,b)} * P_{a,b(r)}$, (equation 3)
where: $F_{a,b(r)}$ = estimated number of fish of sex *a,* age *b* in spawning history class *r*; $F_{(a,b)}$ = estimated number of fish of sex *a*, age *b* (obtained via equation 2); and $P_{a,b(r)}$ = proportion of fish of sex *a*, age *b* in spawning history class *r* (from scale analysis). The estimated number of fish of each sex in each spawning history class was then calculated as:

$$F_{a(r)} = \sum_{b} F_{a,b(r)} \text{ ,} \qquad \text{(equation 4)}$$

The spawning run was primarily composed of ages 3 – 6 (Figs. 19, 20). Age 2 fish were sparse and were eliminated in analyses of interannual variation in age structure. Age structures of female (χ^2_6= 454, $p < 0.0001$) and male (χ^2_6= 338, $p < 0.0001$) blueback herring differed significantly among years of SWG project sampling (2005-2007). Large numbers of age 3 and 4 fish were present in the 2006 and 2007 runs, respectively, indicating a strong 2003 year class. The 2005 run contained a relatively high proportion of age 5 and 6 fish. The spawning run was dominated by virgin fish in all years of SWG project sampling (Table 22, Table 23, Fig. 21, Fig. 22). Fish that had spawned at least once previously were combined into a single 'repeat-spawner' class in analyses of interannual variation in spawning history. Spawning history of females (χ^2_2 = 25, $p < 0.0001$) and males (χ^2_2 = 50, $p < 0.0001$) varied among years of SWG project sampling. Repeat-spawners (both sexes combined) composed 30% of the 2005 run, but then dropped to 16% of the run in 2006 and 15% in 2007

Population structure and life history of blueback herring in the Connecticut River has changed in recent decades. There is a single previous study of historical population structure data for blueback herring in Connecticut: Loesch (1987) reported size, age, and spawning history of blueback herring from the Thames River in 1966, and size of blueback herring from the Connecticut River in 1967. These data were collected when river herring runs in Connecticut were relatively robust, and therefore provide an appropriate baseline to identify changes in population structure that are relevant to recent river herring population declines (Davis and Schultz in press). We tested for differences among historic and contemporary means of blueback herring size using Tukey Studentized Range Tests. Mean blueback herring length was 6 – 16% larger in 1966-1967 than in 2005-2007 (Fig. 23). Significant differences in age and spawning history structures were also evident. The Thames River run in 1966 was dominated by fish age 5 and older, and fish younger than age 4 were relatively rare (Fig. 19, Fig. 20). Repeat-spawners composed 82% of the 1966 run (Fig. 21, Fig. 22).

Objective 2: Assess Abundance, Temporal/Spatial Distribution, and Size Structure of Striped Bass

Distribution and abundance

All striped bass collected on all sampling trips were enumerated, measured (TL), and weighed (kg). In the first three years of the study, all striped bass > 300 mm TL captured during SWG project sampling were subjected to gastric lavage to collect diet samples. No diet samples were collected during Mark-Recapture Project sampling in 2008. In 2006 through 2008, all striped bass > 300 mm TL (during SWG project and Mark-Recapture Project sampling) were also tagged with a uniquely-coded FLOY internal anchor tag (Fig. 24). These tags featured a phone number that anglers could call to report capture of tagged striped bass.

A total of 126 striped bass was captured during 2005 (Table 24). A small number of these fish (n = 6) were euthanized due to poor recovery from collection and handling. Of the

various sampling methods used that year, boat electrofishing yielded most of the striped bass (n = 82), followed by night-time controlled angling and night-time gill-netting (n = 14 each), then day-time gill-netting (n = 9) and day-time controlled angling (n = 7). For analyses of along-river distribution, only striped bass captured during electrofishing in the five main sampling strata were considered due to the sporadic nature of catches via other methods. Striped bass captured by all methods, and in all locations, were considered for analyses of size structure and diet.

In 2006, the first year in which all sampling was done by night electrofishing, we collected more than 300 fish (Table 24). A small number (less than 1%) were euthanized because of poor recovery. We tagged striped bass in 2006 to assess the feasibility of conducting a larger-scale mark-recapture project. Over 200 striped bass were tagged during 2006 sampling operations (Table 24).

In 2007, in which two crews were sampling, we collected more than 1000 striped bass (Table 24). SWG Project sampling (up to five nights per week) yielded 625 fish; Mark-Recapture Project sampling (up to two nights a week) yielded 424 fish. Less than 1% was euthanized. Almost two-thirds of the fish collected were tagged (Table 24).

In 2008, the total catch was higher than the other two years in which we were operating with only one boat, but not as high as the previous year in which we were using two boats (Table 24). About 90% of the striped bass collected were tagged.

A wide size range of striped bass was captured. For all analyses, striped bass samples were divided into two size groups; the length used to divide the groups was close to the median length of the size distribution and was the length at which river herring became a major component of the diet (see Objective 3). Bass that were $\leq$ 500 mm TL were designated as Small, and bass that were > 500 mm TL were designated as Large. There was a significant correlation between the catch rate of Small and Large striped bass on a transect ($r = 0.27$, $n = 301$, $p < 0.0001$).

We analyzed spatiotemporal effects on abundance (catch rate, expressed as catch per hour of shocking time) via ANOVA. We first analyzed the combined effects of site and period, including tests for the site-period interactions (Table 25). As in the analysis of spatiotemporal effects on herring abundance, we tested for differences among site and period means even when site-period interactions were significant. There was a significant interaction between spatial and temporal effects on Small striped bass abundance in every year, and on Large striped bass abundance in 2007.

Catch rates varied among years (Table 26). Overall catch rates were lower in 2005 than in subsequent years, probably as a result of our complete reliance on the UConn boat. Catch rates of Small striped bass were several times higher in 2007 than they were in 2006. Catch rates of Large striped bass were comparable in the two years.

Location had an influence on the catch rate of both size classes of striped bass every year (Table 25). Every year, the abundance of Small striped bass was highest at Windsor Locks (Fig. 25, Fig. 26, Fig. 27). Sites with the lowest abundance of Small striped bass varied slightly from year to year; Small bass were always relatively scarce at Enfield and Holyoke, and in every year but 2006 were also scarce at Wethersfield. Along-river variability in Small striped bass abundance was greater than an order of magnitude in 2005 and 2006, but was slightly less than an order of magnitude in 2007. Sites with the lowest abundance of Large striped bass were always Enfield and Wethersfield (Fig. 28, Fig. 29, Fig. 30). In 2005, the site with the highest abundance of Large striped bass was Windsor Locks. In subsequent years, there were more Large striped bass at Holyoke than at Windsor Locks. Along-river variability in Large striped

bass abundance exceeded an order of magnitude in 2005 and approached an order of magnitude in subsequent years.

River-wide abundance of Small, but not Large, striped bass varied over the season in some years (Table 25). In 2005, abundance of Small striped bass was highest in the first two weeks of the sampling season (Fig. 31). There was no temporal variability in river-wide catch rates of Small striped bass in 2006 (Fig. 32). In 2007, the abundance of Small striped bass was lower in the last sampling week than in previous weeks (Fig. 33). There was no temporal variability in river-wide catch rates of Large striped bass in any of the three years (Fig. 34, Fig. 35, Fig. 36).

Size structure

Within-year analyses of striped bass size structure (site and period effects) were restricted to striped bass captured at the five major sample sites, while across-year analyses and annual summaries of size structure included all striped bass captured (i.e. fish captured at other sample sites in 2005). Striped bass captured at Windsor Locks during Mark-Recapture Project sampling in 2007 were included in the summary of size structure for that year, as well as analyses of across-year differences.

Striped bass size varied significantly among years ($F_{3,2076} = 25$, $p < 0.0001$). Multiple comparisons tests (Tukey) revealed that striped bass mean size did not change in the first two years, but mean size in the subsequent two years differed from that in the first two years and differed from each other. Mean size decreased over time; it was largest in 2005 (510 mm $\pm$ 151 SD; Fig. 37), slightly smaller in 2006 (492 mm $\pm$ 243 SD; Fig. 38), and then declined about 10% in both 2007 (443 mm $\pm$ 187 SD; Fig. 39) and 2008 (400 mm $\pm$ 121 SD; Fig. 40). As size declined, the size distribution became more positively skewed (i.e., with a longer tail to larger size). These results should be interpreted with caution due to heavy sampling of the Windsor Locks sample site in 2007-2008 (all Mark-Recapture Project sampling took place in Windsor Locks in these years). Windsor Locks was characterized by high abundance of Small striped bass in all years (Fig. 25, Fig. 26, Fig. 27).

Analysis of variance within year revealed spatial and temporal effects on striped bass size (Table 27). Location had a consistent effect on striped bass size distribution. In 2005 (Fig. 41), 2006 (Fig. 42), and 2007 (Fig. 43), the largest bass were furthest upriver at Holyoke. The smallest bass were furthest downriver at Wethersfield, or were at Windsor Locks. Date had an effect on size every year, but no consistent seasonal pattern is evident. In every year (2005: Fig. 44; 2006: Fig. 45; 2007: Fig. 46; 2008: Fig. 47) size jumped or dropped in at least one period and then returned to the seasonal mean.

Tag-recapture study

While standard SWG Project sampling provided information on striped bass relative abundance (electrofishing CPH), estimates of absolute abundance were crucial to comprehensive evaluation of striped bass predation. Estimates of absolute abundance (hereafter referred to as "population size", the target population being the aggregation of striped bass present in the study stretch during the spring migration season), in conjunction with data on striped bass size structure and per-capita consumption rates, were required to estimate population-level consumption rates (see Objective 3). Previous studies that estimated striped bass population size in the Connecticut River affixed internal anchor tags to striped bass that had been captured via boat electrofishing, and relied on recreational anglers to recapture and report tagged fish (Savoy and Crecco 2004). This approach required estimates of total recreational catch, which was provided by a creel survey of the Connecticut portion of the Connecticut River (Howell and

Molnar 1999). The Lincoln-Peterson model (Pine et al. 2003; Hayes et al. 2007), a simple closed population model, was used to estimate population size. Closed population models assume that the study population does not change with respect to deaths, births, emigration, and immigration during the study period. The Connecticut River striped bass population clearly violates this assumption as there is unrestricted striped bass movement from or into the study area. Closed population models will therefore produce biased estimates of striped bass population size, although the magnitude of this bias is predicated on the severity of assumption violations (Pine et al. 2003).

Tag-recapture studies of population size can be improved by using uniquely-coded tags (i.e. each tagged fish is assigned a unique id number, and this number is reported as part of a standard recapture report). The use of uniquely-coded tags allows for the compilation of individual capture histories, which in turn provides insight into the rate of emigration from the study area (Pine et al. 2003). Individual capture histories can also be used in open population models (e.g. Jolly-Seber, robust model) that do not rely on the assumption of population closure (Pine et al. 2003; Hayes et al. 2007). However, fitting open population models to mark-recapture data requires relatively high recapture rates. In particular, it is crucial that some individuals are recaptured on multiple occasions (Pine et al. 2003; Hayes et al. 2007). Given these considerations, we tagged striped bass with uniquely-coded tags with the hope that we would be able to both a) apply open-population models to our mark-recapture data, and b) assess the potential bias in abundance estimates derived from closed population models.

We conducted a pilot study in 2006 to determine the feasibility of successfully executing a mark-recapture study solely by tagging striped bass during standard SWG Project sampling operations. All striped bass > 300 mm TL were tagged with a uniquely-coded internal anchor FLOY tag that featured a phone number for recapture reports (Fig. 22). Posters advertising the tagging program were posted at boat launches and popular shore-fishing locations along the Connecticut River, and postings were made on local internet fishing forums. No reward was offered for tag reports in 2006. More than 200 tagged striped bass were tagged and released (Table 24). Very few of these individuals were subsequently recaptured in the study stretch during the sampling season (Table 28). The number of fish tagged as well as the recapture rates produced by this level of sampling effort were lower than those of the previous mark-recapture studies (Savoy and Crecco 2004). The recapture rate was insufficient for application of open-population mark-recapture models (Pine et al. 2003).

To address these shortcomings, additional funding was obtained from the Connecticut Long Island Sound License Plate Fund in 2007 to allow for an expanded striped bass mark recapture effort (Davis et al. 2008). Two complementary approaches were developed to estimate striped bass population size. The primary approach entailed estimating population size in the WL site using a robust mark-recapture model (Pine et al. 2003). Robust mark-recapture models use a "hybrid" study design that incorporates features of both closed and open population models (Pine et al. 2003). Sampling to support this effort would occur exclusively in WL on 3-4 nights per week (referred to as Mark-Recapture Project or "dual purpose" sample nights – see "Summary of Field Sampling Operations"). Estimates of population size in WL, in conjunction with river-wide estimates of relative abundance provided by SWG project sampling, would be used to estimate river-wide population size. The secondary approach was based on the methodology used previously in the Connecticut River (Savoy and Crecco 2004). This approach would rely on both angler and electrofishing recaptures, in conjunction with creel survey data on angler catch. Creel survey data would be obtained via a "bus-stop" creel survey conducted by

the CDEP in 2007 and 2008 (Howell and Molnar 1999; Davis et al. 2009). In addition, the use of uniquely-coded tags would allow for compilation of individual capture histories and coarse-level assessment of emigration from the study area. Seasonal trends in SWG Project electrofishing catch rates would be used to assess the level of immigration into the study stretch during the sample season. This approach would not be specific to the WL site but would instead incorporate fish tagged and recaptured throughout the entire study area. Therefore, the practice of tagging striped bass during SWG Project sampling was continued in 2007. Greater efforts were made in 2007 to advertise the tagging program, and a $15 reward was offered for tag reports.

More than 650 striped bass were tagged during 2007 sampling operations (Table 24). Most fish were tagged on SWG Project sample nights in Wethersfield, lower Farmington River, Enfield, and Holyoke, while almost half were tagged during Mark-Recapture Project sample nights in Windsor Locks; about 10% were tagged during dual purpose sample nights in Windsor Locks. Of 41 recaptures in 2007, anglers accounted for more than 80% (Table 29). Almost half of the recaptures (designated "A" in Table 29) of fish tagged in 2007 occurred during the sampling season (4/10/07 – 6/15/07) and within the study stretch, and were therefore useful for mark-recapture modeling. The A-level recapture rate (2.7%) was comparable to those obtained in previous mark-recapture studies (Savoy and Crecco 2004). Because no multiple recaptures of the same individual were obtained, and because CDEP was not able to conduct a creel survey in 2007, a striped bass population size estimate for 2007 is not possible.

In light of the failure of the robust model approach in 2007, sampling operations in 2008 focused on supporting the closed-population model approach (see Summary of Field Sampling Operations). Greater efforts were made to advertise the tagging program, including sending letters and advertisement posters to all tackle shops in Connecticut. High-reward tags ($50) were also instituted in addition to the standard tags ($15). The addition of high-reward tags was intended to increase angler interest in the tagging program and to assess standard tag reporting rates. Differences in reporting rates between high-reward and standard tags can be used to estimate reporting rates for standard tags, assuming that all high-reward tags are reported (Pine et al. 2003). This correction for reporting rates can improve the accuracy of abundance estimates (Hayes et al. 2007).

More than 500 striped bass were tagged during 2008 sampling operations (Table 24), divided about equally between standard-reward and high-reward tags. Of the 26 striped bass recaptures in 2007 (Table 30), anglers provided almost 90%. More than two-thirds of the 2008 recaptures (designated "A" in Table 30) occurred during the sampling season and within the study stretch. The A-level recapture rate was 3.3%. Among the A-level recaptures, high-reward tags were not reported at a higher rate than standard-reward tags (high reward: 3.3%; standard-reward: 3.2%). Our interpretation of this result is that standard tags were already being reported at a very high rate, as tripling the reward did not produce an increase in reporting rate. Therefore, reporting rate was assumed to be close to 100% for both standard and high-reward tags. CDEP was able to carry out a "bus stop" creel survey in 2008. This creel survey covered the portion of the Connecticut River between Middletown, CT and the Massachusetts/Connecticut border, and provided estimates of recreational angler effort and catch during the open-water fishing season (Davis et al. 2009).

A Schnabel mark-recapture model was used to estimate striped bass abundance in 2008. The Schnabel model incorporates multiple marking and recapture samples, a sampling design

that is highly recommended for closed population modeling (Pine et al. 2003). Fish are marked and recaptured on multiple occasions, and population size is estimated as (Hayes et al. 2007):

$$N = \frac{\sum_{i=2}^{t} n_i * M_i}{\sum_{i=2}^{t} m_i}, \qquad \text{(equation 5)}$$

where: N = estimated population size; n_i = total fish captured on sampling occasion i; M_i = number of tagged fish at large for sample occasion i; m_i = number of tagged fish recaptured on sample occasion i; t = number of sampling occasions.

The study period was restricted to the month of May because: a) the recommended study period length for closed population models is < 1 month (Pine et al. 2003), b) all applicable recaptures occurred during the month of May (designated “A” in Table 30), and c) only 7% (n = 35) of the striped bass tagged in 2008 were tagged after the month of May. Every day on which a tagged striped bass was recaptured, either by anglers or during electrofishing operations, was treated as a sample occasion (hereafter referred to as a “sample day”). The total number of striped bass ≥ 300mm TL captured on that sample day via electrofishing was known; the total number of striped bass ≥ 300mm TL captured that day by recreational anglers was estimated from creel data (Davis et al. 2009). These quantities were summed to estimate the total fish captured on the sampling day (n_i). Estimates of striped bass catch were available for sampling days on which creel surveys were conducted. For sample days on which a creel survey was not conducted, the mean catch for that day-type stratum (weekend vs. weekday) within the month of May was used as an estimate of striped bass catch for that sample day. Creel survey results from “Zone 4” (the river stretch from Hartford to the MA/CT border) were used for this analysis (Davis et al. 2009). Because creel survey data were not available for the Connecticut River between Holyoke and the CT/MA border (C. Slater, MA DMF, personal communication), the lone “A” recapture occurring north of the Connecticut border was not included in the Schnabel analysis (Table 30). Our results therefore reflect our best estimate of the number of striped bass ≥ 300 mm TL in the Connecticut River stretch between Hartford and the MA/CT border during May 2008.

The Schnabel model yielded an estimate of 65,744 (95% CI = 2,434 – 109,573) striped bass ≥ 300 mm TL in the Connecticut River between Hartford and the MA/CT border during May 2008 (Table 31). Because fewer than 25 total recaptures were recorded, recaptures were treated as a Poisson variable for the purposes of confidence interval estimation (Hayes et al. 2007).

Association of striped bass and river herring in time and space

The degree to which striped bass and river herring co-occur is of interest. A significant predatory-prey interaction requires that the putative predator and prey come into contact, and that the predator is subsequently successful in capturing the prey. Therefore, the degree to which spatiotemporal distributions of striped bass and river herring correspond provides insight into the relative magnitude of striped bass predatory impacts.

Seasonal fluctuations of river herring and striped bass abundance were congruent. Both Large striped bass (which consumed the majority of river herring – see Objective 3) and river herring were present in the study region during May – early June, and the abundance of both species were relatively low in mid – late June (Fig. 6, Fig. 7, Fig. 8, Fig. 34, Fig. 35, Fig. 36). However, there were differences in the along-river distribution of the two species. River herring

were most abundant in the downstream sites, and became progressively less abundant upstream (Fig. 3, Fig. 4, Fig. 5). In contrast, Large striped bass were generally more abundant in upstream sample sites (Fig. 28, Fig. 29, Fig. 30). Deviations from this general spatial pattern of Large striped bass abundance (low abundance at Holyoke in 2005 and at Enfield in all three years) may reflect low catch effectiveness in turbulent water that appear to be a favorite habitat for these large predators.

Objective 3: Characterize Predator/Prey Interactions between Striped Bass and River Herring

Striped bass diet

As an initial step towards characterizing the impact of striped bass predation on river herring populations in the Connecticut River, a detailed study of striped bass diet was conducted in 2005-2007. Because there is no *a priori* reason to expect that striped bass diet composition and its relationship to striped bass size will vary significantly between years, we combined diet composition data over the three years of the study.

About half of the striped bass that were captured were sampled for diet (Table 32). We sampled few individuals smaller than 300 mm because they were susceptible to injury during gastric lavage. Fish in larger size classes were not sampled for diet if a large number of fish were in the live well, or if equipment malfunctioned. Of the 1,506 striped bass collected in 2005-07, approximately half were lavaged.

All diet samples were frozen and later thawed and sorted by prey category (Table 33). Diet items were enumerated, weighed (blotted wet mass, g), measured where appropriate (TL, mm), and preserved in 95% ethanol. Diet composition was summarized by frequency of occurrence (%), percent composition by number, and percent composition by mass (Bowen 1996), in 100 mm striped bass size classes.

A wide variety of prey items was found in striped bass stomachs. We categorized prey items into 24 categories (Table 34). Smaller striped bass consumed a wide variety of both piscine and invertebrate prey (Tables 34-37). Larger striped bass consumed a narrower variety of prey, mainly fish (Tables 38-42). River herring were a prominent item in diets of 600 – 900 mm TL striped bass (Fig. 48). American shad were the most prevalent diet item in ≥ 900 mm TL striped bass (Fig. 48). Over all years of SWG sampling, 21% of striped bass captured were ≥ 600 mm TL, and 4% were ≥ 900 mm TL. These results, considered in concert with the diet composition data, indicate that a relatively small portion of the striped bass population is feeding heavily on American shad.

Spatial variability in striped bass capture of blueback herring

The along-river distribution of Large striped bass may reflect preference for locations in which they are most successful at capturing preferred prey, or preference for locations in which their preferred prey is most abundant. To test the former hypothesis, we calculated the percentage of Large striped bass that captured river herring at each site, combining all sample nights within a site. To test the second hypothesis, we compared the percentage of Large striped bass that captured river herring on each sample night to the mean herring abundance (as electrofishing CPH) on that sample night. Only nights on which striped bass > 400 mm TL were captured and lavaged were included.

Capture success (defined as the percentage of striped bass containing herring prey) differed across sample sites (Table 43). In Wethersfield, the most-downstream sample site, only 6% of > 400 mm TL striped bass captured river herring; at Holyoke, more than 25% of > 400

mm TL striped bass captured river herring. Large striped bass also captured river herring at high rates in the lower Farmington River. Hence, there is good concordance between the ranking of Large striped bass capture success (EF<WF<WL<FR<HK) and their abundance over all three years (generalizing from Fig. 28, Fig, 28, Fig. 30: WF<EF<FR<WL<HK). In contrast, there is poor concordance between the ranking of Large striped bass capture success and river herring abundance (EN<HK<WL<FR<WF). Furthermore, river herring abundance on a sample night was a poor predictor of > 400 mm TL striped bass capture success (Fig. 49). These results suggest that capture success and not prey abundance may be the primary driver of along-river distribution of > 400 mm TL striped bass; it is likely that other factors (e.g. river flow conditions, the pulsed dynamics of river herring migration) may also play a role.

Per-capita striped bass consumption rate

Estimates of striped bass per-capita consumption rates are required to quantitatively assess striped bass impacts on river herring populations. We considered three general classes of models that could potentially estimate striped bass consumption rates: bioenergetics models, gastric evacuation models, and meal turnover models (Adams and Breck 1990).

Bioenergetic modeling is not feasible for our study. Bioenergetics modeling requires the parameterization of "energy budget" models that incorporate information on growth, metabolic rates, diet composition, and thermal environments of fish to estimate consumption rates (Hartman 2003). This approach has been used by previous researchers to estimate striped bass consumption rates (Hartman 2003). Estimates of individual growth were obtained by sampling large numbers of striped bass over an extended time period, documenting the changes in length and mass of cohorts over the year. Our sampling season was relatively short, and growth could not be confidently estimated from changes in mass and length of yearclasses; hence, bioenergetics modeling was not a viable approach for our study.

The gastric evacuation approach is also not feasible for our study. Gastric evacuation models rely on both experimentally-determined gastric evacuation rates and field measurements of stomach fullness to estimate the average amount of prey biomass consumed over a designated time period (Elliot and Persson 1978). This approach has been used to estimate per-capita consumption rates of age-0 striped bass feeding on small prey (Hartman 2003). Gastric evacuation rate studies have not been conducted for large striped bass feeding on large piscine prey, and estimates of large striped bass consumption based on evacuation rates of small striped bass would be erroneous (Johansen et al. 2004).

We chose to estimate striped bass per-capita consumption using a meal turnover model. Meal turnover models are relatively simple models that rely on: a) the frequency with which prey items are found in the stomachs of predators, and b) the ratio of prey mass to predator mass (Adams and Breck 1990). Our consumption rate estimates used a meal turnover model appropriate for warm-water piscivores (Adams et al. 1982):

$$C = 100\sum_{i=1}^{N}\frac{\left(Pw_i / Bw_i\right)}{N}, \qquad \text{(equation 6)}$$

where: C = striped bass daily ration (% body weight/day); Pw_i = estimated total weight at capture of prey when ingested by predator i over a defined 24 hour period; Bw_i = weight of predator i that consumed those prey; N = total number of predators in a sample, including those with empty stomachs. The meal turnover model assumes that 95% digestion occurs within one day, an assumption supported by previous work on striped bass (Hartman 2003). We estimated striped bass consumption of shad as well as river herring, pooling data from all years. We calculated an

estimate of daily ration by 100 mm size class of striped bass, restricting our analyses to size classes that consumed river herring or shad (≥ 400 mm TL; Fig. 48). Therefore, *N* is the number of striped bass within a particular 100 mm size class that were sampled for diet, whether a diet sample was recovered or not. To parameterize Pw_i (estimated weight of herring or American shad prey at ingestion), the mass of each herring found in a diet sample was set to 147 g (mean of all river herring collected, n = 1,846). For American shad, a value of 1,103 grams was used, based on the mean mass of male shad collected at Holyoke Dam in a previous study (Leonard and McCormick 1999).

Most striped bass size classes consumed 0 – 2% body mass day^{-1} of river herring and shad (Fig. 50). The largest class of striped bass consumed 3 – 7 % body mass day^{-1} of shad. Daily ration estimates were multiplied by the mean mass of striped bass within each size class to estimate daily prey biomass consumption. Consumption of herring was 13 – 43 g day^{-1}, and consumption of shad was 0 – 968 g day^{-1} (Fig. 51).

Estimating population-level consumption rate of blueback herring and shad

Per-capita consumption rates were combined with data on striped bass size structure and population size to estimate population-level consumption of river herring and American shad. Population-level consumption was estimated as (Tabor et al. 2007):

$$C_{pop} = \sum_i \frac{P_i * N * C_i * D}{P_w}, \qquad \text{(equation 7)}$$

where: C_{pop} = striped bass population-level consumption; P_i = proportion of striped bass in size class *i*; *N* = population size (equation 5); C_i = daily ration (g) of size class *i* (equation 6); *D* = days in time period over which population-level consumption is being estimated (set to 31 days – see below); and P_w = estimated weight of individual prey (147 g for river herring, 1,103 g for American shad). Only striped bass large enough to consume river herring or shad (> 400 mm TL) were included (Fig. 48). Population-level consumption was estimated for the month of May (*D* = 31 days), when abundance estimates were available (Table 31). Confidence intervals (95%) for population-level consumption estimates were derived from the upper and lower confidence limits for N (see Objective 2). While inputs for size structure (P_i) and daily ration (*Ci*) incorporate data from the entire study stretch in all three years of sampling, abundance estimates (*N*) are specific to the river stretch from Hartford to the MA/CT border in May 2008. Our estimates of population-level consumption are therefore conservative, as they do not incorporate estimates of predation by abundant large striped bass at the Holyoke site.

We estimate that striped bass consumed over 200,000 herring (95% CI = 8,187 – 368,351) and almost 100,000 American shad (95% CI = 3,541 – 159,688) in May (Table 45, Table 46). The river herring values represent 35 – 50% of the fish passed at Holyoke Dam during the peak years of the early 1980's (USFWS 2008) and far exceed the number of fish passed in the last decade (Fig. 52). The shad values do not exceed the recent rate of passage at the fish lift but represent about half of the fish passing at Holyoke. These results suggest that striped bass predation is a significant source of mortality for blueback herring and American shad in the upper Connecticut River.

General Conclusions and Recommendations

Blueback herring population structure has changed over recent decades. Fish in the Connecticut River in 2005-2007 were smaller and younger than those in 1966-1967. The proportion of repeat-spawners in contemporary runs was also significantly reduced. The substantial difference between historic and contemporary data suggests directional shifts in

demography and life history. These findings are consistent with our previous studies of river herring populations in Connecticut (Davis and Schultz in press).

The lower numbers of repeat spawners and younger age of spawners is likely to reduce stability (Morris and Doak 2003). Iteroparity, the reproductive strategy of repeated spawning each year, promotes population resilience in environments in which offspring survival is variable and uncertain; American shad runs in the northeast are often-cited examples of this 'bet-hedging' strategy (Leggett and Carscadden 1978; Leggett et al. 2004). If a similar selective scenario applies to blueback herring, then the reduced incidence of repeat spawning will result in larger variations in adult population size, because years of poor juvenile survival and poor subsequent recruitment will be followed by years of depleted spawning migrations. A decline in the age and size of spawners entails a loss of population-wide reproductive potential (LaPlante and Schultz 2007). Smaller herring have lower fecundity (Jessop 2003), and smaller fish may produce larvae that have lower survival, as has been seen in other species (Monteleone and Houde 1990; Berkeley et al. 2004). Finally, shifts to younger age-at-maturity such as those documented here (assuming recruitment to the spawning run is a reasonable proxy for the onset of maturity) have been a precursor to collapse in some fisheries (Olsen et al. 2004). Identification and mitigation of the factors driving these deleterious changes in the study population are critical steps in managing for long-term persistence.

The observed shifts in blueback herring life-history and population structure indicate increased levels of extrinsic mortality on older, larger fish. Size-selective mortality can have significant effects on demography and life history within fish populations (Ricker 1981; Reznick and Endler 1982). Predation and fishing mortality are two likely sources of this mortality. Predation on larger, older fish within a population can reduce the abundance of older age classes and favor the rapid evolution of earlier maturation at smaller sizes (Reznick and Endler 1982). Similarly, fisheries that selectively harvest older, larger fish have the capacity to shift the demographic composition of the exploited population towards younger, smaller individuals (Beard and Essington 2000; Levin et al. 2005). Such selective fishing pressure may also favor rapid evolution of earlier-maturing phenotypes (Conover et al. 2005; De Roos et al. 2006). Shifts of spawning runs to smaller, younger virgin fish have been demonstrated in heavily fished populations of river herring and American shad (Maki et al. 2002; Jessop 2003).

Large striped bass appear in the upper Connecticut River during spring months in pursuit of river herring on their spawning run. Our diet analysis shows that river herring represent a significant portion of Connecticut striped bass energy intake during May and June. This study also revealed that striped bass congregate in locations where their feeding success is high. Some striped bass in the Connecticut River may be engaged in spawning runs of their own; we did capture running-ripe females in our study region. However, it has not been confirmed that striped bass spawning is occurring in the river. Our findings indicate, at a minimum, that river herring on their spawning run in a large river provide a considerable feeding opportunity for Large striped bass that migrate with them.

Our study provides evidence that striped bass predation in the Connecticut River is a significant source of mortality on adult blueback herring. The estimated seasonal consumption of river herring by the local striped bass population is substantial; it far exceeds the number of herring that are passed at the Holyoke fish lift, and is comparable to the number that passed in years before a sharp decline in the early 1990's. Population-wide consumption of American shad is also considerable, albeit smaller relative to the number of fish that are passing at the fish lift.

Predation by striped bass on adult river herring is probably limited to the time when both species are in the river. Striped bass are opportunistic predators, and river herring spawning runs may represent a seasonal opportunity to efficiently capture highly nutritional alosine prey (Yako et al. 2000). River herring are likely particularly vulnerable to striped bass predation during spawning runs due to the constricted nature of the riverine environment and relaxation of normal predator avoidance behavior during spawning (Crecco and Benway 2008). While we have documented that striped bass consume large numbers of adult river herring during our study, studies of striped bass food habits in the New England coastal environment (Nelson et al. 2003) indicate that adult river herring are a relatively insignificant component of striped bass diet during coastal residence. The relatively brief period of co-residence in the Connecticut River during spring months may therefore account for the majority of predator-prey interaction between these two species.

The bioenergetic implications of this feeding opportunity have not been fully explored in this project. Data comparing the relative feeding success of Large striped bass in coastal waters relative to those in the study region would be helpful. A more detailed bioenergetic analysis would require quantifying terms such as gastric evacuation. Gastric evacuation rate has been quantified for young of year striped bass but not for the Large fish that consume blueback herring.

The population-level impact of striped bass predation on river herring is evidently dependent on the number of predators that the river herring encounter. Our estimate of local population size, based on a tag-recapture study and the assumption that the population is closed to immigration and emigration, is imprecise and biased. For several reasons, we could not employ a mark-recapture model that is more robust to assumptions regarding emigration and immigration. Additional work on the seasonal abundance of large striped bass in the Connecticut River would be desirable; progress towards more precise and accurate estimates of local population size would require: 1) more extensive tagging; 2) a more comprehensive recapture program, ideally combining a structured electroshocking program with a regional creel survey; 3) telemetry studies to further clarify movement rates into and out of the study region.

The results on population-wide consumption will need to be interpreted in a dynamical context. River herring population growth may be relatively insensitive or may be highly sensitive to the rate of mortality during the run. Work in this vein is continuing; a stage-structured population model for blueback herring is being developed that will incorporate these empirically-grounded estimates of mortality rate, combined with historical data on striped bass abundance, to hindcast the likely effect of striped bass stock recovery on river herring abundance.

Little is known about interactions between striped bass and blueback herring in their early life stages. Young of year striped bass prey upon young of year herring in estuaries during summer and autumn months (Hartman 2003). Thus it seems plausible that the burgeoning striped bass population has increased mortality of young of year herring in the Connecticut River and that this has contributed to population declines. Analysis of this possibility would require a sampling effort of similar or greater magnitude than that described here (albeit with different gear).

The conclusion that a majority of the spawning stock biomass of blueback herring is currently consumed by striped bass is based on assumptions that merit close scrutiny. One assumption is that counts at the Holyoke fish lift can be interpreted as evidence for herring population trends. The extent to which the Connecticut River population of blueback herring

relies on spawning habitat above the Holyoke Dam is not known: does the small number passing at the fish lift represent a nontrivial portion of the spawning population, or a thin wedge of highly migratory pioneers? The proportion of the spawning population that migrates as far as the dam may be constant over time, in which case the decline in herring passage at the dam is a fair indicator of population trends. Alternatively, herring may have responded in several ways to the high risk of mortality upon migration: there may be more spawning occurring in waters downriver of the dam, and other runs subject to lower predation rates may now be supplying recruits to the region. Data on the distribution of herring spawning, in the Connecticut River and elsewhere in the region, are needed to clarify whether a meaningful portion of the blueback herring spawning stock biomass is lost to striped bass predation.

There are management implications of our findings. Blueback herring recovery appears to be tightly linked to the abundance and size distribution of a large generalist predator that pursues its prey on the latter's spawning migration. Regulations that are designed to manage the abundance of striped bass will have follow-on effects on blueback herring in locations like the Connecticut River. When these regulations include size limits they are especially likely to affect the abundance of striped bass that prey on adult herring. Our findings are also pertinent to the relative importance of other stressors on herring populations, particularly the possibility that the coastal trawl fleet is depleting river herring as bycatch. It is quite likely that the herring population is subject to multiple stresses rather than a single source of mortality. If further work as described here demonstrates that striped bass are having a pronounced effect, a comprehensive management plan for river herring recovery will need to take both the trawl fishery and striped bass populations into account.

References

Adams, S. M., and J. E. Breck. 1990. Bioenergetics. Pages 389-415 *in* C. B. Schreck, and P. B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, MD USA.

Adams, S. M., R. B. McLean, and M. M. Huffman. 1982. Structuring of a predator population through temperature-mediated effects on prey availability. Canadian Journal of Fisheries and Aquatic Sciences 39:1175-1184.

Atlantic States Marine Fisheries Commission. 1999. Amendment 1 to the interstate fishery management plan for shad and river herring. Fishery Management Report 35.

Beard, T. D., Jr., and T. E. Essington. 2000. Effects of angling and life history processes on bluegill size structure: insights from an individual-based model. Transactions of the American Fisheries Society 129(2):561-568.

Berkeley, S. A., C. Chapman, and S. M. Sogard. 2004. Maternal age as a determinant of larval growth and survival in a marine fish, *Sebastes melanops*. Ecology 85(5):1258-1264.

Bowen, S. H. 1996. Quantitative description of the diet. Pages 513-532 *in* B. R. Murphy, and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, MD USA.

Collette, B. C., and G. K. Klein-MacPhee, editors. 2002. Bigelow and Schroeder's fishes of the Gulf of Maine, 3 edition. Smithsonian University Press, Washington DC.

Conover, D. O., S. A. Arnott, M. R. Walsh, and S. B. Munch. 2005. Darwinian fishery science: lessons from the Atlantic silverside (*Menidia menidia*). Canadian Journal of Fisheries and Aquatic Sciences 62:730-737.

Davis, J., E. Schultz, and J. Vokoun. 2008. Estimating predation on declining river herring: Tag-recapture study of striped bass in the Connecticut River. 2007 Progress Report submitted to the Long Island Sound Fund.

Davis, J. P., T. J. Barry, N. T. Hagstrom, and C. McDowell. 2009. Angler survey of the Connecticut River and Candlewood Lake. Connecticut Department of Environmental Protection, Bureau of Natural Resources, Inland Fisheries Division. Federal Aid to Sportfish Restoration F-57-R-25 Annual Performance Report.

Davis, J. P., and E. T. Schultz. in press. Temporal shifts in demography and life history of an anadromous alewife population in Connecticut. Marine and Coastal Fisheries.

De Roos, A. M., D. S. Boukal, and L. Persson. 2006. Evolutionary regime shifts in age and size at maturation of exploited fish stocks. Proceedings of the Royal Society of London, Series B: Biological Sciences 273(1596):1873-1880.

Devries, D. R., and R. V. Frie. 1996. Determination of age and growth. Pages 483-512 *in* B. R. Murphy, and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, MD USA.

Durbin, A. G., S. W. Nixon, and C. A. Oviatt. 1979. Effects of the spawning migration of the alewife, *Alosa pseudoharengus*, on freshwater ecosystems. Ecology 60(1):8-17.

Elliot, J. M., and L. Persson. 1978. The estimation of daily rates of food consumption for fish. Journal of Animal Ecology 47:977-991.

Fuller, P. L., L. G. Nico, and J. D. Williams. 1999. Nonindigenous Fishes Introduced into Inland Waters of the United States, volume 27. American Fisheries Society, Bethesda, MD.

Hartman, K. 2003. Population-level consumption by Atlantic coastal striped bass and the influence of population recovery upon prey communities. Fisheries Management and Ecology 10(5):281-288.

Hattala, K. A. 1999. Summary of American shad aging workshop. American Shad Aging Workshop. Delaware River Fish and Wildlife Management Cooperative Technical Committee - Shad Subcommittee, Smyrna, Delaware USA.

Hayes, D. H., J. R. Bence, T. J. Kwak, and B. E. Thompson. 2007. Abundance, biomass, and production. Pages 327-374 *in* C. S. Guy, and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Howell, P., and D. R. Molnar. 1999. An angler survey of the Connecticut portion of the Connecticut River. Pages 190-205 *in* A study of marine recreational fisheries on Connecticut. Connecticut Department of Environmental Protection, Hartford, CT USA.

Jessop, B. M. 2003. The effects of exploitation on alewife and blueback herring stock composition at the Mactaquac Dam, Saint John River, New Brunswick. Pages 349-359 *in* K. E. Limburg, and J. R. Waldman, editors. Biodiversity, Status, and Conservation of the World's Shads. American Fisheries Society Symposium 35.

Johansen, G. O., B. Bogstad, S. Mehl, and O. Ultang. 2004. Consumption of juvenile herring (*Cluepea harengus*) by cod (*Gadus morhua*) in the Barents Sea: a new approach to estimating consumption in piscivorous fish. Canadian Journal of Fisheries and Aquatic Sciences 61(3):343-359.

Kissil, G. W. 1974. Spawning of the anadromous alewife, *Alosa pseudoharengus*, in Bride Lake, Connecticut. Transactions of the American Fisheries Society 103(2):312-317.

LaPlante, L. H., and E. T. Schultz. 2007. Annual fecundity of tautog in Long Island Sound: size effects and long-term changes in a harvested population. Transactions of the American Fisheries Society 136:1520-1533.

Leggett, W. C., and J. E. Carscadden. 1978. Latitudinal variation in reproductive characteristics of American shad (*Alosa sapidissima*): evidence for population specific life history strategies in fish. Journal of the Fisheries Research Board of Canada 35(11):1469-1478.

Leggett, W. C., T. F. Savoy, and C. A. Tomichek. 2004. The impact of enhancement initiatives on the structure and dynamics of the Connecticut River population of American shad. Pages 391-405 *in* P. M. Jacobsen, D. A. Dixon, W. C. Leggett, B. C. J. Marcy, and R. R. Massengill, editors. The Connecticut River Ecological Study (1965 - 1973) revisited: ecology of the lower Connecticut River 1973-2003. American Fisheries Society, Monograph 9, Bethesda, MD USA.

Leonard, J. B. K., and S. D. McCormick. 1999. Effects of migration distance on whole-body and tissue-specific energy use in American shad (*Alosa sapidissima*). Canadian Journal of Fisheries and Aquatic Sciences 56:1159-1171.

Levin, P. S., E. E. Holmes, K. R. Piner, and C. J. Harvey. 2005. Shifts in a Pacific Ocean fish assemblage: the potential influence of exploitation. Conservation Biology 20(4):1181-1190.

Libby, D. A. 1985. A comparison of scale and otolith aging methods for the alewife, *Alosa pseudoharengus*. Fishery Bulletin 83(4):696-700.

Loesch, J. G. 1987. Overview of life history aspects of anadromous alewife and blueback herring in freshwater habitats. Pages 97-103 *in* M. J. Dadswell, and coeditors, editors. International Symposium on Common Strategies of Anadromous and Catadromous Fishes. American Fisheries Society, Boston, MA USA.

Maceina, M. J., J. Boxrucker, D. L. Buckmeier, R. S. Gangl, D. O. Lucchesi, D. A. Isermann, J. R. Jackson, and P. J. Martinez. 2007. Current status and review of freshwater fish aging procedures used by state and provincial fisheries agencies with recommendation for future directions. Fisheries 32:329-340.

Maki, K. L., J. M. Hoenig, and J. E. Olney. 2002. Interpreting maturation data for American Shad in the presence of fishing mortality: a look at historical data from the York River, Virginia. North American Journal of Fisheries Management 22(4):1209-1217.

Marcy, B. C., Jr. 1969. Age determinations from scales of *Alosa pseudoharengus* (Wilson) and *Alosa aestivalis* (Mitchill) in Connecticut waters. Transactions of the American Fisheries Society 98:622-630.

Monteleone, D. M., and E. D. Houde. 1990. Influence of maternal size on survival and growth of striped bass *Morone saxatilis* Walbaum eggs and larvae. Journal of Experimental Marine Biology and Ecology 140(1-2):1-11.

Morris, W. F., and D. F. Doak. 2003. Quantitative conservation biology: theory and practice of population viability analysis. Sinauer Associates, Sunderland, MA USA.

Mullen, D. M., C. W. Fay, and J. R. Moring. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic): alewife/blueback herring, FWS-82/11.56.

Neves, R. 1981. Offshore distribution of alewife, *Alosa pseudoharengus* , and blueback herring, *Alosa aestivalis* , along the Atlantic coast. Fisheries Bulletin 79(3):473-485.

Olsen, E. M., M. Heino, G. R. Lilly, M. J. Morgan, J. Brattey, B. Ernande, and U. Dieckmann. 2004. Maturation trends indicative of rapid evolution preceded the collapse of northern cod. Nature 428(6986):932-935.

Pine, W. E., K. H. Pollock, J. E. Hightower, T. J. Kwak, and J. A. Rice. 2003. A review of tagging methods for estimating fish population size and components of mortality. Fisheries 28(10):10-23.

Reznick, D. N., and J. A. Endler. 1982. The impact of predation on life history evolution in Trinidadian guppies. Evolution 36:160-177.

Richards, R. A., and P. J. Rago. 1999. A case history of effective fishery management: Chesapeake Bay striped bass. North American Journal of Fisheries Management 19:356-375.

Ricker, W. E. 1981. Changes in the average size and average age of Pacific salmon. Canadian Journal of Fisheries and Aquatic Sciences 38(12):1636-1656.

Savoy, T. F., and V. A. Crecco. 2004. Factors affecting the recent decline of blueback herring and American shad in the Connecticut River. Pages 361-377 *in* P. M. Jacobsen, D. A. Dixon, W. C. Leggett, B. C. J. Marcy, and R. R. Massengill, editors. The Connecticut River Ecological Study (1965-1973) revisited: ecology of the lower Connecticut River 1973-2003. American Fisheries Society, Monograph 9, Bethesda, MD USA.

Tabor, R. A., B. A. Footen, K. L. Fresh, M. T. Celedonia, F. Mejia, D. L. Low, and L. Park. 2007. Smallmouth bass and largemouth bass predation on juvenile chinook salmon and other salmonids in the Lake Washington basin. North American Journal of Fisheries Management 27(4):1174-1188.

USFWS. 2008. Connecticut River Migratory Fish Counts 1967-2007. Connecticut River Coordinator's Office. Available: www.fws.gov/r5crc/Fish/oldcts.html. (November 2008).

Walter, J. F., A. S. Overton, K. H. Ferry, and M. E. Mather. 2003. Atlantic coast feeding habits of striped bass: a synthesis supporting a coast-wide understanding of trophic biology. Fisheries Management and Ecology 10(5):349-360.

Tables

Table 1. Site codes.

Chicopee, MA	CP
Springfield, MA	SF
Holyoke, MA	HK
Enfield	EF
Kings Island	KI
Windsor Locks	WL
Farmington River	FR
Windsor	WS
Hartford	HF
Wethersfield	WF

Table 2. Summary of sampling in 2005. Site codes are given in Table 1. Electrofishing effort is included for each sample night

Period Start Date	Date	Site	Transects Completed	Total Shocking Time (s)
5/10[a]	5/10	FR	3	1956
	5/11	WF	3	1961
	5/12	EF	3	1992
	5/15	CP	3	1551
	5/16	WL	5	2813
5/17[b]	5/17	KI	2	1068
	5/17	EF	3	2031
	5/18	HF	2	1305
	5/18	WF	1	690
	5/19	FR	4	2604
	5/22	WL	4	2509
	5/23	HK	3	1739
5/24[c]	5/24	SF	3	1919
	5/25	WF	3	1954
	5/26	FR	3	1982
	5/30	EF	4	2930
5/31[d]	5/31	WL	4	2675
	6/1	HK	3	2038
	6/2	FR	3	2007
	6/3	WF	1	659
	6/5	WL	4	2640
	6/6	HK	3	1887
6/7[e]	6/9	WF	3	1959
	6/10	FR	3	1958
	6/12	EF	3	2016
	6/13	WL	3	2009
	6/15	HK	3	1746

[a] HK not sampled during this sample period
[b] KI sampled prior to EF on 5/17, HF sampled prior to WF on 5/18, 5/18 WF sample consisted of one transect due to time constraints
[c] WL and HK not sampled during this sample period due to flooding
[d] HK sampled twice during this sample period, 6/3 WF sample consisted of one transect due to time constraints
[e] 6/15 HK sample included in this period despite being outside end-date

Table 3. Electrofishing effort in 2005 summarized by period. Site codes are given in Table 1.

Period Start Date	Transects Completed	Sites Sampled	Total Shocking Time (s)
5/10	17	WF, FR, WL, EF, CP	10273
5/17	19	WF, FR, WL, EF, HK, KI, HF	11946
5/24	13	WF, FR, EF, SF	8785
5/31	18	WF, FR, WL, HK	11906
6/7	15	WF, FR, WL, EF, HK	9688

Table 4. Electrofishing effort in 2005 summarized by site. Site codes are given in Table 1.

Site	Transects Completed	Total Shocking Time (s)
WF	11	7223
FR	16	10507
WL	20	12646
EF	13	8969
HK	12	7410
HF	2	1305
KI	2	1068
SF	3	1919
CP	3	1551

Table 5. Species codes.

American shad	AS
black crappie	BC
Bluegill	BG
chain pickerel	CP
channel catfish	CHC
common carp	COC
gizzard shad	GS
largemouth bass	LMB
northern pike	NP
smallmouth bass	SMB
striped bass	SB
Walleye	WA
white catfish	WC
white perch	WP
white sucker	WS

Table 6. Herring and striper gill net effort in 2005: A) By site; B) Herring net, day sets and night sets. Site codes are given in Table 1.

A)	Herring net		Striper net	
Site	N sets	hr-net foot	N sets	hr-net foot
CP	1	14.9	1	28.75
SF	1	52.1	0	0
EF	4	92.4	2	53.75
WL	4	179.3	2	98.96
FR	5	170.2	3	109.38
WS	7	82.6	5	106.67
HF	2	17.7	2	37.50
WF	8	211.7	5	153.96
B)	First date	Last date	N sets	hr-net foot
Day	4/16	5/10	15	177.60
night	5/11	6/12	17	643.23

Table 7. Herring gill net catch per unit effort by site in 2005. Catch for striped bass is number of fish per hr-net foot (X 1000), for other species it is number of times species was captured per net set. Site codes are given in Table 1 and species codes are given in Table 5.

Site	SB	CHC	WA	SMB	LMB	NP	AS	COC	WS	BG	CP	WC	BC	GS	WP
CP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EF	75.8	0.5	0.3	0.3	0	0	0.8	0.5	0	0	0	0	0	0.5	0
WL	16.7	0.5	0	0.3	0	0.3	0	0.3	0	0	0	0	0	0	0.3
FR	5.9	0.2	0	0	0.2	0	0.4	0.0	0.2	0	0	0	0	0	0.2
WS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HF	0	0	0	1.0	0	0	0	0	0	0	0	0	0	0	0
WF	56.7	0.5	0.3	0	0.1	0.3	0.1	0.5	0.4	0.1	0.5	0.3	0.3	0.1	0.1

Table 8. Striper gill net catch per unit effort by site in 2005. Catch for striped bass is number of fish per hr-net foot (X 1000), for other species it is number of times species was captured per net set. Site codes are given in Table 1 and species codes are given in Table 5.

Site	SB	CHC	WA	SMB	LMB	NP	AS	COC
CP	0	0	0	0	0	0	0	0
EF	0	0	0	0	0	0	0	0
WL	0	0	0	0	0	0	0	0
FR	0	0	0	0	0	0	0	0
WS	0	0.6	0	0	0	0	0	0.2
HF	0	0	0	0	0	0	0	0
WF	0	0	0	0	0	0	0	0

Table 9. Herring gill net catch per unit effort by day and night sets in 2005. Catch for striped bass is number of fish per hr-net foot (X 1000), for other species it is number of times species was captured per net set. Species codes are given in Table 5.

Time	SB	CHC	WA	SMB	LMB	NP	AS	COC	WS	BG	CP	WC	BC	GS	WP
Day	50.7	0	0	0.13	0	0	0	0	0	0	0	0	0	0	0
Night	21.8	0.53	0.18	0.12	0.12	0.18	0.35	0.41	0.24	0.06	0.24	0.12	0.12	0.18	0.18

Table 10. Controlled angling catch per unit effort by site. Effort is expressed in angler-hours and CPUE is striped bass catch per angler-hour. Site codes are given in Table 1.

Site	Angler-hours	CPUE
HK	10.3	0.2
SF	6.0	0.17
EF	12.4	0.1
WL	52.3	0.7
FR	10.3	0
WF	20.1	0.6

Table 11. Summary of electrofishing sampling effort by sample night in 2006. Site codes are given in Table 1.

Period Start Date	Date	Site	Transects Completed	Total Shocking Time (s)
4/23[a]	4/27	FR	3	2018
	4/28	WF	3	1972
4/30[b]	5/01	FR	3	1972
	5/02	WL	3	2049
	5/03	EF	3	2207
	5/05	HK	3	1261
5/07	5/07	WF	6	3512
	5/08	FR	5	3287
	5/09	WL	3	2069
	5/10	EF	6	3660
	5/11	HK	4	2196
5/14[c]	5/14	WF	5	3282
5/21[d]	5/24	EF	6	3242
	5/25	HK	3	1523
5/28	5/28	WF	4	2608
	5/29	FR	5	3357
	5/30	WL	4	2567
	5/31	EF	5	3087
	6/01	HK	3	1876
6/04[e]	6/04	WF	5	2736
	6/05	FR	5	3301
6/18	6/19	FR	4	2631
	6/20	WL	3	1739
	6/21	EF	6	3429
	6/22	HK	3	2074
6/25	6/25	WF	3	1968
	6/26	FR	4	2629
	6/27	WL	3	1994
	6/28	EF	3	1376
	6/29	HK	3	1424

[a] WL, EF, HK not sampled due to limited availability of personnel
[b] WF not sampled due to limited availability of personnel
[c] FR, WL, EF, HK not sampled due to flooding
[d] WF, FR, WL not sampled due to flooding
[e] WL, EF, HK not sampled due to equipment malfunction, flooding; no sampling conducted during following week (6/11 – 6/17) due to same reasons.

Table 12. Electrofishing sampling effort in 2006 summarized by sample period. Site codes are given in Table 2.

Period Start Date	Transects Completed	Sites Sampled	Total Shocking Time (s)
4/23	6	WF,FR	3990
4/30	12	FR,WL,EF,HK	7489
5/07	24	ALL	14724
5/14	5	WF	3282
5/21	9	EF,HK	4765
5/28	21	ALL	13495
6/04	10	WF,FR	6037
6/11	0	--	0
6/18	16	FR,WL,EF,HK	9873
6/25	16	ALL	9391

Table 13. Electrofishing sampling effort in 2006 summarized by site. Site codes are given in Table 1.

Site	Transects Completed	Total Shocking Time (s)
WF	26	16078
FR	29	19195
WL	16	10418
EF	29	17001
HK	19	10354

Table 14. Summary of electrofishing sampling effort by sample night in 2007. Site codes are given in Table 1. Samples conducted as part of the SWG Project and Mark-Recapture Project are denoted as "SWG" and "MR", respectively ("Dual" = dual purpose nights serving both projects).

Period Start Date	Date	Site	Project	Transects Completed	Total Shocking Time (s)
4/08[a]	4/10	WF	SWG	3	1900
	4/13	FR	SWG	3	1980
5/06[b]	5/06	WF	SWG	5	3295
	5/07	FR	SWG	5	3271
	5/08	WL	Dual	4	2424
	5/09	EF	SWG	5	2984
	5/09	WL	MR	4	2029
	5/10	HK	SWG	3	1915
	5/10	WL	MR	4	2211
	5/11	WL	MR	5	2407
5/13	5/13	WF	SWG	5	3357
	5/14	FR	SWG	4	2836
	5/15	WL	Dual	4	2288
	5/16	EF	SWG	3	1461
	5/16	WL	MR	3	1425
	5/17	HK	SWG	3	2023
	5/17	WL	MR	4	1960
	5/18	WL	MR	5	2616
5/20[c]	5/21	FR	SWG	5	3316
	5/22	WL	Dual	4	2474
	5/23	WF	SWG	4	2636
	5/23	WL	MR	3	1848
	5/24	HK	SWG	3	1786
	5/25	WL	MR	6	3551
5/27[d]	5/27	WF	SWG	6	3955
	5/28	FR	SWG	4	2666
	5/29	HK	SWG	3	1380
	5/30	WL	Dual	4	2337
	5/31 (AM)	WL	SWG	5	2479
	5/31 (PM)	WL	MR	4	3197
	6/01	WL	MR	5	3292
6/03	6/03	WF	SWG	5	3220
	6/04	FR	SWG	3	1970
	6/05	HK	SWG	3	2047
	6/06	WL	Dual	4	2389
	6/07	WL	MR	4	2834
	6/08	WL	MR	5	3036

Table 14 (cont'd)

Period Start Date	Date	Site	Project	Transects Completed	Total Shocking Time (s)
6/10[e]	6/10	WF	SWG	4	2632
	6/12	HK	SWG	3	1723
	6/13	WL	Dual	3	1532
	6/14	WL	MR	4	2708
	6/15	WL	MR	3	1413

[a] WL, EF, HK not sampled due to limited availability of personnel
[b] No sampling 4/14/07 – 5/5/07 due to flooding and limited availability of personnel
[c] No sampling 5/20 due to flooding; WF sampled 5/23 due to EF launch closure
[d] Sampling schedule changed due to logistical constraints (see "Summary of Field Sampling Operations"); 5/31 (AM) sample at WL was experimental daytime electrofishing to assess diel patterns in striped bass gut fullness
[e] No sampling 6/11 due to inclement weather; sampling discontinued after 6/15 due to equipment malfunction, low catch, and large portions of the sample stretch becoming un-navigable due to low river flows

Table 15. Summary of SWG Project electrofishing sampling effort in 2007 by sample period (including dual purpose sample nights). Site codes are given in Table 1.

Period Start Date	Transects Completed	Sites Sampled	Total Shocking Time (s)
4/08	6	WF,FR	3880
5/06	22	ALL	13889
5/13	19	ALL	11965
5/20	16	WF, FR, HK, WL	10212
5/27	17	WF, FR, HK, WL	12817
6/03	15	WF, FR, HK, WL	9626
6/10	10	WF, HK, WL	5887

Table 16. Summary of SWG Project electrofishing sampling effort in 2007 by site (including dual purpose sample nights). Site codes are given in Table 1.

Site	Transects Completed	Total Shocking Time (s)
WF	32	20995
FR	24	16039
WL	28	15923
EF	8	4445
HK	18	10874

Table 17. Summary of Mark – Recapture Project electrofishing sampling effort by sample night in 2008. All sampling took place at WL.

Period Start Date	Date	Transects Completed	Total Shocking Time (s)
5/4	5/6	3	2637
	5/8	6	3954
5/11	5/11	4	3295
	5/13	5	4712
	5/15	5	4415
5/18	5/18	4	3868
	5/20	5	3851
	5/22	4	3428
5/25	5/27	4	2758
	5/28	3	2901
	5/29	4	2750
6/1	6/1	4	2725
	6/5	3	2078
6/8	6/11	2	760

Table 18. Mark-Recapture Project electrofishing sampling effort in 2008 summarized by sample period. All sampling took place at the Windsor Locks site.

Period Start Date	Transects Completed	Total Shocking Time (s)
5/4	9	6591
5/11	14	12422
5/18	13	11147
5/25	11	8409
6/1	7	4803
6/8	2	760

Table 19. Summary of river herring collections from standard study sites by year. Site codes are given in Table 1. Values reflect the total number of herring collected, and the number of those herring that were lethally sub-sampled for analyses of sex, species, age, and spawning history.

Site	Collected	Sub-Sampled
year=2005		
WF	177	133
FR	211	141
WL	125	117
EF	14	14
HK	28	27
Total	555[1]	432[1]
year=2006		
WF	653	298
FR	646	275
WL	146	131
EF	46	47
HK	32	26
Total	1523	777
year=2007		
WF	699	292
FR	444	173
WL	71	70
EF	9	9
HK	103	90
Total	1326	634

[1]3 additional river herring were collected and subsampled from other sites in 2005 (2 from SF, 1 from CP)

Table 20. ANOVA of site and sample period effects on relative abundance of river herring by year.

	DF	MS	F	Pr
year=2005				
site	4	19000	10	0.0001
period	4	16000	8.6	0.0001
site*period	12	5600	3	0.003
Error	51	1800		
year=2006				
site	4	57000	5.1	0.001
period	8	47000	4.2	0.0003
site*period	17	18000	1.6	0.09
Error	89	11000		
year=2007				
site	4	11000	14	0.0001
period	6	53000	6.6	0.0001
site*period	16	10000	1.2	0.25
Error	83	8000		

Table 21. ANOVA of site and sample period effects on size structure of river herring by year.

	DF	MS	F	Pr
year=2005				
site	4	210	0.89	0.47
period	4	1800	7.7	0.0001
site*period	8	170	0.73	0.67
Error	538	240		
year=2006				
site	4	360	1.3	0.28
period	8	9100	32	0.0001
site*period	11	1500	5.42	0.0001
Error	1499	290		
year=2007				
site	4	390	2.2	0.063
period	6	530	3.0	0.0063
site*period	12	440	2.5	0.0031
Error	1303	180		

Table 22. Repeat-spawning percentages by age class of female blueback herring by year.

Age	Virgin	1 Previous Spawn	2 Previous Spawns	3 Previous Spawns	4 Previous Spawns
Year=2005					
3	80	20			
4	92	8			
5	78	11	11		
6	50	29	21		
Year=2006					
2	100				
3	100				
4	100				
5	45	27	18	9	
6	27	27	27	7	13
Year=2007					
3	100				
4	95	5			
5	71	29			
6	55	18	18	0	9

Table 23. Repeat-spawning percentages by age class of male blueback herring by year.

Age	Virgin	1 Previous Spawn	2 Previous Spawns
Year=2005			
2	100		
3	100		
4	80	20	
5	43	43	14
6	58	17	25
Year=2006			
2	100		
3	100		
4	83	17	
5	78	22	
6	22	44	33
Year=2007			
2	100		
3	100		
4	100		
5	83	17	
6	43	29	29

Table 24. Summary of striped bass collections. The recaptures column refers to recaptures of striped bass tagged previously during sampling operations. These fish were released without additional tags.

Year	Captured	Euthanized	Released – Untagged	Released – Tagged	Recaptures
2005	126	6	120	N/A	N/A
2006	331	3	117	210	1
2007	1049	9	371	662	7
2008	591	3	50	535	3

Table 25. ANOVA of site and period effects on catch rates of Small and Large striped bass by year.

		Small			Large		
Source	DF	MS	F	Pr	MS	F	Pr
year=2005							
site	4	100	4.8	0.0022	70	2.5	0.055
period	4	72	3.5	0.014	19	0.66	0.62
site*period	12	48	2.3	0.019	29	1.0	0.44
Error	51	21			28		
year=2006							
site	4	3900	17	0.0001	1000	8.5	0.0001
period	8	400	1.7	0.11	140	1.2	0.30
site*period	17	630	2.7	0.0014	160	1.4	0.16
Error	89	240			120		
year=2007							
site	4	19000	14	0.0001	1600	6.0	0.0003
period	6	5100	3.8	0.0023	500	1.9	0.097
site*period	16	5300	3.9	0.0001	600	2.3	0.0092
Error	83	1400			270		

Table 26. Mean catch rates of Small and Large striped bass (river- and season-wide).

		Small		Large	
year	N	Mean	SD	Mean	SD
2005	72	3.3	6.1	2.9	5.7
2006	119	9.4	20	7.4	12
2007	110	23	52	11	19

Table 27. ANOVA of site and period effects on striped bass size by year.

	DF	MS	F	Pr
year=2005				
site	4	55000	3.3	0.015
period	5	44000	2.8	0.02
site*period	11	55000	3.3	0.0006
Error	101	17000		
year=2006				
site	4	93000	34	0.0001
period	8	13000	4.7	0.0001
site*period	16	61000	2.2	0.005
Error	302	27000		
year=2007				
site	4	140000	51	0.0001
period	6	76000	2.7	0.012
site*period	16	66000	2.4	0.0019
Error	1021	28000		

Table 28. Striped bass recaptures in 2006. Recapture classifications are as follows: A" = recaptures made during the sampling season and within the study stretch (WE to HK); "B" = recaptures made during the sampling season, within the Connecticut River but outside of the study stretch; "F" = recaptures made after the sampling season within Long Island Sound (LIS); "OS" = recaptures of fish outside the State of Connecticut. Site codes are listed in Table 1.

Tag Number	Tag site	Capture Date	Recapture Location	Recapture Date	Recapture Type	Recapture Class
unknown[a]	unknown[a]	unknown[a]	CT River (Windsor)	5/03	Angler	A
12	WL	5/02	CT River[b]	5/15	Angler	A or B[b]
154	HK	5/25	CT River[b]	6/05	Angler	A or B[b]
193	HK	6/01	LIS (Plum Gut)	7/10	Angler	F
6	FR	5/01	LIS (New Haven)	8/05	Angler	F
89	WL	5/09	MA (Martha's Vineyard)	6/24	Angler	OS
40	WL	5/02	MA (Plymouth)	8/21	Angler	OS
167	HK	5/25	NY (Fisher's Island)	9/19	Angler	OS
160	HK	5/25	VA (Chesapeake Bay)	12/17	Angler	OS
165	HK	5/25	CT River (HK)	6/22	Electrofish	A

[a]Angler reported recapture date and location but not tag number.
[b]Anglers reported recapture and tag number but omitted recapture date/location. Repeated attempts to reach the anglers were unsuccessful. Recapture date provided is date that call was received. Due to the relatively short time between capture and recapture, recaptures are assumed to have occurred in the Connecticut River.

Table 29. Striped bass recaptures in 2007. Recapture classifications are as follows: "2006" = recaptures of fish tagged in 2006; "A" = recaptures made during the sampling season and within the study stretch (WE to HK); "B" = recaptures made during the sampling season, within the Connecticut River but outside of the study stretch; "C" = recaptures made after the sampling season, within the Connecticut River and within the study stretch; "D" = recaptures made after the sampling season, within the Connecticut River but outside the study stretch; "E" = recaptures made during the sampling season within Long Island Sound; "F" = recaptures made after the sampling season within Long Island Sound (LIS); "OS" = recaptures of fish tagged in 2007 made outside the State of Connecticut; "UK" = unknown. Site codes are listed in Table 1.

Tag Number	Tag Site	Capture Date	Recapture Location	Recapture Date	Recapture Type	Recapture Class
168	WF	2006	NJ (Raritan Bay)	4/4	Angler	2006
78	WL	2006	CT River (WL)	5/12	Angler	2006
242	FR	2006	CT River (Windsor)	5/27	Angler	2006
321	FR	4/13	CT River (FR)	5/26	Angler	A
647	WL	5/18	CT River (WL)	6/7	Angler	A
471	FR	5/14	CT River (Hartford)	5/15	Angler	A
582	WL	5/16	CT River (WL)	5/22	Angler	A
382	WL	5/8	CT River (WL)	5/15	Angler	A
714	WL	5/23	CT River (WL)	5/25	Angler	A
399	WL	5/8	CT River (WF)	5/30	Angler	A
2556	WL	5/22	CT River (Hartford)	5/30	Angler	A
353	WL	5/8	CT River (FR)	5/23	Angler	A
650	WL	5/18	CT River (WL)	5/19	Angler	A
617	WL	5/17	CT River (WL)	6/1	Angler	A
507	WL	5/9	CT River (Hartford)	5/26	Angler	A
2530	EN	5/16	CT River (mouth)	6/13	Angler	B
457	HK	5/10	CT River (mouth)	5/16	Angler	B
306	FR	4/13	CT River (Chicopee)	8/30	Angler	C
479	FR	5/14	CT River (mouth)	6/19	Angler	D
2642	WF	5/27	CT River (Essex)	6/18	Angler	D
449	FR	5/14	CT River (mouth)	7/3	Angler	D

Table 29 (cont'd)

Tag Number	Tag Site	Capture Date	Recapture Location	Recapture Date	Recapture Type	Recapture Class
2688	WL	6/1	CT River (mouth)	6/26	Angler	D
2527	EN	5/16	LIS (Old Saybrook)	6/8/07	Angler	E
580	WL	5/11	LIS (Race)	6/15	Angler	E
628	WL	5/18	LIS (Orient Point)	7/4	Angler	F
283	FR	4/13	LIS (Old Lyme)	7/11	Angler	F
2628	HK	5/24	LIS (Westbrook)	7/18	Angler	F
2807	WL	6/7	LIS (Race)	8/4	Angler	F
259	FR	4/13	MA (Merrimack River)	7/8	Angler	OS
724	WL	5/23	MA (Cape Cod Canal)	6/3	Angler	OS
577	WL	5/11	NJ (Seaside Park)	11/25	Angler	OS
272	FR	4/13	ME (Saco River)	9/8	Angler	OS
Unknown[a]	Unknown	Unknown	CT River (Keeney Cove)	10/13	Angler	UK
Unknown[a]	Unknown	Unknown	CT River (Crow Point Cove)	10/20	Angler	UK
21	WL	2006	CT River (WL)	5/9	Electrofish	2006
373	WL	5/8	CT River (WL)	5/17	Electrofish	A
526	WL	5/9	CT River (WL)	5/18	Electrofish	A
564	WL	5/11	CT River (WL)	5/25	Electrofish	A
721	WL	5/23	CT River (WL)	6/6	Electrofish	A
2569	WL	5/22	CT River (WL)	5/25	Electrofish	A
2620	HK	5/24	CT River (WL)	5/31	Electrofish	A

[a] Angler caught 3 tagged fish on 10/13/07 and 1 tagged fish on 10/20/07 but did not record tag numbers

Table 30. Striped bass recaptures in 2008. Recapture classifications are as follows: "2006" = recaptures of fish tagged in 2006; "2007" = recaptures of fish tagged in 2007; "A" = recaptures made during the sampling season and within the study stretch (WE to HK); "B" = recaptures made during the sampling season, within the Connecticut River but outside of the study stretch; "OS" = recaptures of fish tagged in 2007 made outside the State of Connecticut. Site codes are listed in Table 1.

Tag Number	Tag Site	Capture Date	Recapture Location	Recapture Date	Recapture Type	Recapture Class
66	FR	2006	CT River (FR)	5/18	Angler	2006
707	WL	2007	CT River (WL)	4/30	Angler	2007
2945	HK	2007	CT River (Springfield, MA)	5/20	Angler	2007
2499	WL	5/6	CT River (Hartford)	5/10	Angler	A
5253	WL	5/6	CT River (WL)	5/12	Angler	A
2452	WL	5/6	CT River (WL)	5/08	Angler	A
5264	WL	5/6	CT River (Springfield, MA)	5/17	Angler	A
1219	WL	5/6	CT River (WL)	5/10	Angler	A
5296	WL	5/6	CT River (WL)	5/09	Angler	A
2489	WL	5/6	CT River (Hartford)	5/24	Angler	A
1757	WL	5/22	CT River (WL)	5/23	Angler	A
5233	WL	5/6	CT River (WL)	5/22	Angler	A
5236	WL	5/6	CT River (WL)	5/24	Angler	A
5245	WL	5/6	CT River (WL)	5/08	Angler	A
5276	WL	5/6	CT River (WL)	5/14	Angler	A
1204	WL	5/6	CT River (South Windsor)	5/22	Angler	A
5246	WL	5/6	CT River (WL)	5/11	Angler	A
5016	WL	5/6	CT River (Rocky Hill)	6/09	Angler	B
2044	WL	5/18	CT River (Rocky Hill)	6/01	Angler	B
5215	WL	5/8	CT River (Rocky Hill)	5/14	Angler	B
1034	WL	5/8	CT River (Old Lyme)	5/18	Angler	B
5279	WL	5/6	RI (Newport)	5/28	Angler	OS
2848	WL	5/6	RI (Barrington)	6/01	Angler	OS
1764	WL	5/22	CT River (WL)	5/27	Electrofish	A

Table 30 (cont'd)

Tag Number	Tag Site	Capture Date	Recapture Location	Recapture Date	Recapture Type	Recapture Class
2711	WL	5/27	CT River (WL)	5/30	Electrofish	A
2841	WL	5/6	CT River (WL)	5/22	Electrofish	A

Table 31. Schnabel mark-recapture estimate of population size for striped bass ≥ 300 mm TL in the river stretch between Hartford and the MA/CT border in May 2008. All sample days on which striped bass were recaptured via electrofishing and/or anglers are shown. Angler catch for each day was estimated from creel survey data.

Date	Angler Catch	Electrofishing Catch	Total Catch (n_i)	Angler Recaps	Electrofishing Recaps	Total Recaps (m_i)	Tags-at-Large (M_i)	$n_i * M_i$
5/7	101	0	126	0	0	0	173	17473
5/8	101	76	202	2	0	2	173	30621
5/9	82	0	102	1	0	1	249	20418
5/10	309	0	386	2	0	2	249	76941
5/11	139	21	195	1	0	1	249	39840
5/12	8	0	10	1	0	1	270	2160
5/13	101	11	137	0	0	0	270	30240
5/14	249	0	311	1	0	1	281	69969
5/15	101	35	161	0	0	0	281	38216
5/16	101	0	126	0	0	0	316	31916
5/17	139	0	174	0	0	0	316	43924
5/18	139	33	207	0	0	0	316	54352
5/19	101	0	126	0	0	0	349	35249
5/20	101	49	175	0	0	0	349	52350
5/21	101	0	126	0	0	0	411	41511
5/22	154	42	235	2	1	3	411	80556
5/23	101	0	126	1	0	1	453	45753
5/24	139	0	174	2	0	2	453	62967
5/25	139	0	174	0	0	0	453	62967
5/26	117	0	146	0	0	0	453	53001
5/27	101	21	147	0	1	1	453	55266
5/28	42	16	68	0	0	0	474	27492
5/29	42	0	53	0	0	0	490	20580
5/30	101	10	136	0	1	1	490	54390
5/31	139	0	174	0	0	0	500	69500

Table 31 (cont'd).

Date	Angler Catch	Electrofishing Catch	Total Catch (n_i)	Angler Recaps	Electrofishing Recaps	Total Recaps (m_i)	Tags-at-Large (M_i)	$n_i * M_i$
Total						16		1117652
Equation 5: (1117652) / (16 + 1) = 65,744								

Table 32. Number of striped bass collected (N), lavaged (N lavaged), with empty stomachs (N Empty), and with prey items in the stomach (N Diet) by 100 mm size (TL) intervals in 2005-07.

Size Class (mm)	N	N Lavaged	N Empty	N Diet
TL < 300	433	23	13 (57%)	10 (43%)
(300 ≤ TL < 400)	187	88	40 (45%)	48 (55%)
(400 ≤ TL < 500)	355	199	99 (50%)	100 (50%)
(500 ≤ TL < 600)	210	133	60 (45%)	73 (55%)
(600 ≤ TL < 700)	151	91	45 (49%)	46 (51%)
(700 ≤ TL < 800)	70	70	36 (51%)	34 (49%)
(800 ≤ TL < 900)	40	40	15 (38%)	25 (62%)
(900 ≤ TL < 1000)	29	27	4 (15%)	23 (85%)
TL ≥ 1000	31	31	1 (3%)	30 (97%)
Overall	1506	702	313	389

Table 33. Prey category definitions and assignment rules for striped bass diet composition analysis.

Prey Category	Definition/Assignment Rules
American Eel	Carcass of an individual American eel (*Anguilla rostrata*).
Amphipoda	Crustaceans of the Order Amphipoda
Ephemeroptera	Insects of the Order Ephemeroptera (mayflies). Both larvae and adults have been recovered from diet samples.
Herring	Carcass of an individual river herring (*Alosa pseudoharengus, aestivalis*)
Herring Rem	Remnants that can be identified as having come from a river herring (e.g. digested scales, bones) but that can not be positively attributed to only one individual. Enumeration rules are the same as for "UI Fish Rem".
Hirudinea	Invertebrates of the Class Hirudinea (leeches)
Lamprey (A)	Carcass of an individual adult sea lamprey (*Petromyzon marinus*)
Lamprey (T)	Carcass of an individual transformant (small adult) sea lamprey (*Petromyzon marinus*)
Lamprey (AM)	Carcass of an individual sea lamprey (*Petromyzon marinus*) amnocoete (juvenile)
Odonata	Insects of the Order Odonata (dragonflies). To date only larvae have been recovered from diet samples.
Oligochaeta	Worms of the Class Oligochaeta (earthworms)
Plecoptera	Insects of the Order Plecoptera (stoneflies). To date only larvae have been recovered from diet samples.
Polychaeta	Worms of the Class Polychaeta
Shad	Carcass of an individual American shad (*Alosa sapidissima*)
Shad Rem	Remnants that can be identified as having come from an American shad (e.g. digested scales, bones) but that can not be positively attributed to only one individual. Enumeration rules are the same as for "UI Fish Rem".
Spottail Shiner	Carcass of an individual Spottail shiner (*Notropis hudsonius*)
Trichoptera	Insects of the Order Trichoptera (caddisflies). To date only larvae have been recovered from diet samples.
UI	Unidentified organic matter
UI Arth Rem	Remnants from various arthropod diet items (insects, amphipods) that can not be attributed to one individual. This category is assigned the frequency "1" in all cases as enumeration is generally not possible.
UI Fish Rem	Any fish remnants (bones, scales, flesh) that can not be identified to species and definitively attributed to one individual. In cases where it is possible to count the individual remnants they are enumerated, otherwise they are assigned the frequency "1" (conservative representation). Also applicable when remains can be attributed to an individual fish but do not allow any reasonable inference about size (TL) of the individual.
UI Insect	Unidentified invertebrate of the Class Insecta (see "UI Invert")

Table 33 (cont’d)

Prey Category	Definition/Assignment Rules
UI Invert	Unidentified invertebrate. Unidentifiable invertebrates that can be identified as belonging to the Class Insecta (3 pairs walking legs and/or presence of paired wings) are classified as "UI Insect", otherwise they are assigned to this category.
UI Large Fish	Carcass of an individual fish that can not be identified to species, TL > approx. 100 mm. Items are only assigned to this category when the remains allow reasonable inference of size (TL).
UI Small Fish	Same as above, TL < approx. 100 mm

Table 34. Frequency of occurrence (%), mean percent composition by number, standard error (SE) of mean composition by number, mean percent composition by mass (g), and standard error (SE) of mean percent composition by mass for all prey categories present in diet samples from striped bass of < 300 mm TL collected in 2005-07 (n = 10).

Prey Category	Frequency of Occurrence (%)	Mean % by Number	SE Mean % by Number	Mean % by Mass	SE Mean % by Mass
American Eel	10.0	2.5	2.5	7.1	7.1
Amphipoda	20.0	7.6	6.6	7.7	7.6
Ephemeroptera	20.0	4.2	3.4	0.8	0.8
Hirudinea	10.0	0.9	0.9	3.5	3.5
Spottail Shiner	20.0	13.3	10.2	20.0	13.3
Trichoptera	10.0	2.5	2.5	0.2	0.2
UI Arth Rem	20.0	3.7	3.3	6.9	6.9
UI Fish Rem	60.0	43.1	15.7	45.6	15.8
UI Insect	20.0	10.9	9.2	4.9	3.4
UI Invert	30.0	11.2	6.3	3.4	2.7

Table 35. Frequency of occurrence (%), mean percent composition by number, standard error (SE) of mean composition by number, mean percent composition by mass (g), and standard error (SE) of mean percent composition by mass for all prey categories present in diet samples from striped bass (300 mm ≤ TL < 400 mm) collected in 2005-07 (n = 48).

Prey Category	Frequency of Occurrence (%)	Mean % by Number	SE Mean % by Number	Mean % by Mass	SE Mean % by Mass
American Eel	16.7	4.8	2.0	9.7	3.7
Lamprey (AM)	4.2	2.2	2.1	3.1	2.3
Amphipoda	10.4	5.7	3.2	2.9	1.9
Ephemeroptera	4.2	4.1	2.9	2.3	1.7
Herring Rem	2.1	1.8	1.8	0.8	0.8
Lamprey (T)	8.3	3.6	2.3	7.1	3.5
Odonata	10.4	3.0	1.5	3.6	2.2
Plecoptera	10.4	3.8	2.2	6.8	3.5
Polychaeta	2.1	0.1	0.1	1.8	1.8
Spottail Shiner	2.1	1.0	1.0	2.1	2.1
Trichoptera	2.1	0.1	0.1	0.2	0.2
UI	27.1	14.8	4.3	12.4	4.6
UI Arth Rem	10.4	6.2	3.2	4.8	2.5
UI Fish Rem	31.3	22.1	5.3	21.6	5.7
UI Small Fish	8.3	1.5	1.1	3.1	2.2
UI Insect	20.8	10.5	3.8	7.8	3.6
UI Invert	33.3	14.8	4.1	9.9	3.9

Table 36. Frequency of occurrence (%), mean percent composition by number, standard error (SE) of mean composition by number, mean percent composition by mass (g), and standard error (SE) of mean percent composition by mass for all prey categories present in diet samples from striped bass (400 mm ≤ TL < 500 mm) collected in 2005-07 (n = 100).

Prey Category	Frequency of Occurrence (%)	Mean % by Number	SE Mean % by Number	Mean % by Mass	SE Mean % by Mass
American Eel	19.0	8.6	2.4	13.8	3.3
Lamprey (AM)	4.0	1.6	1.1	2.2	1.6
Amphipoda	18.0	10.9	2.8	10.3	2.8
Crayfish	4.0	0.8	0.4	1.8	1.2
Ephemeroptera	5.0	2.1	1.1	0.8	0.4
Herring	4.0	1.3	1.0	3.5	1.7
Herring Rem	18.0	12.4	3.0	9.0	2.6
Hirudinea	2.0	0.4	0.3	0.4	0.3
Lamprey (T)	6.0	2.8	1.4	3.5	1.7
Odonata	5.0	3.0	1.6	2.7	1.5
Plecoptera	5.0	1.5	0.9	1.0	0.8
Spottail Shiner	4.0	1.5	1.1	3.4	1.7
Trichoptera	9.0	4.6	1.7	3.7	1.5
UI	11.0	5.1	2.0	4.1	1.9
UI Arth Rem	24.0	9.2	2.4	12.8	2.8
UI Large Fish	1.0	0.2	0.2	0.1	0.1
UI Fish Rem	32.0	17.1	3.2	14.6	3.1
UI Small Fish	9.0	4.3	1.7	5.9	2.1
UI Insect	19.0	5.7	1.6	3.7	1.3
UI Insect	2.0	0.8	0.6	0.1	0.1
UI Invert	12.0	4.4	1.7	2.5	1.4

Table 37. Frequency of occurrence (%), mean percent composition by number, standard error (SE) of mean composition by number, mean percent composition by mass (g), and standard error (SE) of mean percent composition by mass for all prey categories present in diet samples from striped bass (500 mm ≤ TL < 600 mm) collected in 2005-07 (n = 73).

Prey Category	Frequency of Occurrence (%)	Mean % by Number	SE Mean % by Number	Mean % by Mass	SE Mean % by Mass
American Eel	12.3	7.2	2.7	9.6	3.3
Lamprey (AM)	2.7	1.0	0.7	1.1	1.0
Amphipoda	6.8	2.1	1.5	1.8	1.4
Crayfish	4.1	3.1	1.9	3.7	2.1
Ephemeroptera	6.8	5.9	2.6	2.3	1.1
Herring	1.4	0.1	0.1	1.4	1.4
Herring Rem	13.7	7.8	2.8	3.7	1.9
Lamprey (T)	2.7	0.9	0.7	1.8	1.2
Odonata	2.7	2.7	1.9	2.7	1.9
Oligochaeta	1.4	0.3	0.3	0.4	0.4
Plecoptera	2.7	1.3	1.0	1.7	1.2
Shad Rem	2.7	2.3	1.7	2.4	1.7
Trichoptera	6.9	2.8	2.0	2.2	1.7
UI	23.3	15.0	3.7	15.5	3.9
UI Arth Rem	13.7	2.9	1.5	5.1	2.1
UI Large Fish	1.4	1.4	1.4	1.4	1.4
UI Fish Rem	43.8	31.2	4.8	31.4	5.0
UI Small Fish	2.7	2.7	1.9	2.7	1.9
UI Insect	12.3	5.2	2.0	4.5	2.0
UI Invert	8.2	4.2	2.0	4.6	2.1

Table 38. Frequency of occurrence (%), mean percent composition by number, standard error (SE) of mean composition by number, mean percent composition by mass (g), and standard error (SE) of mean percent composition by mass for all prey categories present in diet samples from striped bass (600 mm ≤ TL < 700 mm) collected in 2005-07 (n = 46).

Prey Category	Frequency of Occurrence (%)	Mean % by Number	SE Mean % by Number	Mean % by Mass	SE Mean % by Mass
American Eel	2.2	0.2	0.2	1.7	1.7
Lamprey (AM)	2.2	2.2	2.2	2.2	2.2
Amphipoda	4.3	2.4	2.2	2.2	2.2
Herring	8.7	6.7	3.7	8.7	4.2
Herring Rem	19.6	13.9	4.7	11.7	4.6
Lamprey (T)	2.2	2.2	2.2	2.2	2.2
Odonata	2.2	2.2	2.2	2.2	2.2
Shad Rem	4.3	4.3	3.0	3.6	2.6
Trichoptera	4.3	1.3	1.2	0.8	0.6
UI	10.9	5.5	2.8	6.6	3.3
UI Arth Rem	4.3	0.5	0.4	0.5	0.5
UI Fish Rem	56.5	43.6	6.7	44.1	6.9
UI Small Fish	4.3	3.8	2.7	4.3	3.0
UI Insect	15.2	5.6	3.1	4.8	3.2
UI Invert	6.5	3.5	2.5	2.4	2.2

Table 39. Frequency of occurrence (%), mean percent composition by number, standard error (SE) of mean composition by number, mean percent composition by mass (g), and standard error (SE) of mean percent composition by mass for all prey categories present in diet samples from striped bass (700 mm ≤ TL < 800 mm) collected in 2005-07 (n = 34).

Prey Category	Frequency of Occurrence (%)	Mean % by Number	SE Mean % by Number	Mean % by Mass	SE Mean % by Mass
Lamprey (AM)	2.9	2.9	2.9	2.9	2.9
Amphipoda	8.8	1.9	1.2	0.3	0.2
Herring	23.5	6.2	3.4	20.1	6.5
Herring Rem	26.5	20.2	6.1	7.7	3.7
Shad	5.9	0.3	0.3	5.9	4.1
Shad Rem	11.8	10.3	4.9	7.8	4.4
UI	8.8	7.4	4.3	11.9	4.1
UI Large Fish	2.9	0.6	0.6	1.1	1.1
UI Fish Rem	58.8	39.0	7.3	36.3	7.8
UI Insect	14.7	8.4	4.1	3.1	2.9
UI Invert	2.9	2.9	2.9	2.9	2.9

Table 40. Frequency of occurrence (%), mean percent composition by number, standard error (SE) of mean composition by number, mean percent composition by mass (g), and standard error (SE) of mean percent composition by mass for all prey categories present in diet samples from striped bass (800 mm ≤ TL < 900 mm) collected in 2005-07 (n = 25).

Prey Category	Frequency of Occurrence (%)	Mean % by Number	SE Mean % by Number	Mean % by Mass	SE Mean % by Mass
American Eel	4.0	4.0	4.0	4.0	4.0
Herring	20.0	4.3	4.0	16.7	7.3
Herring Rem	32.0	29.8	9.0	19.7	7.4
Lamprey (A)	4.0	4.0	4.0	4.0	4.0
Plecoptera	4.0	4.0	4.0	0.1	0.1
Shad Rem	8.0	4.0	4.0	8.0	5.5
UI	12.0	6.3	4.2	11.1	5.2
UI Arth Rem	4.0	0.7	0.7	0.1	0.1
UI Fish Rem	44.0	36.2	9.2	34.8	9.3
UI Insect	8.0	5.3	4.2	0.1	0.1
UI Invert	4.0	1.3	1.3	1.4	1.4

Table 41. Frequency of occurrence (%), mean percent composition by number, standard error (SE) of mean composition by number, mean percent composition by mass (g), and standard error (SE) of mean percent composition by mass for all prey categories present in diet samples from striped bass (900 mm ≤ TL < 1000 mm) collected in 2005-07 (n = 23).

Prey Category	Frequency of Occurrence (%)	Mean % by Number	SE Mean % by Number	Mean % by Mass	SE Mean % by Mass
American Eel	8.7	0.2	0.1	3.9	3.6
Ephemeroptera	4.3	0.3	0.3	0.1	0.1
Herring	26.1	5.4	4.4	21.4	8.5
Herring Rem	21.7	20.4	8.3	4.6	4.3
Lamprey (A)	4.3	0.3	0.3	4.3	4.3
Shad	30.4	13.3	6.4	29.6	9.6
Shad Rem	21.7	16.3	6.9	4.7	4.3
UI	4.3	4.3	4.3	4.3	4.3
UI Fish Rem	39.1	29.8	9.2	22.5	8.6
UI Insect	4.3	2.2	2.2	2.7	2.7
UI Invert	13.0	3.1	2.2	1.9	1.7

Table 42. Frequency of occurrence (%), mean percent composition by number, standard error (SE) of mean composition by number, mean percent composition by mass (g), and standard error (SE) of mean percent composition by mass for all prey categories present in diet samples from striped bass of TL ≥ 1000 mm collected in 2005-07 (n = 30).

Prey Category	Frequency of Occurrence (%)	Mean % by Number	SE Mean % by Number	Mean % by Mass	SE Mean % by Mass
Herring	6.7	0.3	0.2	0.1	0.1
Herring Rem	3.3	0.7	0.7	3.3	3.3
Shad	83.3	40	8.3	81.2	6.8
Shad Rem	43.3	35.1	8.0	5.1	3.4
Trichoptera	3.3	0.1	0.1	0.1	0.1
UI Fish Rem	30.0	21.7	7.3	10.4	5.6
UI Invert	3.3	2.2	2.2	0.1	0.1

Table 43. The percentage of striped bass ≥ 400 mm TL that contained herring prey ("Percent Herring") and mean herring catch-per-hour ("Herring CPH") by sample site in 2005-2007.

Site	Percent Herring	Herring CPH
Wethersfield	6	137
Farmington River	16	121
Windsor Locks	7	34
Enfield	5	8
Holyoke	26	18

Table 44. Estimated abundance of striped bass ≥ 300 mm TL by size class. Proportions within each size class (P_i) were derived from size structure of striped bass ≥ 300 mm TL (2005 – 07 pooled). Total abundance of striped bass ≥ 300 mm TL (n = 65,744; 95% CI = 109,573 – 2,434) was estimated using the Schnabel Mark-Recapture Model.

Size Class (mm)	Proportion (P_i)	Abundance in Size Class (N_i)	N_i (upper 95% CL)	Ni (lower 95% CL)
300	0.17	11458	19096	424
400	0.33	21751	36252	805
500	0.20	12867	21445	476
600	0.14	9252	15420	343
700	0.07	4289	7148	159
800	0.04	2451	4085	91
900	0.03	1777	2961	66
≥1000	0.03	1899	3166	70

Table 45. Estimate of population-level consumption of river herring by striped bass ≥ 400 mm TL in the river stretch from Hartford to the CT/MA border in May 2008. Estimates of striped bass abundance by size class are taken from Table 44. Daily ration was estimated using the meal turnover model.

Striped Bass Size Class	Abundance	Abundance (upper CI)	Abundance (lower CI)	Mean Daily Ration (g)	Monthly Consumption (n)	Monthly Consumption (upper 95% CL)	Monthly Consumption (lower 95% CL)
400	21751	36252	805	15.1	69173	115289	2560
500	12867	21445	476	12.6	34187	56978	1265
600	9252	15420	343	25.2	49151	81918	1822
700	4289	7148	159	28.5	25758	42929	955
800	2451	4085	91	35.7	18461	30769	685
900	1777	2961	66	43.3	16236	27054	603
≥1000	1899	3166	70	20.1	8046	13414	297
Total					221,012	368,351	8,187

Table 46. Estimate of population-level consumption of American shad by striped bass ≥ 400 mm TL in the river stretch from Hartford to the CT/MA border in May 2008. Estimates of striped bass abundance by size class are taken from Table 44. Daily ration was estimated using the meal turnover model.

Striped Bass Size Class	Abundance	Abundance (upper CI)	Abundance (lower CI)	Mean Daily Ration (g)	Monthly Consumption (n)	Monthly Consumption (upper 95% CL)	Monthly Consumption (lower 95% CL)
400	21751	36252	805	0	0	0	0
500	12867	21445	476	17.7	6396	10661	237
600	9252	15420	343	33.8	8800	14667	326
700	4289	7148	159	77.2	9307	15511	345
800	2451	4085	91	54.5	3751	6252	139
900	1777	2961	66	317.9	15875	26452	590
≥1000	1899	3166	70	968.1	51671	86145	1905
Total					95,801	159,688	3,541

Figures

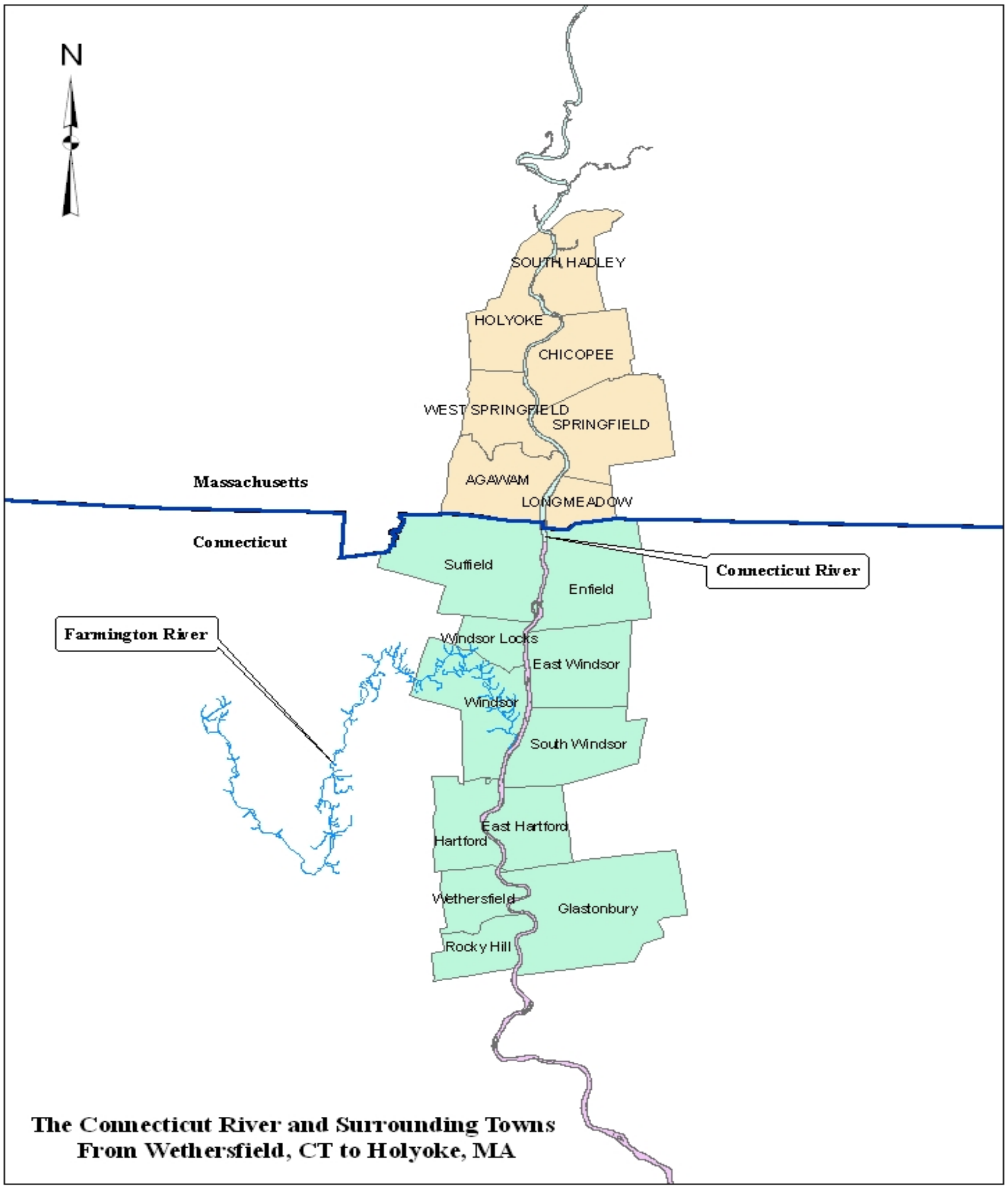

Figure 1. Site map of Connecticut River study area, with the five sample zones indicated: Wethersfield (WF), lower Farmington River (FR), Windsor Locks (WL), Enfield (EF), and Holyoke (HK).

Figure 2. Night electrofishing with the Smith-Root boat.

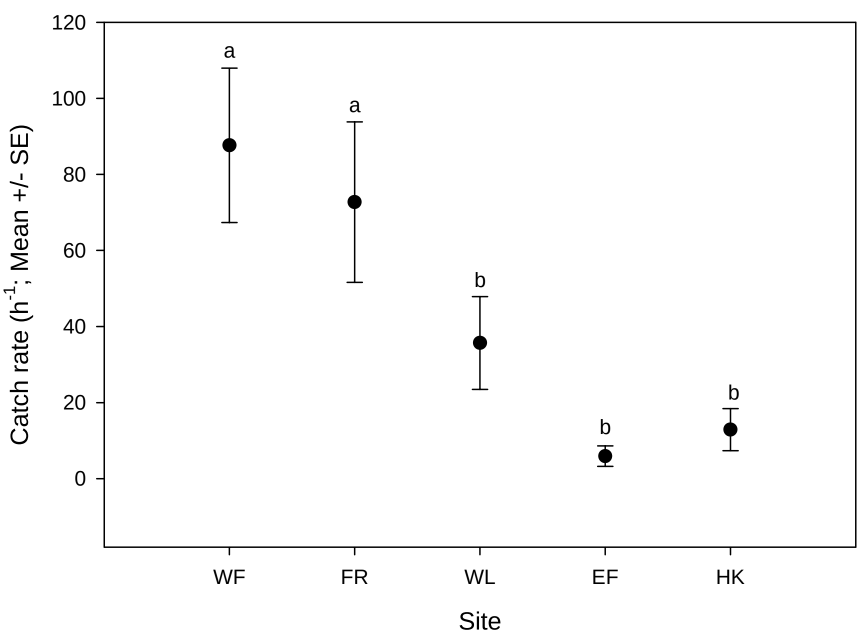

Figure 3. Season-long average abundance of river herring by site, 2005.
Letters indicate means not significantly different at $p < 0.05$ (Tukey).

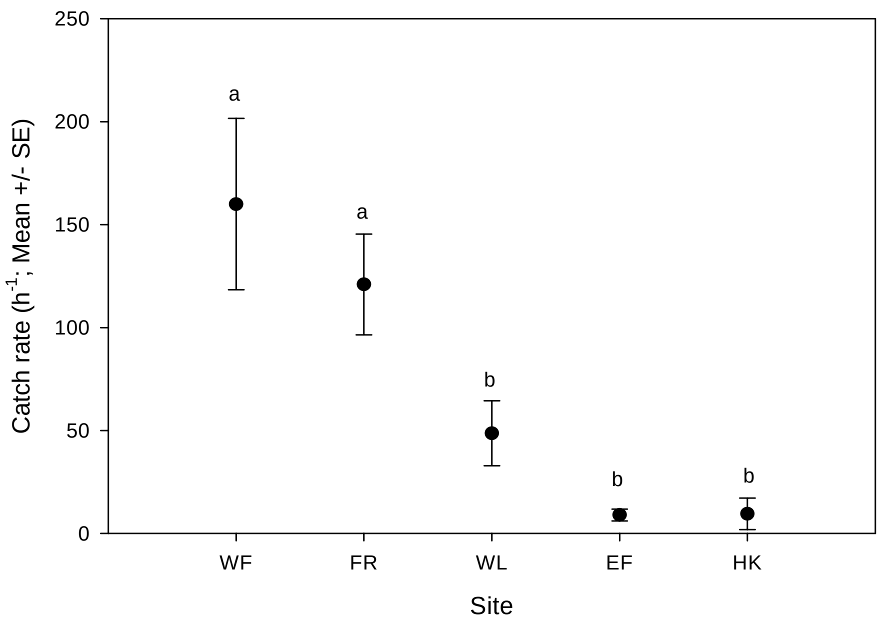

Figure 4. Season-long average abundance of river herring by site, 2006.
Letters indicate means not significantly different at p <0.05 (Tukey).

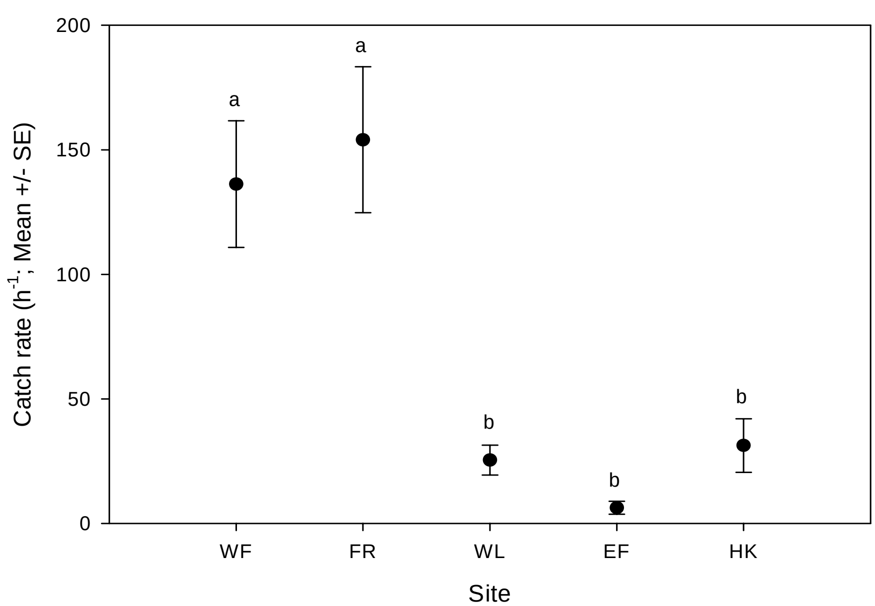

Figure 5. Season-long average abundance of river herring by site, 2007.
Letters indicate means not significantly different at p <0.05 (Tukey).

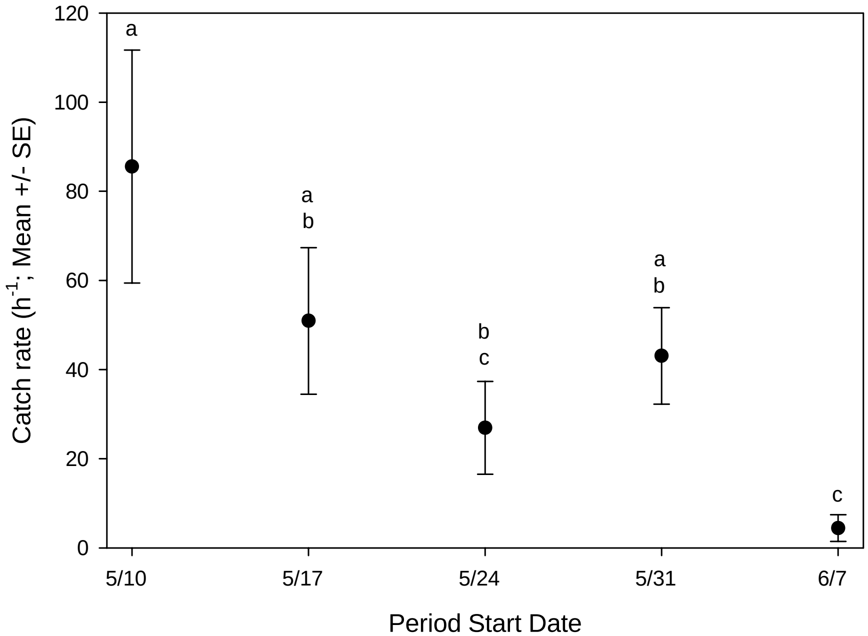

Figure 6. River-wide average abundance of river herring by period, 2005. Letters indicate means not significantly different at p <0.05 (Tukey).

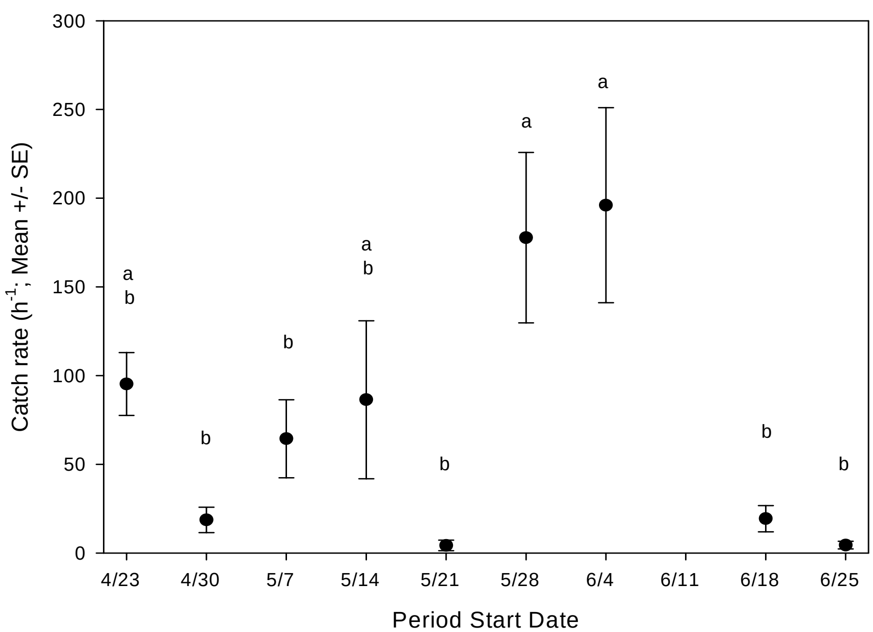

Figure 7. River-wide average abundance of river herring by period, 2006. Letters indicate means not significantly different at p <0.05 (Tukey).

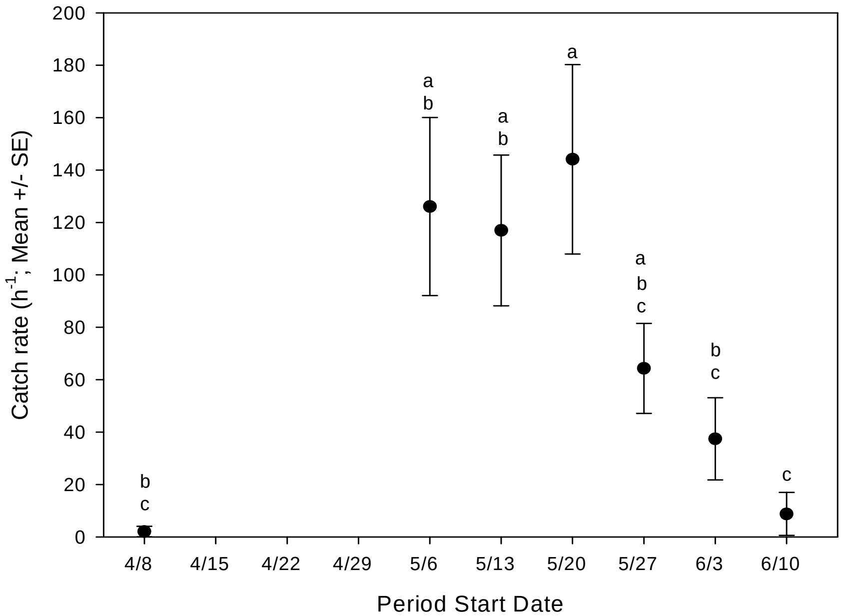

Figure 8. River-wide average abundance of river herring by period, 2007. Letters indicate means not significantly different at p <0.05 (Tukey).

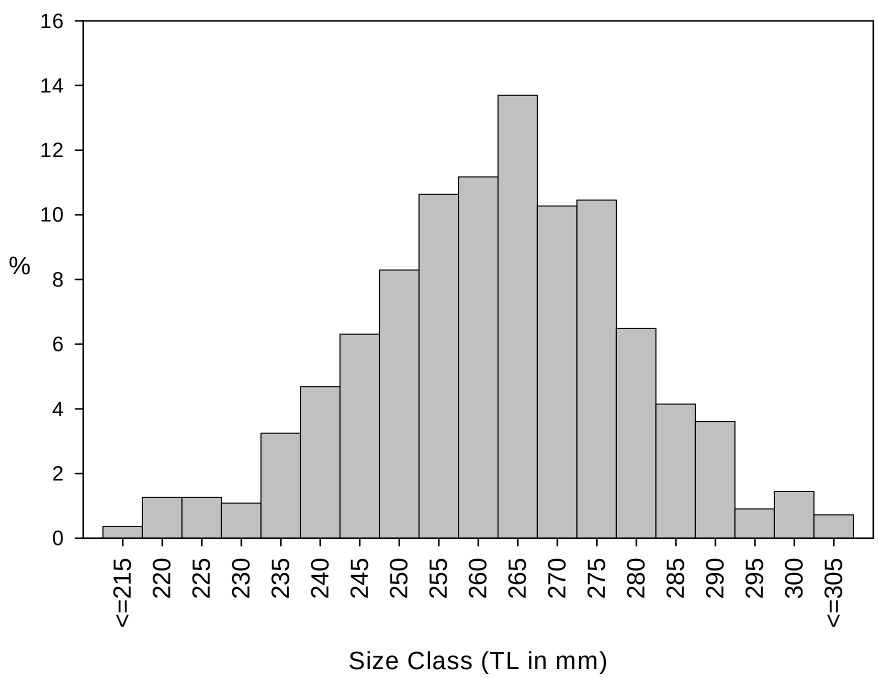

Figure 9. Size distribution of river herring collected in 2005.

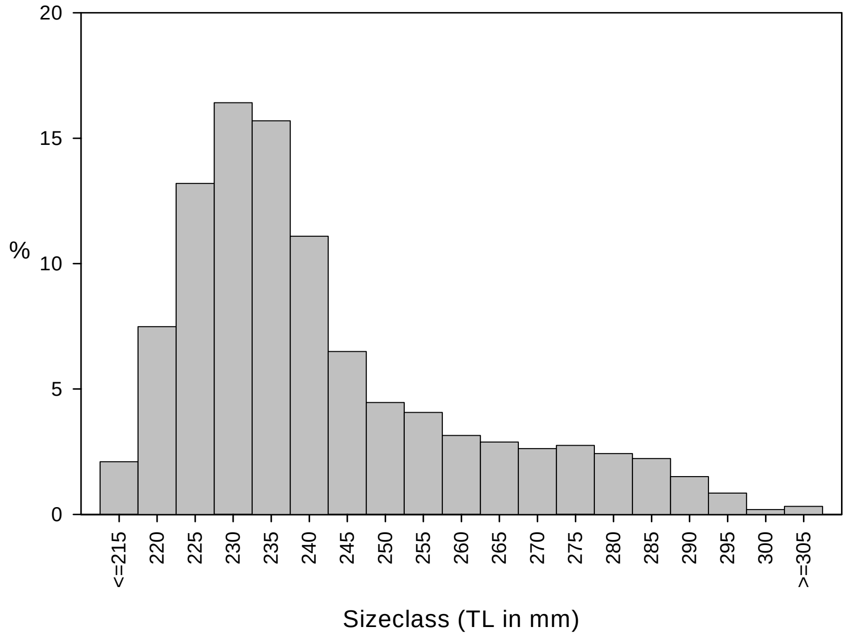

Figure 10. Size distribution of river herring collected in 2006.

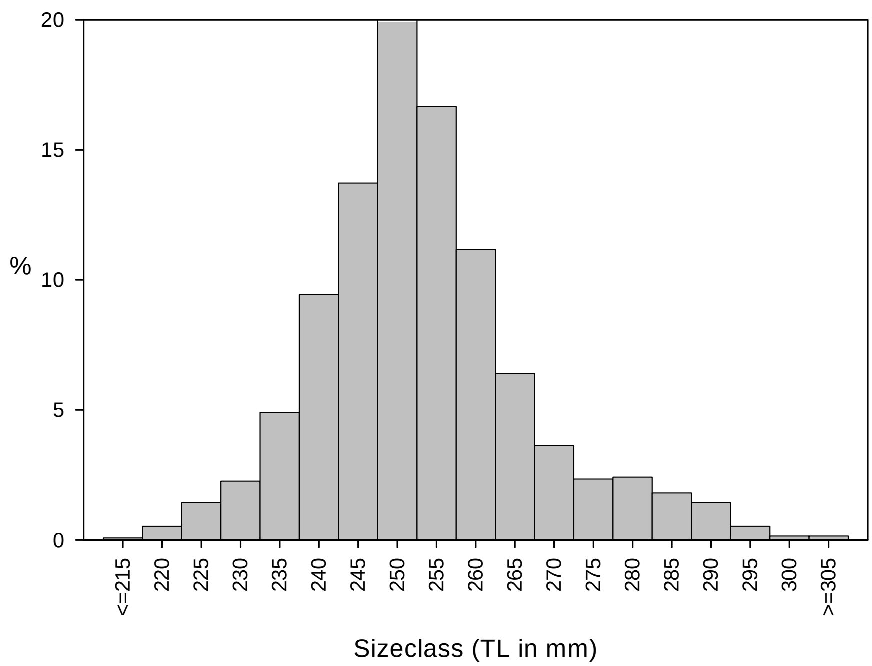

Figure 11. Size distribution of river herring collected in 2007.

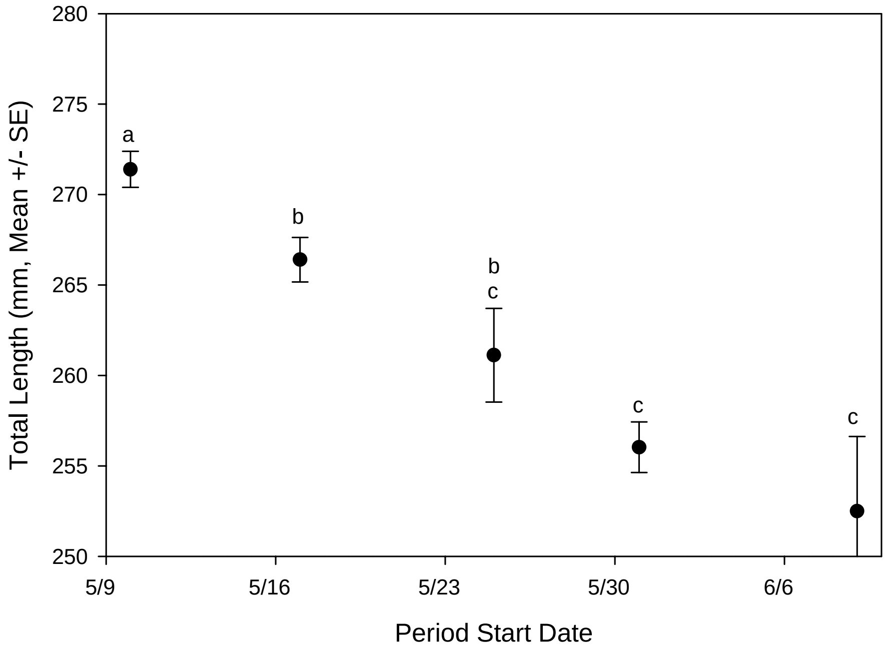

Figure 12. River-wide mean length of river herring by period, 2005. Letters indicate means not significantly different at p <0.05 (Tukey).

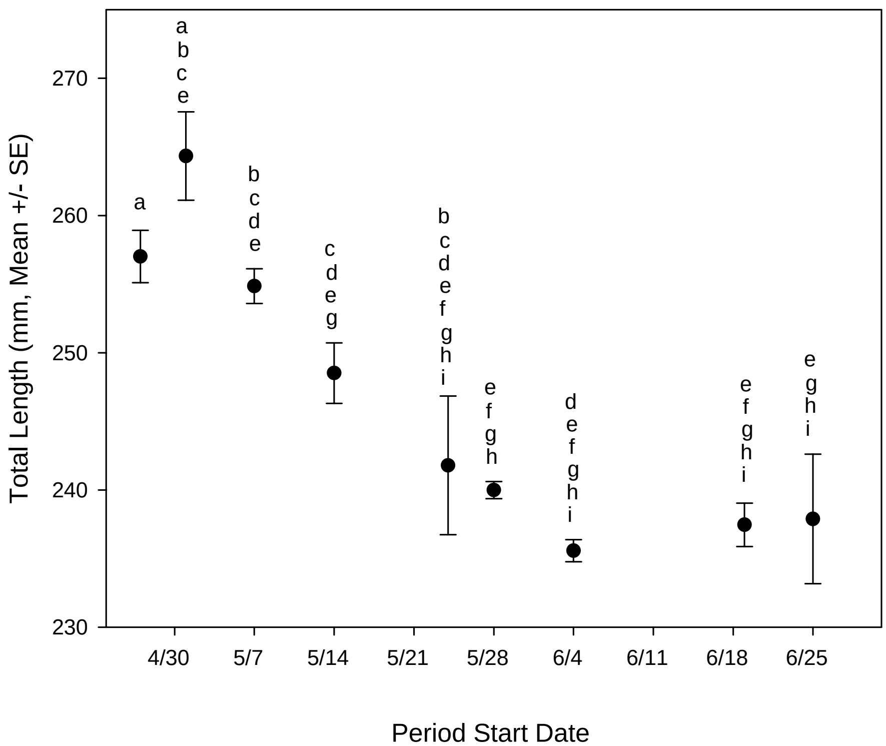

Figure 13. River-wide mean length of river herring by period, 2006. Letters indicate means not significantly different at p <0.05 (Tukey).

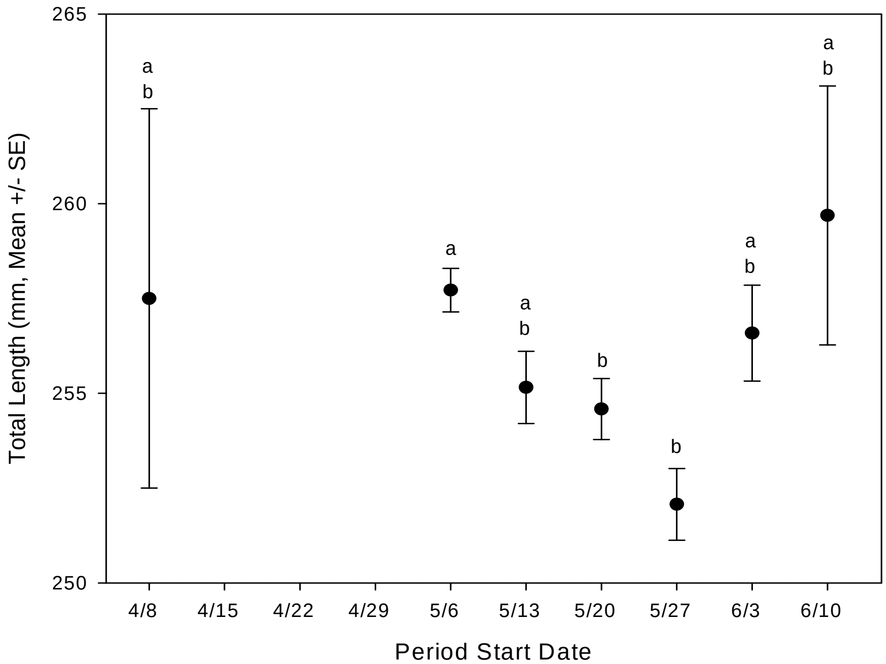

Figure 14. River-wide mean length of river herring by period, 2007. Letters indicate means not significantly different at p <0.05 (Tukey).

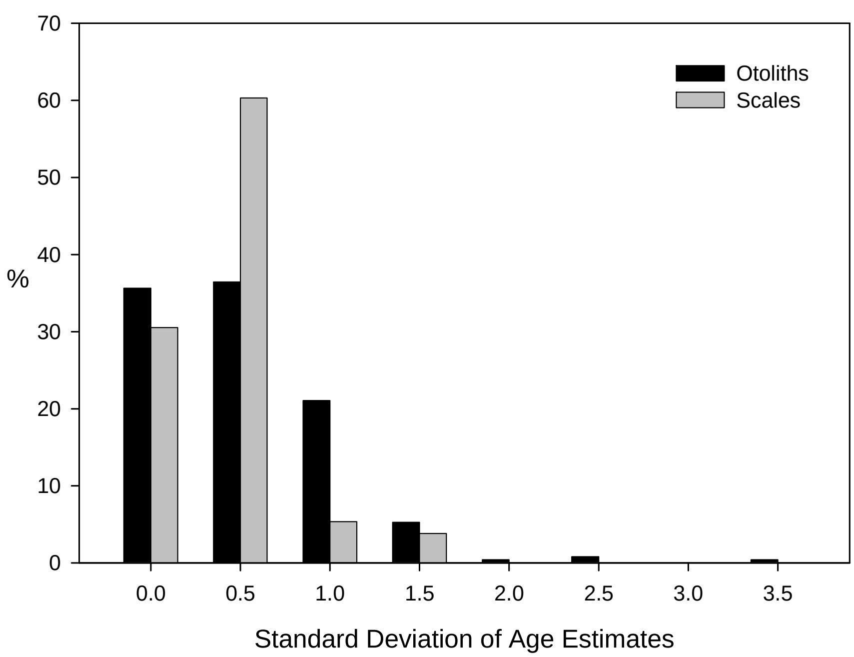

Figure 15. Frequency distribution of standard deviation (rounded to the nearest 0.5) of age estimates derived from scales and otoliths for blueback herring.

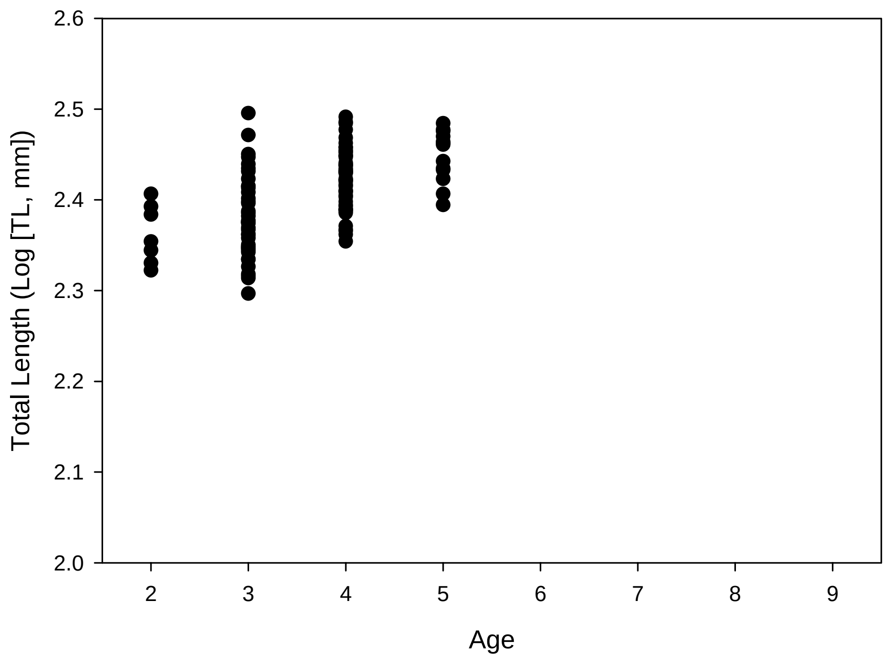

Figure 16. Length vs. age for blueback herring age estimates derived from scales.

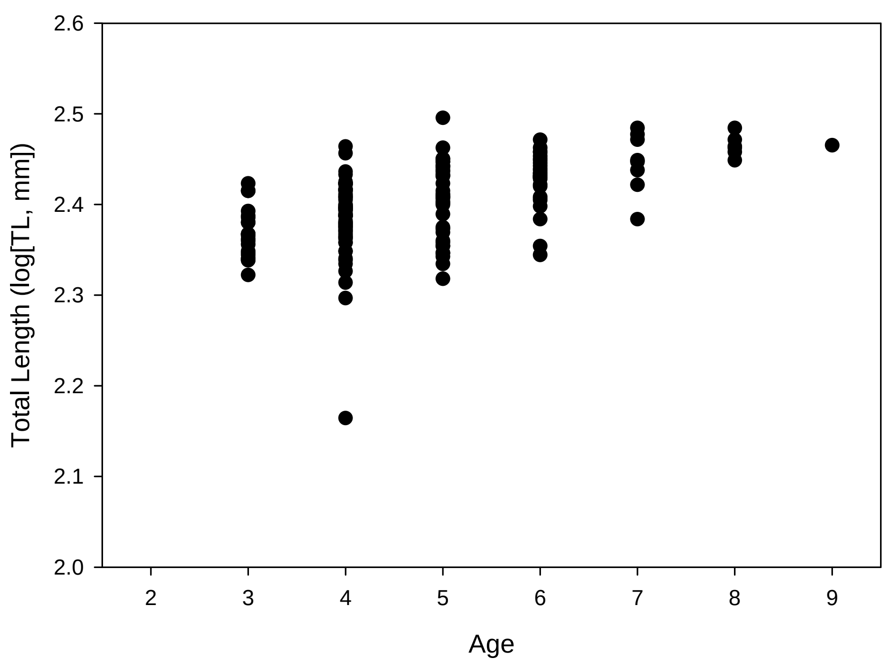

Figure 17. Length vs. age for blueback herring age estimates derived from otoliths.

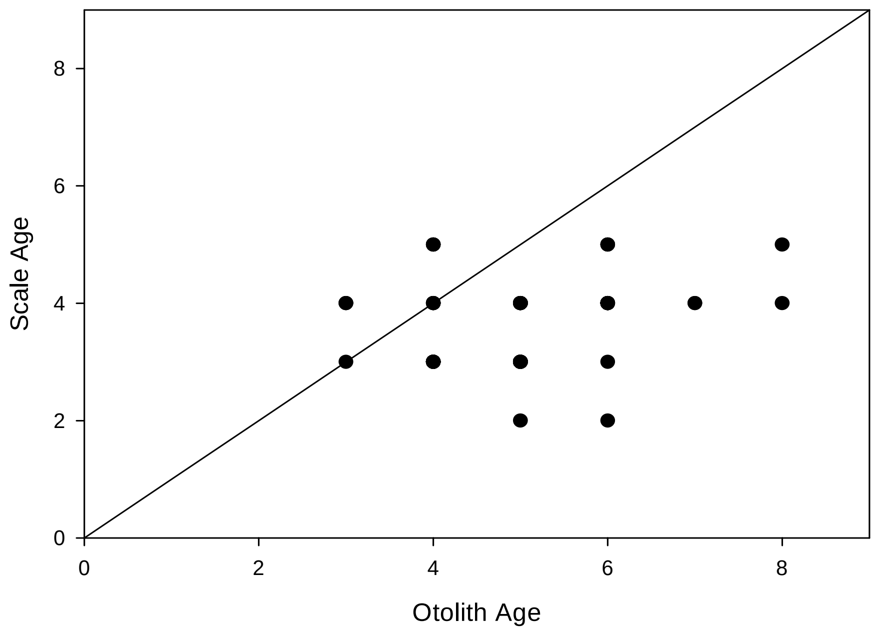

Figure 18. Age estimate derived from scales vs. age estimate derived from otoliths for individual blueback herring. Dots represent multiple data points.

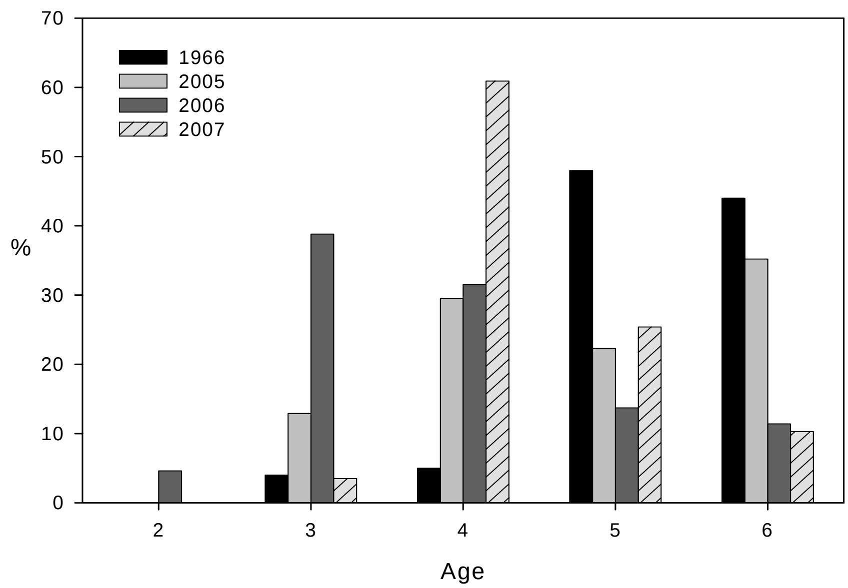

Figure 19. Age structure of female blueback herring collected in the Thames River in 1966 and in the Connecticut River in 2005-2007 Age 6 represents all fish estimated as age 6 or older.

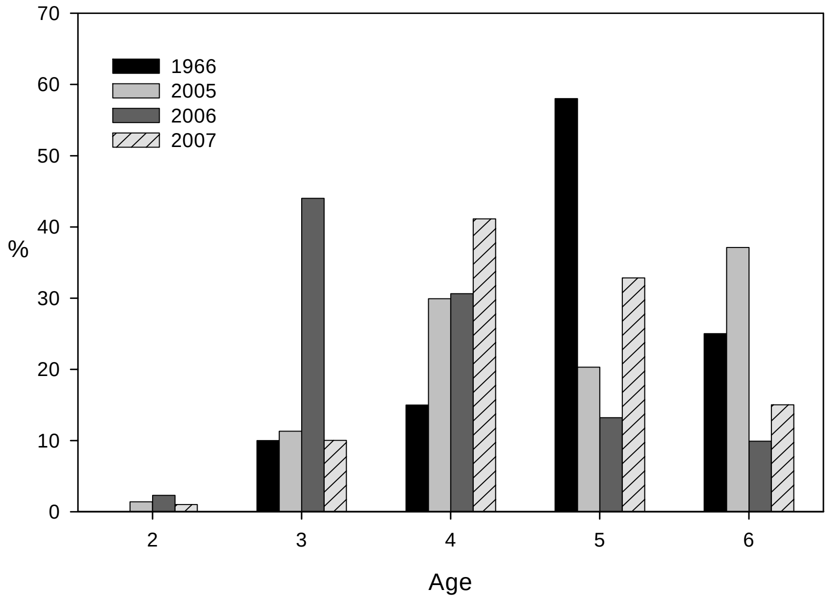

Figure 20. Age structure of male blueback herring collected in the Thames River in 1966 and in the Connecticut River in 2005-2007. Age 6 represents all fish estimated as age 6 or older.

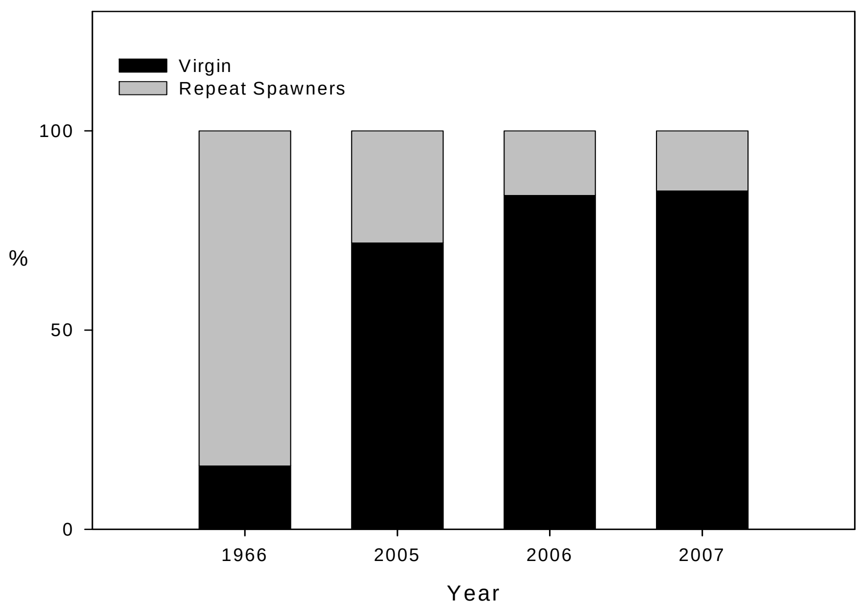

Figure 21. Spawning history structure of female blueback herring in the Thames River in 1966 and the Connecticut River in 2005-2007.

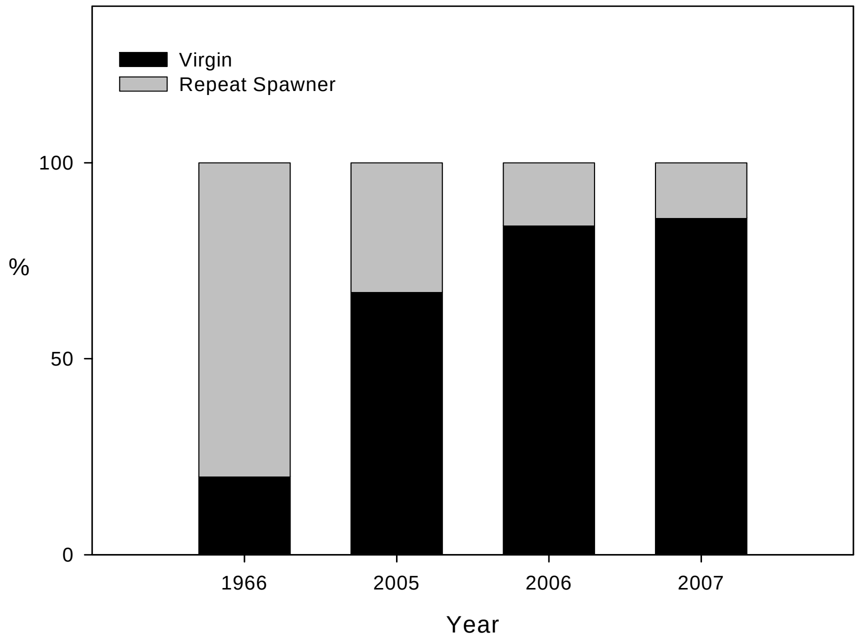

Figure 22. Spawning history structure of male blueback herring in the Thames River in 1966 and the Connecticut River in 2005-2007..

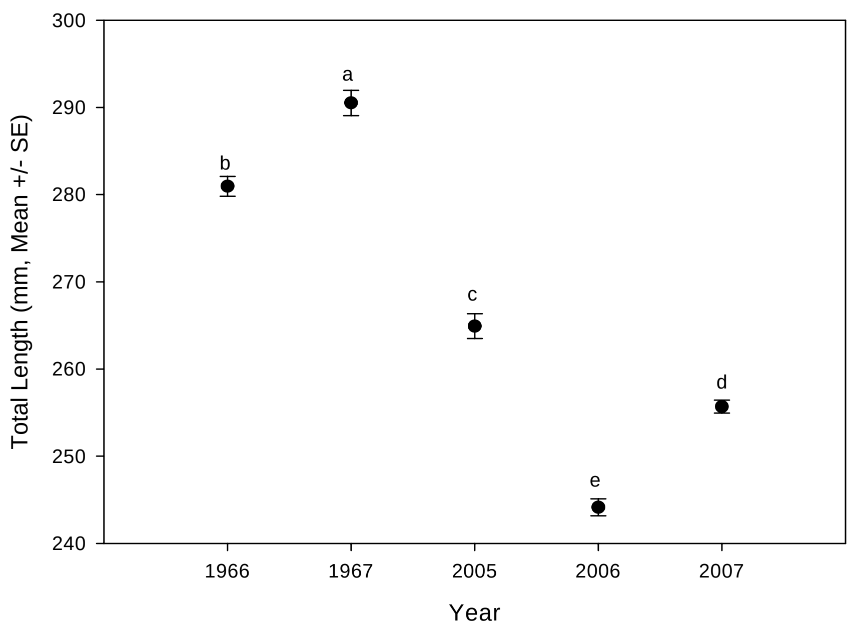

Figure 23. Mean length of blueback herring collected in the Thames River in 1966 and the Connecticut River in 1967 and 2005-2007. Letters indicate means not significantly different at $p<0.05$ (Tukey)

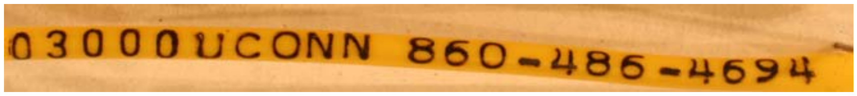

Figure 24. Close-up view of uniquely-coded FLOY internal anchor tags used to tag striped bass in 2006 - 08. The unique 5-digit ID code can be seen to the left, while the phone number for anglers to call to report recaptures can be seen to the right.

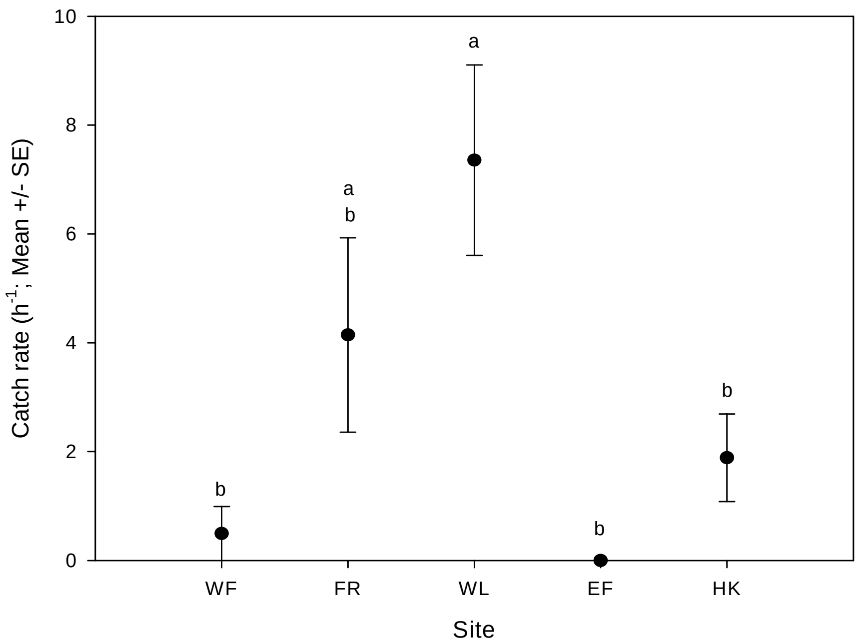

Figure 25. Season-long average abundance of Small striped bass by site, 2005. Letters indicate means not significantly different at $p < 0.05$ (Tukey).

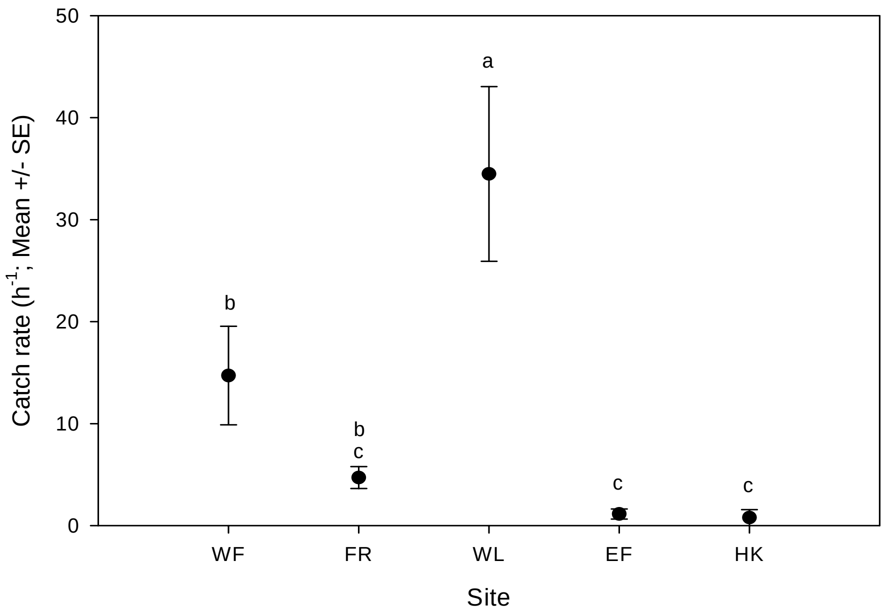

Figure 26. Season-long average abundance of Small striped bass by site, 2006. Letters indicate means not significantly different at $p < 0.05$ (Tukey).

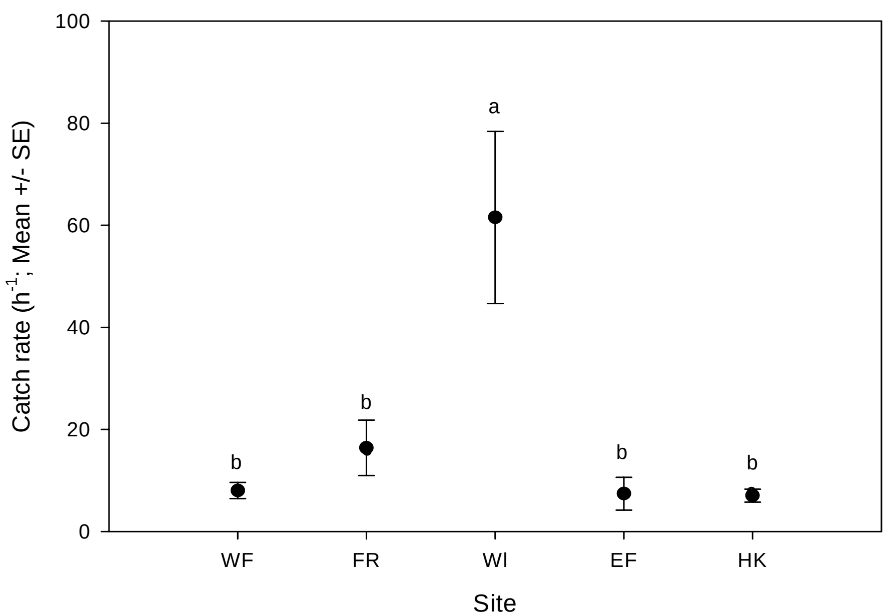

Figure 27. Season-long average abundance of Small striped bass by site, 2007. Letters indicate means not significantly different at $p < 0.05$ (Tukey).

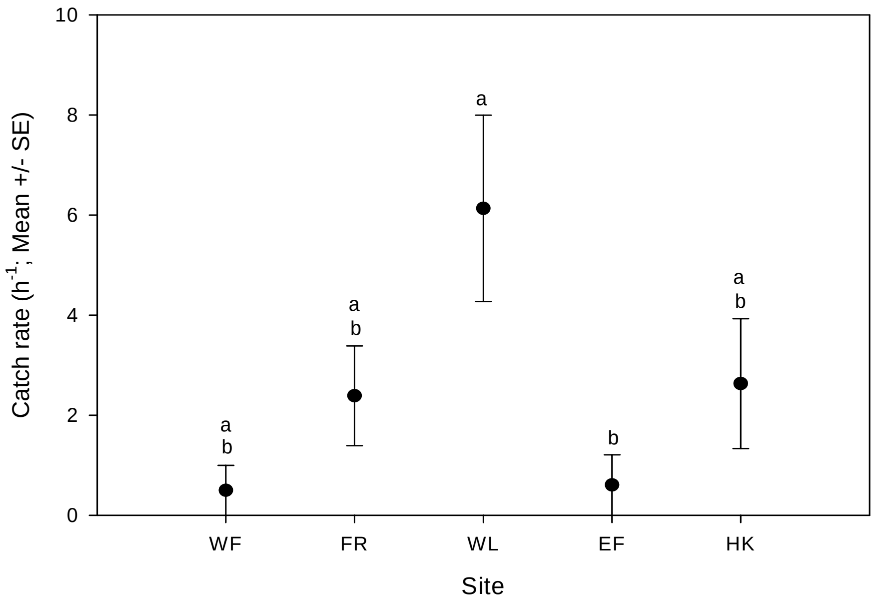

Figure 28. Season-long average abundance of Large striped bass by site, 2005. Letters indicate means not significantly different at $p < 0.05$ (Tukey).

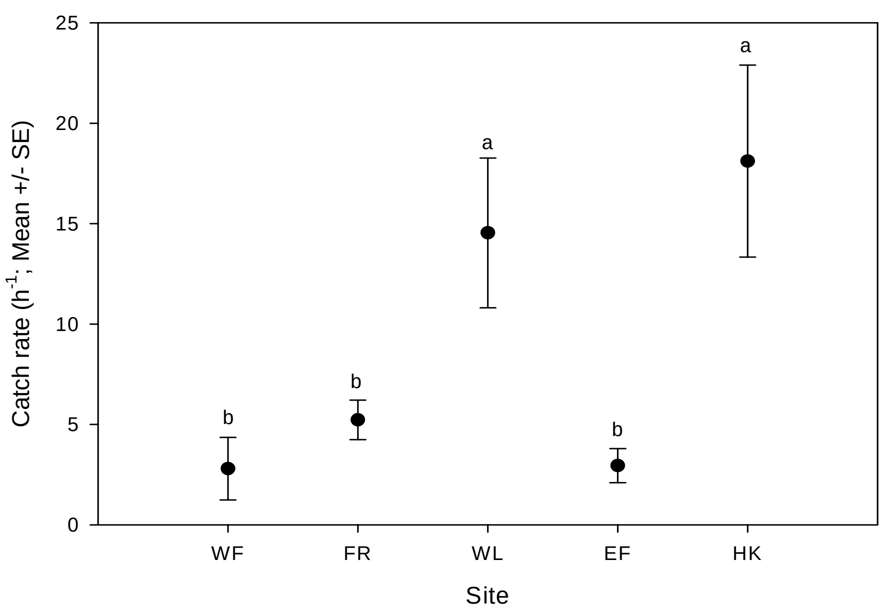

Figure 29. Season-long average abundance of Large striped bass by site, 2006. Letters indicate means not significantly different at $p < 0.05$ (Tukey).

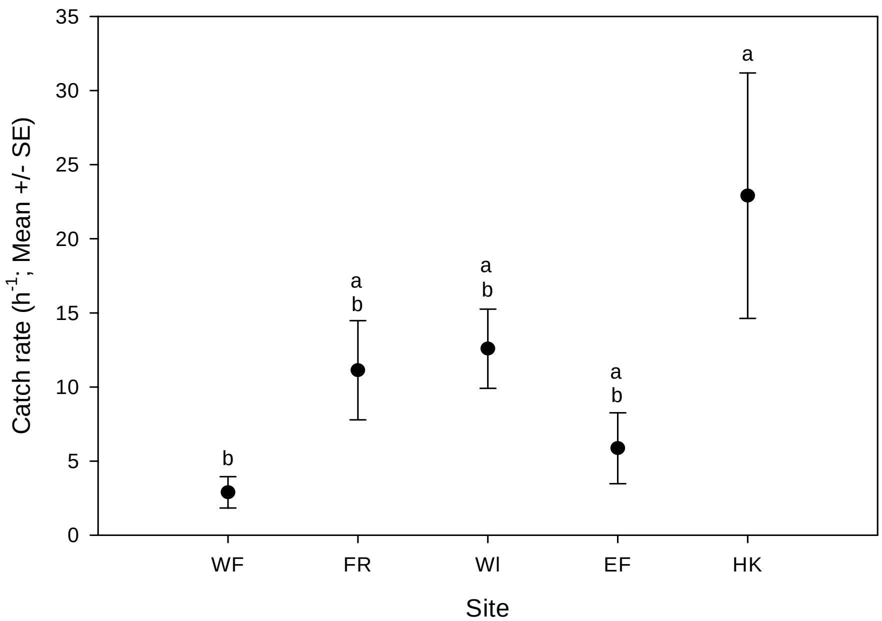

Figure 30. Season-long average abundance of Large striped bass by site, 2007. Letters indicate means not significantly different at p <0.05 (Tukey).

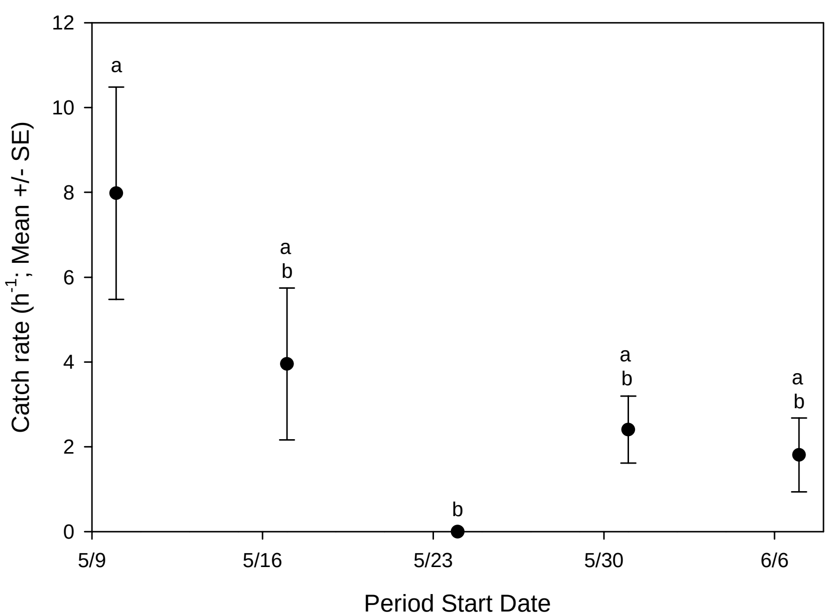

Figure 31. River-wide average abundance of Small striped bass by period, 2005. Letters indicate means not significantly different at p <0.05 (Tukey).

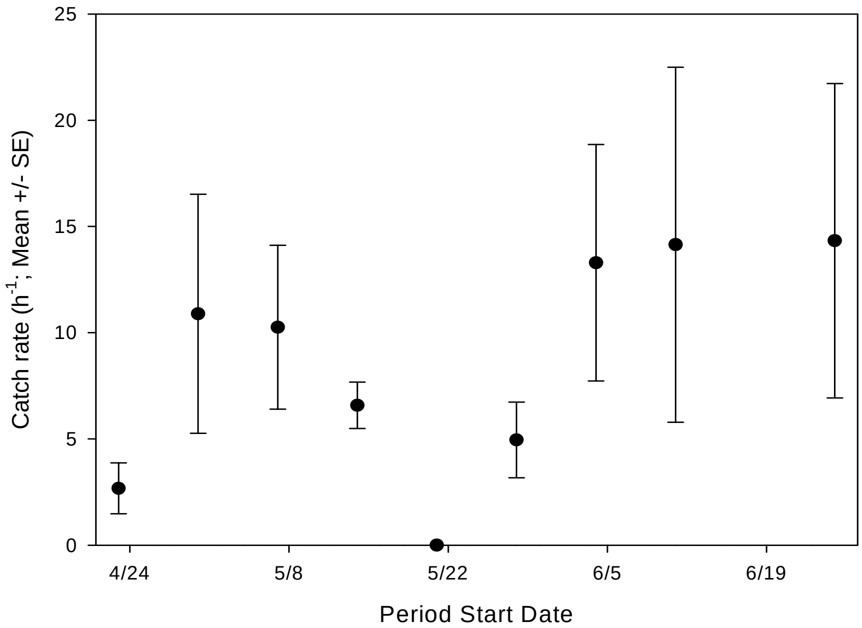

Figure 32. River-wide average abundance of Small striped bass by period, 2006. Letters indicate means not significantly different at $p < 0.05$ (Tukey).

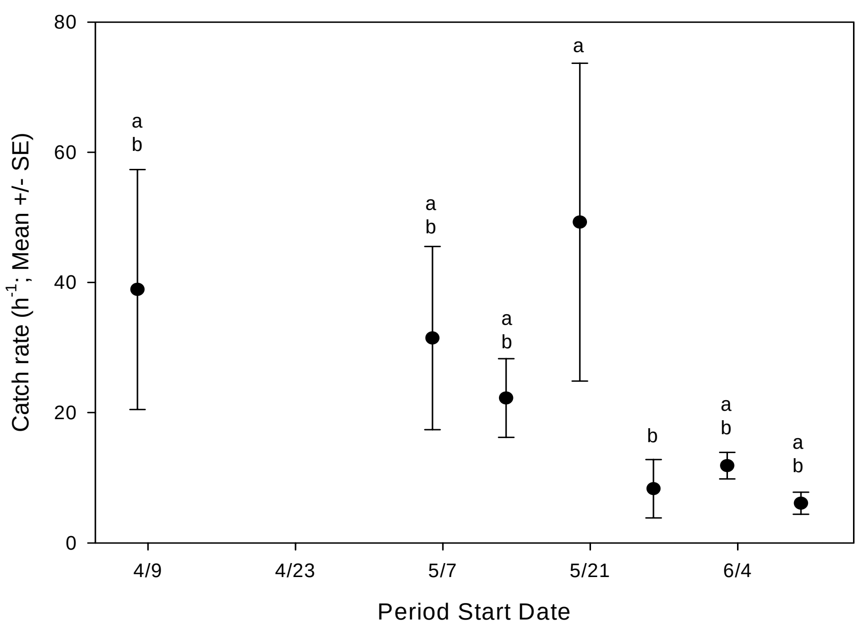

Figure 33. River-wide average abundance of Small striped bass by period, 2007. Letters indicate means not significantly different at $p < 0.05$ (Tukey).

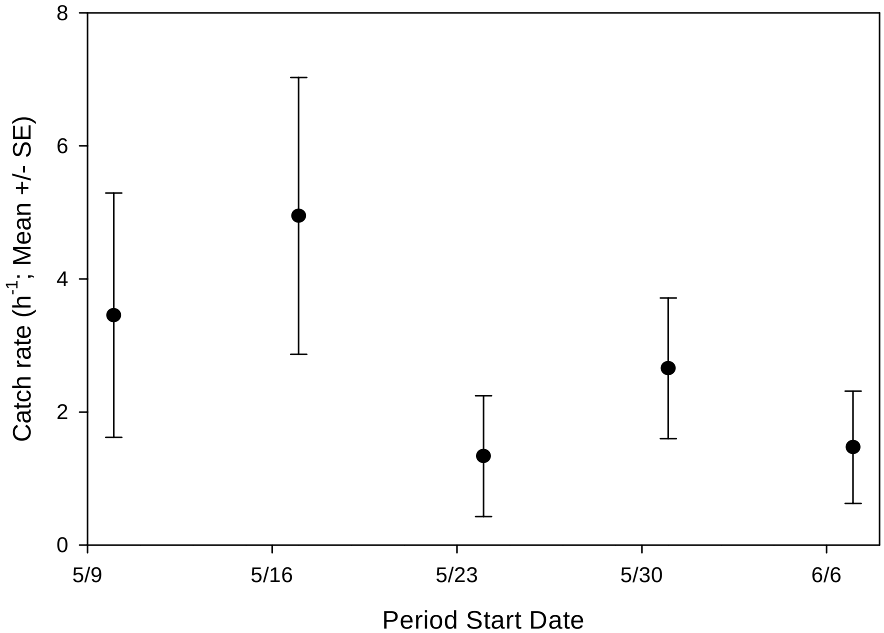

Figure 34. River-wide average abundance of Large striped bass by period, 2005.

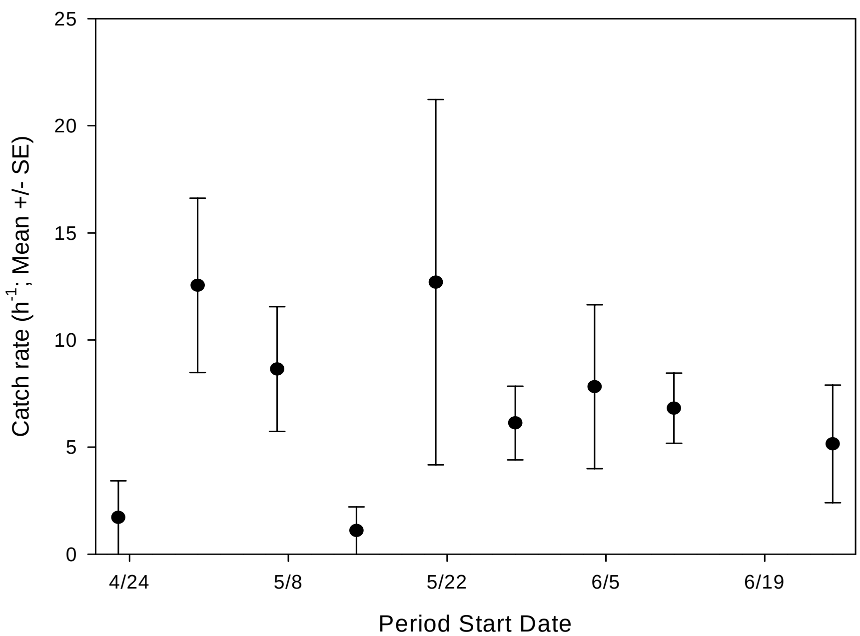

Figure 35. River-wide average abundance of Large striped bass by period, 2006.

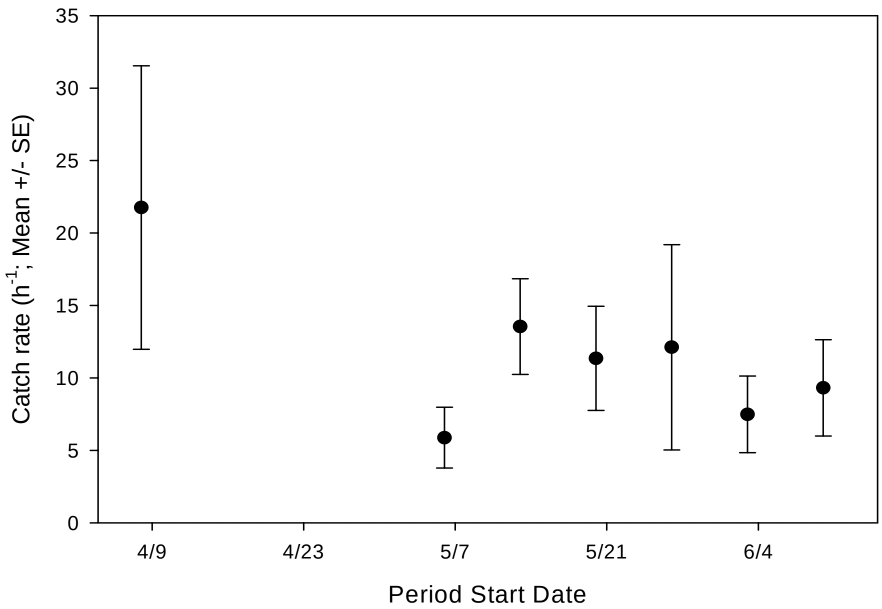

Figure 36. River-wide average abundance of Large striped bass by period, 2007.

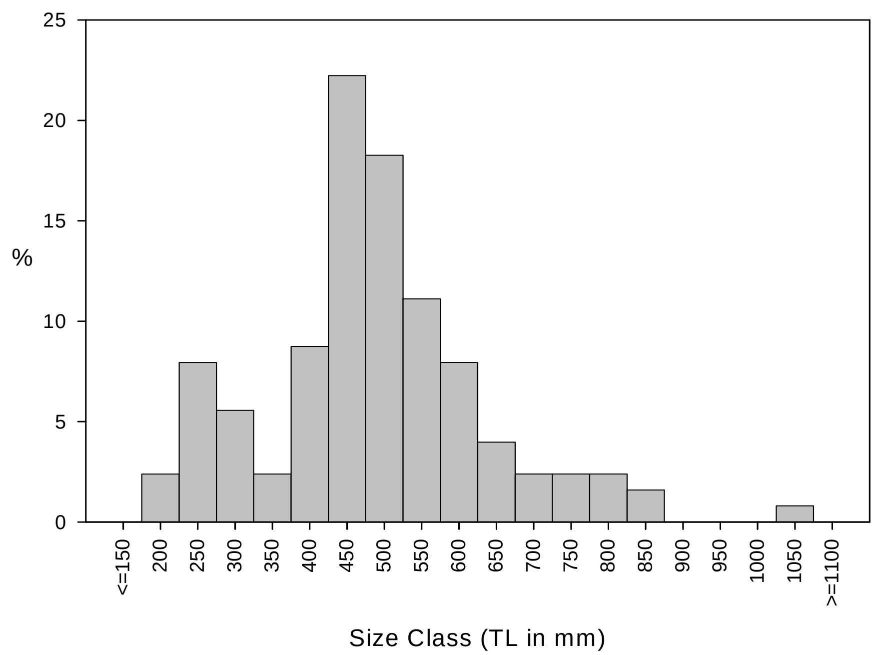

Figure 37. Size distribution of striped bass collected in 2005.

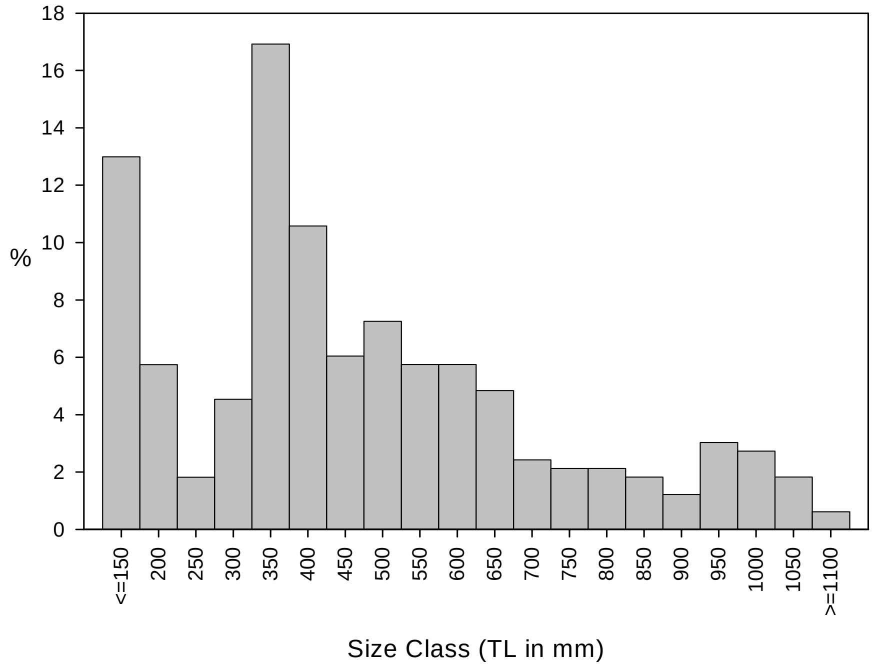

Figure 38. Size distribution of striped bass collected in 2006.

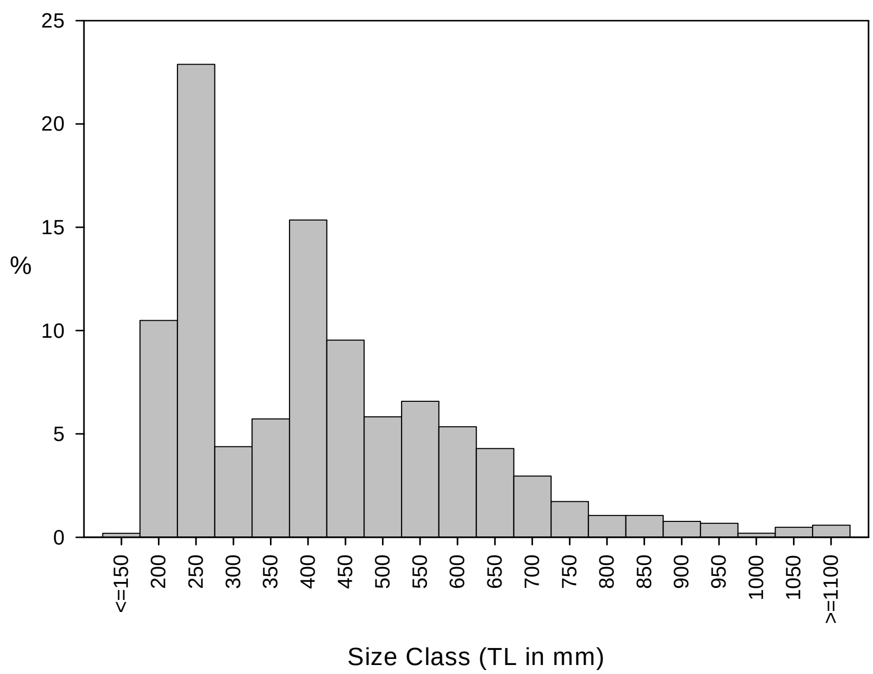

Figure 39. Size distribution of striped bass collected in 2007.

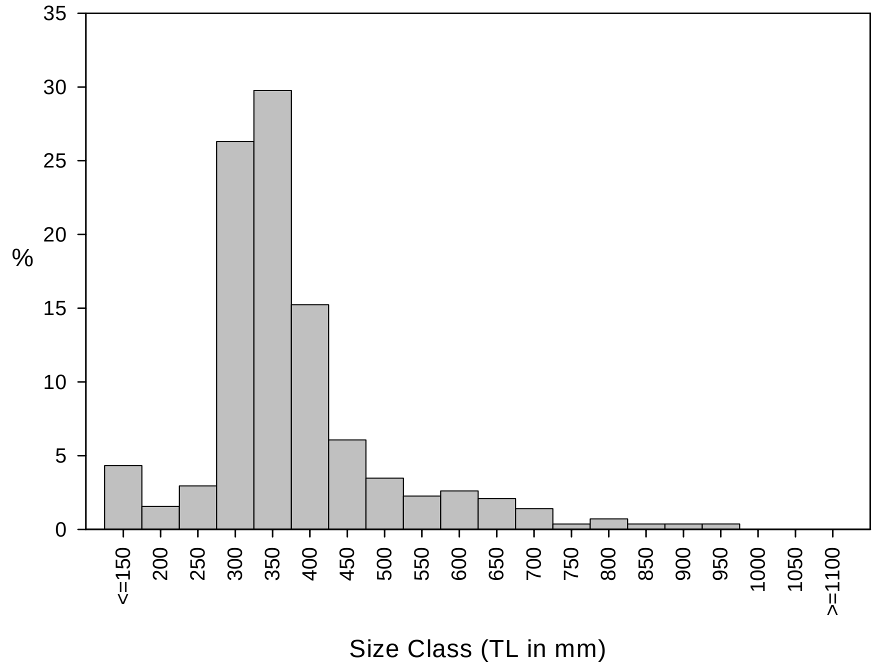

Figure 40. Size distribution of striped bass collected in 2008. All striped bass were captured at Windsor Locks.

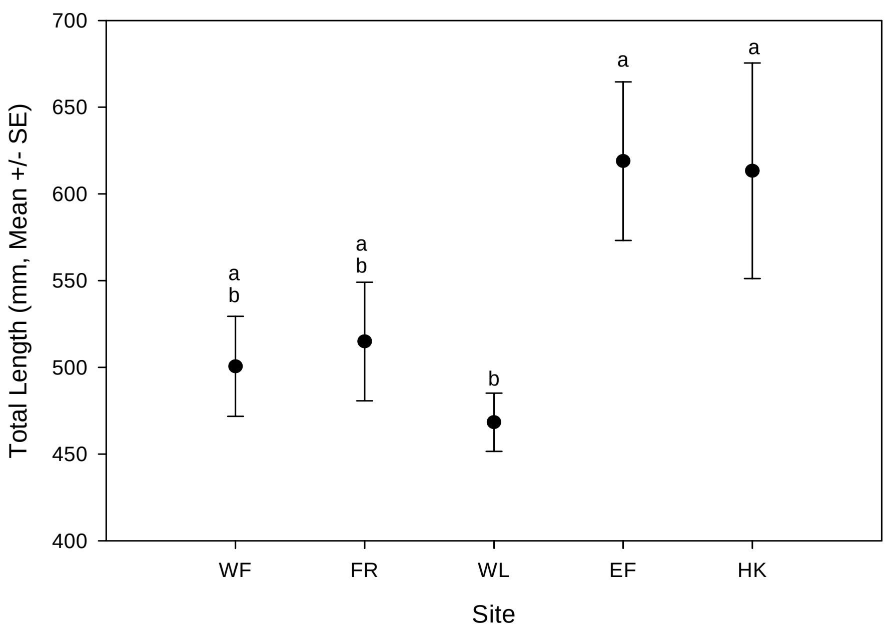

Figure 41. Season-long mean length of striped bass by site, 2005. Letters indicate means not significantly different at p <0.05 (Tukey).

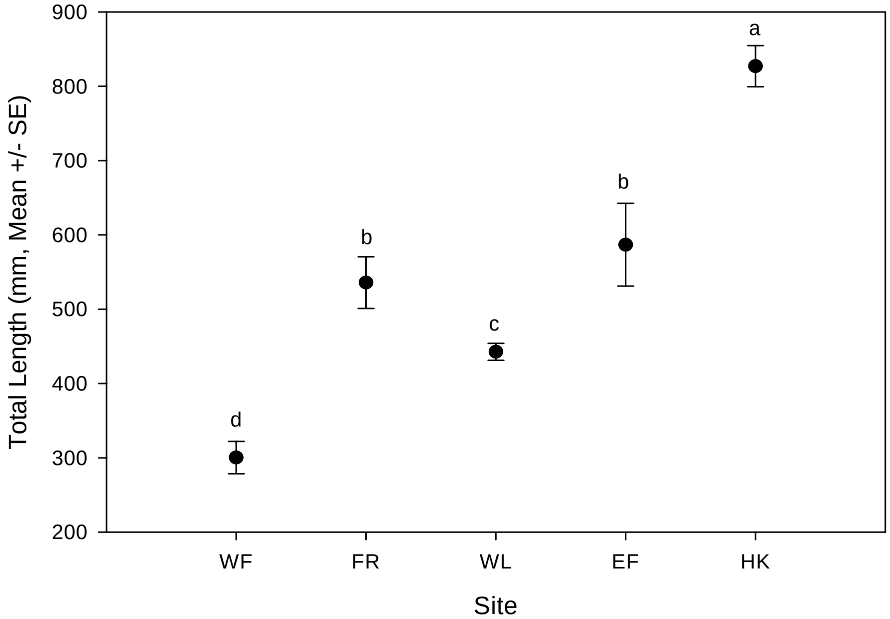

Figure 42. Season-long mean length of striped bass by site, 2006.
Letters indicate means not significantly different at p <0.05 (Tukey).

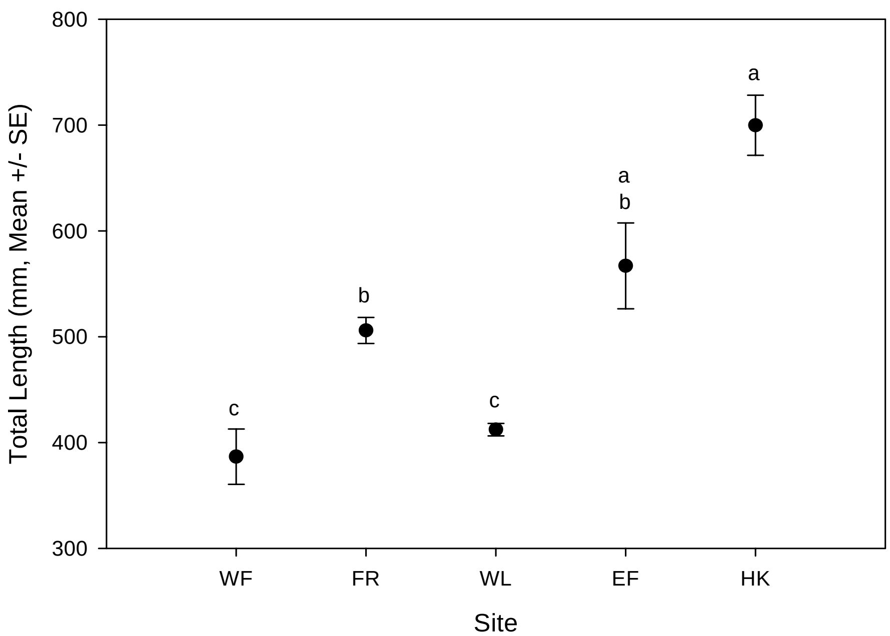

Figure 43. Season-long mean length of striped bass by site, 2007.
Letters indicate means not significantly different at p <0.05 (Tukey).

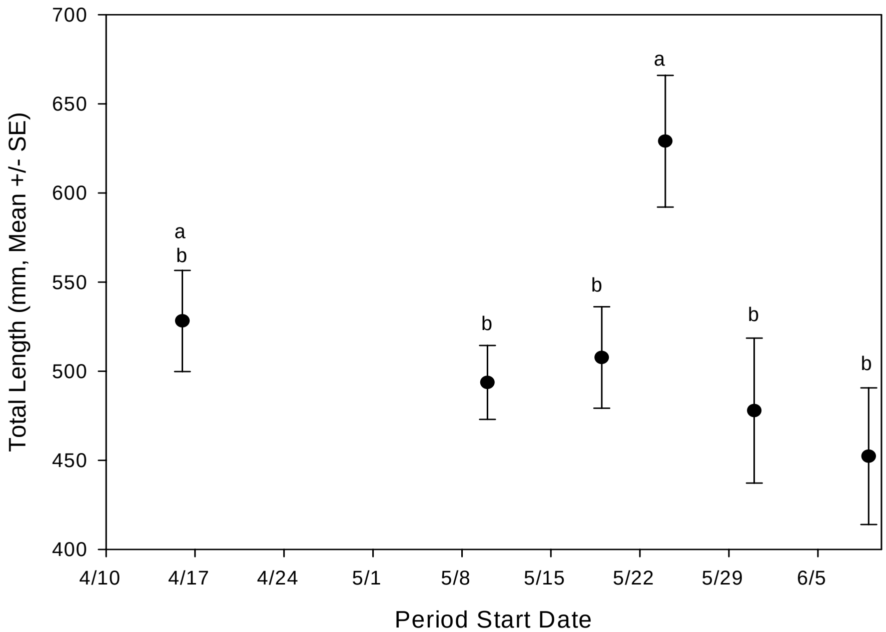

Figure 44. River-wide mean length of striped bass by period, 2005.
Letters indicate means not significantly different at p <0.05 (Tukey).

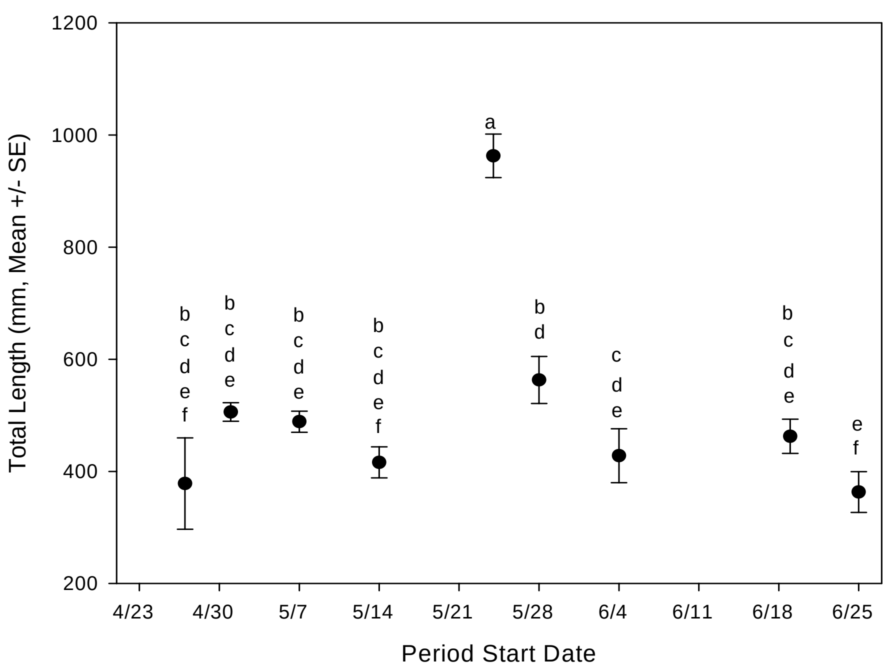

Figure 45. River-wide mean length of striped bass by period, 2006.
Letters indicate means not significantly different at p <0.05 (Tukey).

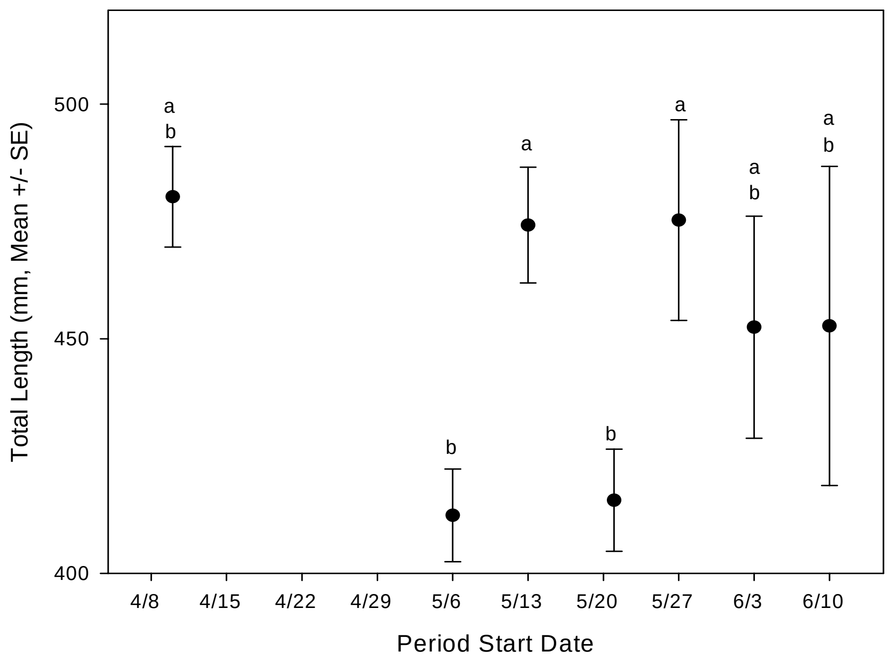

Figure 46. River-wide mean length of striped bass by period, 2007.
Letters indicate means not significantly different at p <0.05 (Tukey).

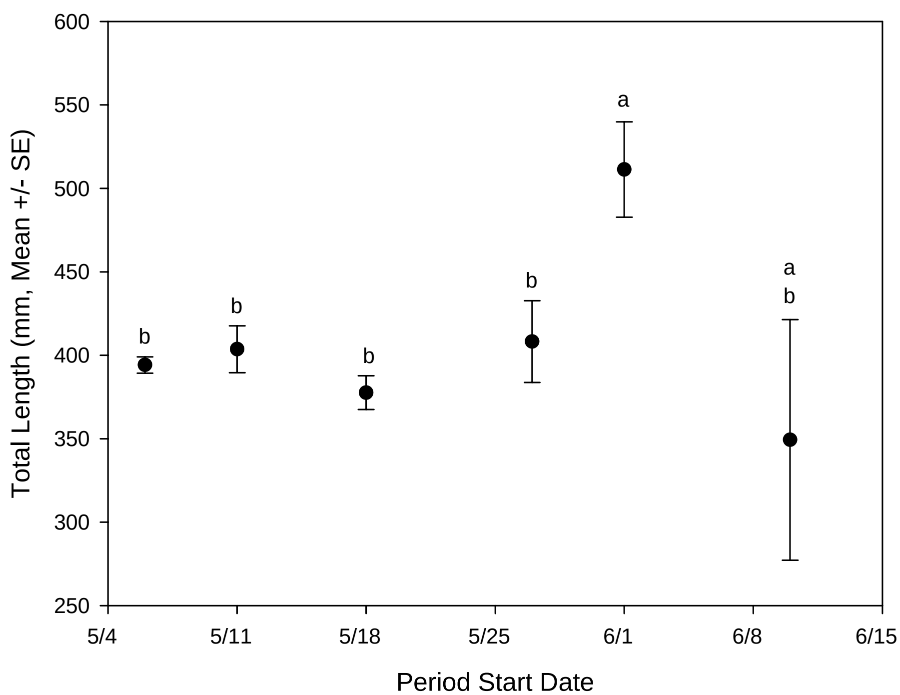

Figure 47. Mean length of striped bass at Windsor Locks by period, 2008.
Letters indicate means not significantly different at p <0.05 (Tukey).

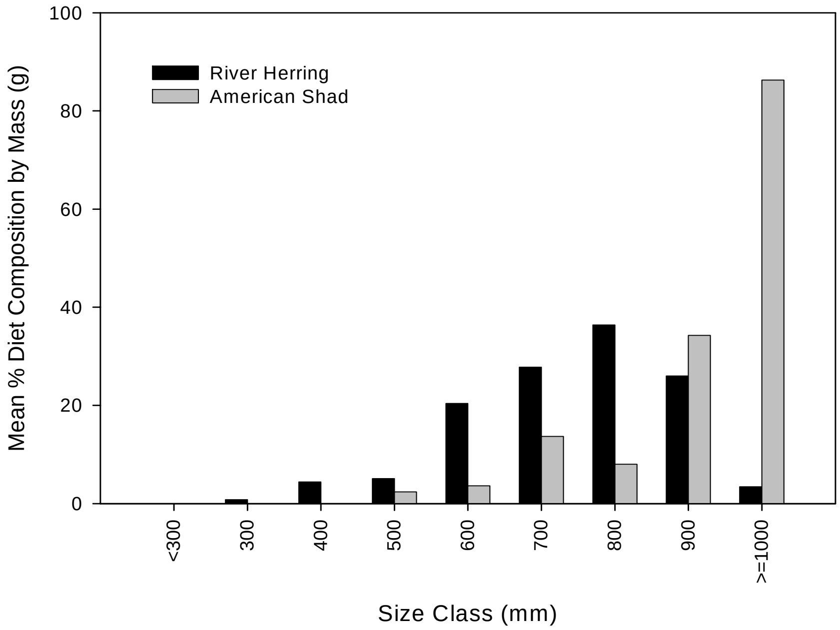

Figure 48. Mean percent by mass of river herring and American shad in diet samples from striped bass collected in 2005-2007. Striped bass have been grouped into 100 mm size intervals.

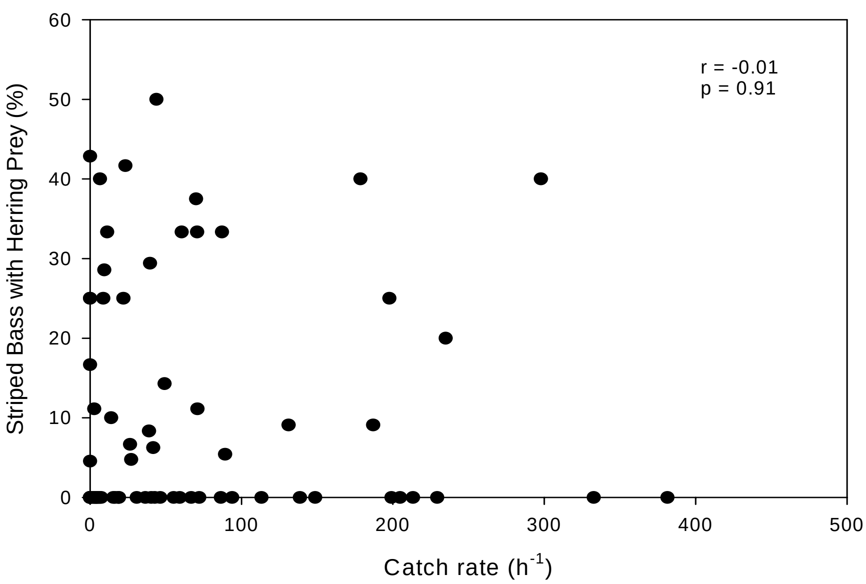

Figure 49. Percentage of striped bass consuming herring prey vs. river herring abundance for sample-nights in 2005-07. Sample nights on which no striped bass > 400 mm TL were lavaged were excluded.

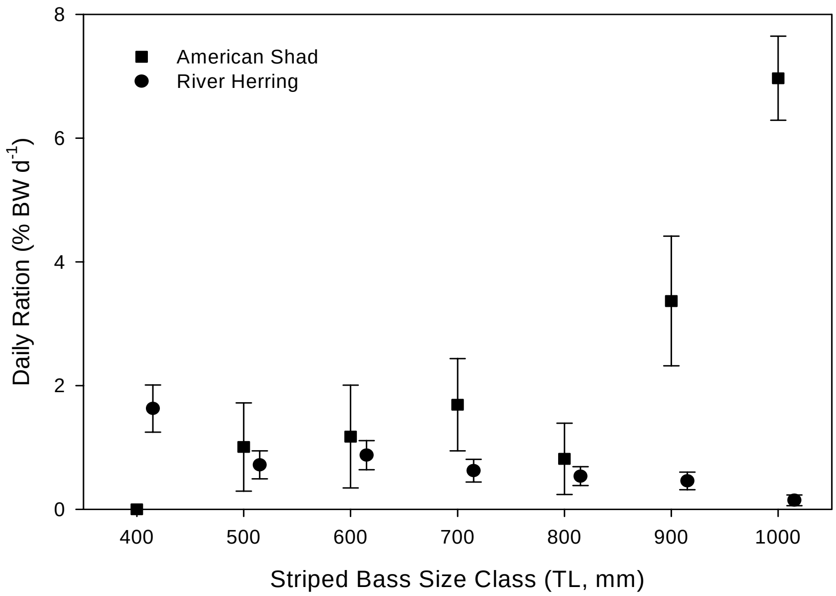

Figure 50. Estimated daily ration of river herring and American shad prey by striped bass size class. Error bars represent one standard error.

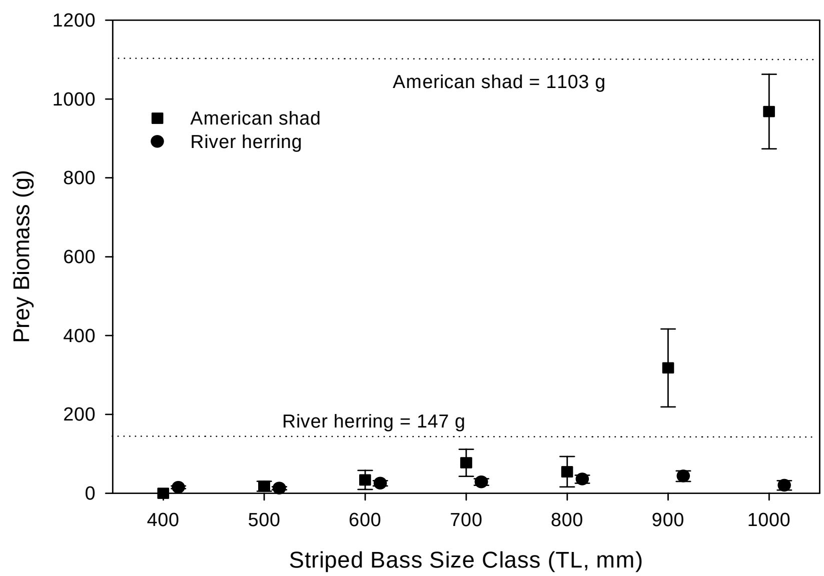

Figure 51. Estimated daily consumption of river herring and American shad biomass by striped bass size class. Error bars represent one standard error. Reference lines indicate prey mass inputs used in consumption rate estimation.

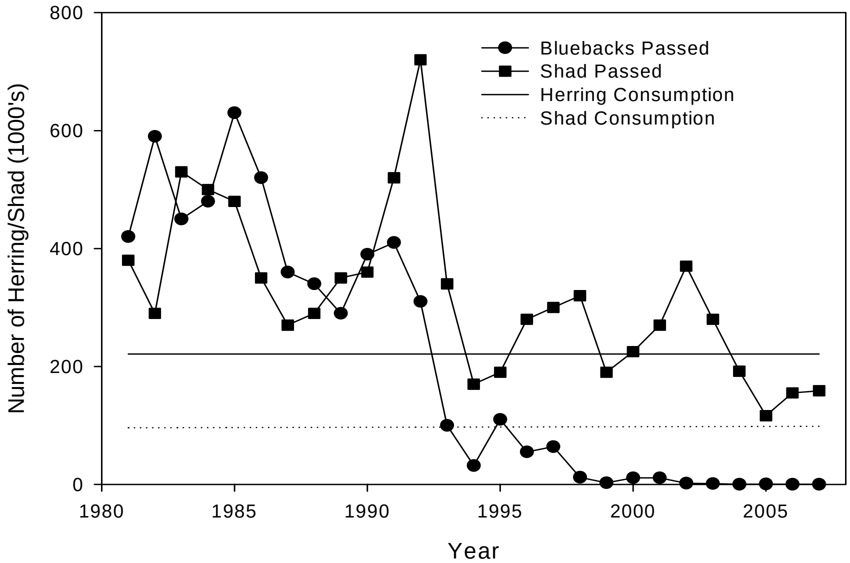

Figure 52. Number of blueback herring and American shad passed at the Holyoke fishlift 1981 - 2007. Reference lines indicate striped bass population-level consumption estimates for river herring and American shad in 2005-07.