US Army Corps
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New York District

NEW YORK AND NEW JERSEY
HARBOR DEEPENING PROJECT

Migratory Finfish Survey Summary Report

December 2015

NEW YORK AND NEW JERSEY HARBOR DEEPENING PROJECT

MIGRATORY FINFISH SURVEY SUMMARY REPORT

Part I: Spatial and Temporal Trends in Abundance for Mid-Water Species

Part II: River Herring

December 2015

Prepared for:

U.S. Army Corps of Engineers – New York District

Jacob K. Javits Federal Building
26 Federal Plaza
New York, New York 10278

The 2006 and 2011-2013 Migratory Finfish Surveys (MFS) were conducted as part of the New York and New Jersey Harbor Deepening Project (HDP), a United States Army Corps of Engineers – New York District (USACE-NYD) and Port Authority of New York and New Jersey (PANYNJ) sponsored project to deepen navigation channels to 50 feet to accommodate larger commercial vessels and improve Harbor navigation and safety while minimizing impacts to the overall environment and promoting environmental sustainability. Prior to construction, a comprehensive review of the literature related to the biological resources in the Harbor indicated that there were insufficient data available to evaluate the relative importance of aquatic habitats, including the use of the Harbor's navigation channels by resident and migratory finfish, shellfish and benthic macroinvertebrates and the potential dredging-related negative impacts on finfish populations using Harbor habitats, primarily channels (USACE-NYD 1998).

The overall goal of the MFS was to identify spatial and temporal trends in abundance for target and other common mid-water species using the Harbor relative to environmental factors (specifically temperature and freshwater flow/discharge). Specific objectives of the MFS included: 1) identification of the timing and duration of spawning migrations within the Harbor; 2) documentation of spatial and temporal patterns of habitat use by common mid-water species (primarily migratory species); 3) relate spatial and temporal information to recent (2015) draft conservation recommendations for overwintering striped bass and on spawning migrations of anadromous species (NMFS 2015) and 4) further investigation and description of spatial and temporal patterns of habitat use within the Harbor and biological information specifically for alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), collectively referred to as "river herring."

To accomplish these objectives, the Harbor was divided into four study areas representing distinct subsections of the Harbor in order to detect different usage by migratory species: the Arthur Kill/Kill Van Kull, Newark Bay, Upper Bay, and Lower Bay. Each of these study areas was sampled during all four years using a 18-foot (5.5 m) balloon trawl rigged for mid-water deployment; in addition during 2006 a 30-foot (9.1 m) otter trawl was used to sample near-bottom habitats, concurrent with ongoing benthic ecology studies throughout the Harbor (USACE-NYD's Aquatic Biology Survey [ABS]).

The mid-water finfish assemblages in the Harbor included very abundant species such as bay anchovy (*Anchoa mitchilli*), which accounted for 98% of all fish collected during the MFS and were collected during every season and from all Harbor regions, along with alewife and blueback herring which were most abundant during winter-spring and fall. Bay anchovy became more numerous in late spring to summer as Atlantic herring (*Clupea harengus*), alewife, and blueback herring numbers decreased. Atlantic herring were commonly collected during the spring, along with spotted hake (*Urophycis regius*). Bay anchovy dominated the summer fish assemblage along with Atlantic menhaden (*Brevoortia tyrannus*), Atlantic butterfish (*Peprilus triacanthus*), bluefish (*Pomatomus saltatrix*), and striped anchovy (*Anchoa hepsetus*). Bay anchovy continued to be the dominant species present in fall surveys; other common species during this time included alewife and blueback herring, American shad (*Alosa sapidissima*), Atlantic butterfish, Atlantic menhaden, Atlantic moonfish (*Selene setapinnis*), bluefish, silver hake (*Merluccius bilinearis*), and weakfish (*Cynoscion regalis*). American shad juveniles were collected in low numbers from all Harbor regions during spring (April and May) and fall (September) and early winter (December). Similarly, striped bass (*Morone saxatilis*) juveniles were sporadically collected from the Arthur Kill/Kill Van Kull, Newark Bay, and Upper Bay during mid-water trawl surveys during spring (April and May) and fall (September) and early winter (December). During ABS bottom trawl surveys, striped bass were collected from January through May.

Within each season, mid-water fish assemblages were similar among all Harbor areas. In the fall, inter-annual differences in fish assemblages were related to variation in freshwater discharge. Migratory species were very abundant throughout the Harbor in 2011, coincident with high fall Hudson River discharges associated with severe weather events in that time period. Across all study years, peak adult river herring abundances occurred in April; these numbers potentially represent the occurrence of both pre-and post-spawning individuals. River herring abundances declined dramatically across all Harbor regions in May and few river herring were collected in June. Furthermore, no clear association between river herring collections and temperature were noted, although alewife were generally collected at lower temperatures than blueback herring. Finally, analysis of total river herring abundance across the four study years of the MFS indicate that the migratory pathway through the Upper Bay to the mainstem of the Hudson River (and ultimately the individual tributary spawning areas used by river herring) is much stronger than the migration corridor through the Arthur Kill- Kill Van Kull complex leading to spawning areas within the upper (i.e., non-tidal freshwater) Hackensack and Passaic Rivers.

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1.0 INTRODUCTION

1.1 BACKGROUND

The 2006 and 2011-2013 Migratory Finfish Surveys (MFS) were conducted as part of the New York and New Jersey Harbor Deepening Project (HDP). The HDP is a United States Army Corps of Engineers – New York District (USACE-NYD) and Port Authority of New York and New Jersey (PANYNJ) sponsored project to deepen navigation channels to 50 feet to accommodate larger commercial vessels and improve Harbor navigation and safety while minimizing impacts to the overall environment and promoting environmental sustainability. Prior to construction, a comprehensive review of the literature related to the biological resources in the Harbor indicated that there were insufficient data available to evaluate the relative importance of aquatic habitats, including the use of the Harbor's navigation channels by resident and migratory finfish, shellfish and benthic macroinvertebrates and the potential dredging-related negative impacts on finfish populations using Harbor habitats, primarily channels (USACE-NYD 1998).

Since determinations of seasonal dredging restrictions throughout the United States are frequently found to be based on outdated information or perceptions of the dredging process and in only a few instances are based on conclusive scientific evidence (National Research Council 2001), additional biological data for assessing current dredging restrictions in the New York/New Jersey Harbor (Harbor) area were warranted. The purpose of the MFS study is to investigate the spatial and temporal distribution of migratory finfish during their seasonal movements through the Harbor. General life history information on these species are well known, however less is known of their use of the Harbor during migrations, such as seasonal timing, duration, migratory pathways and depth distributions. The MFS program provides data on migratory species, primarily during the spring and fall migration periods that are evaluated in relation to management of dredging operations in Harbor-wide contract areas.

Migratory finfish access upstream freshwater spawning/nursery habitat by traversing the Harbor and the Hudson-Raritan Estuary. Finfish migrations in the Harbor are primarily composed of anadromous species (marine species that spawn in freshwater) that occur bi-annually in the Harbor during spring (spawning adults and accompanying juveniles) and fall/winter (young-of-the-year/yearling out-migrations). New Jersey rivers and tributaries are primarily used by river herring (i.e., blueback herring, *Alosa aestivalis*, and alewife, *Alosa pseudoharengus*), and in some cases American shad (*Alosa sapidissima*) (NJDEP 2005). However, the majority of anadromous river herring spawning occurs in the Hudson River and its tributaries (via the Lower Bay and Upper Bay). Other important anadromous herring spawning rivers include the Bronx River (via the East River) in New York and in New Jersey, the Hackensack and Passaic Rivers (via Arthur Kill/Kill Van Kull and Newark Bay) and the Raritan River and Shrewsbury/Navesink Rivers (via the Lower Bay and Raritan Bay). Other migratory species utilize the Harbor during some part of their annual migration (Waldman 2006); these species include Atlantic sturgeon (*Acipenser oxyrinchus*), shortnose sturgeon (*Acipenser brevirostrum*), striped bass (*Morone saxatilis*), hickory shad (*Alosa mediocris*), American eel (*Anguilla rostrata*), and Atlantic tomcod (*Microgadus tomcod*). Both shortnose sturgeon and the New York Bight Distinct Population Segment (DPS) of Atlantic sturgeon are federally listed as endangered species.

Finfish migrations in the Harbor are primarily composed of alewife, blueback herring, American shad, and striped bass (the primary anadromous species moving through the Harbor to and from less saline spawning/nursery areas). These four species were identified by National Marine Fisheries Service (NMFS) and state agencies (state managed species) as migratory species of particular concern. Atlantic menhaden (*Brevoortia tyrannus*) were also included as target species to characterize migratory movements through the Harbor. While not an anadromous species, Atlantic menhaden is a seasonal migrant (spawning primarily in the ocean during spring and fall, however some spring spawning may extend into coastal waters of bays) and was added as a target species due to its important role as a commercial and forage species (ASMFC 2012). All the target species have commercial and recreational value or are forage species. Striped bass is also a large predator in the Harbor that represents a higher trophic level than the other target species.

Recent evidence suggests that blueback herring and alewife (collectively referred to as river herring) stocks have declined in abundance since the 1970's and there are currently restrictions in place to prevent excessive commercial harvest (ASMFC 2012). According to the most recent river herring stock assessment, populations have experienced a 93% decrease in commercial landings compared to the 1970's. From 1999-2010, numbers of spawning river herring declined in ten out of seventeen rivers studied. Although some independent studies have recently shown increasing trends, overall, biological data suggest that river herring are experiencing a decline in mean length, mean length-at-age, and percent repeat spawners (ASMFC 2012). These characteristics are typical of declining populations undergoing increasing mortality (ASMFC 2012). At the beginning of 2013, both river herring species were candidates for federal listing. Based on the best scientific and commercial data available, NMFS provided their determination on August 12, 2013 that listing alewife and blueback herring as endangered or threatened under the Endangered Species Act was not warranted at this time.

Migratory fish, especially those with high fidelity to spawning sites are potentially vulnerable to habitat disturbance (factors reducing their ability to migrate), predation, and commercial and recreational fishing along migration corridors because their migratory behavior concentrates them in relatively small areas over short periods of time. For example, adult spawning stocks of American shad, blueback herring, alewife and striped bass that use the Hudson River and pass through the Harbor to access upstream spawning areas and out-migrating young-of-the-year/juveniles must pass through the Harbor as they emigrate to the marine environment. Timing and duration of passage within the Harbor are influenced by the individual species' biology, environmental cues including temperature and river discharge, as well as the specific migratory pathway (e.g., spawning migration and adult/juvenile emigration routes through the Harbor). Spawning runs to the Hudson River and its tributaries as well as the Hackensack and Passaic Rivers and the East River are of particular importance because access to these waterbodies requires passage through and/or adjacent to navigation channels and other areas within the Harbor.

For the NY/NJ HDP, seasonal dredging restrictions for finfish have been instituted primarily to protect essential fish habitat, specifically spawning and nursery habitat for winter flounder (USACE-NYD 2010, USACE-NYD 2012). However, regional concerns have become increasingly focused on migratory finfish stocks. Species-specific depth preferences during migration (near surface, mid-water, or near bottom preferences when in channels vs non-channel/shoal habitats), rates of passage, and whether their movements/abundances are concentrated near shore (lateral distribution), in shoals, deep non-channels or channels influences their potential exposure to dredging activities.

Developing an understanding of where migratory pathways occur and the timing of peak seasonal use will improve effective management of dredging activities within the Harbor and enhance protection of migratory finfish and habitat. The initial MFS study was conducted during 2006 and follow-up studies were conducted in 2011, 2012 and 2013. The 2006 MFS included spring and fall sampling using mid-water and bottom trawls within the Harbor. The 2011, 2012 and 2013 MFS consisted of spring, summer and fall sampling using only mid-water trawls within the Harbor. Data from the 2006 MFS indicated that, with the exception of striped bass, the target species were collected in greater abundances using the mid-water trawl and exhibited distinct seasonal patterns in abundance. Therefore, preliminary findings from the 2006 MFS formed a basis for the sampling protocol used in the follow-up MFS programs of 2011 through 2013, in terms of collection methods, timing and spatial coverage of stations.

1.2 STUDY OBJECTIVES

The overall goal of the MFS was to identify spatial and temporal trends in abundance for target and other common mid-water species using the Harbor during 2006 and 2011-2013. Spatial and temporal patterns in abundance and distribution in Harbor regions were examined relative to environmental factors (specifically temperature and freshwater flow/discharge). Specific objectives of the MFS include:

1. Identify the timing and duration of spawning migrations within the Harbor.
2. Identify spatial and temporal patterns of habitat use of common mid-water species (primarily migratory species) within the Harbor regions relative to existing habitats, environmental factors, and consistency across years.
3. Relate spatial and temporal information to recent (2015) conservation recommendations (NMFS 2015) for overwintering striped bass and on spawning migrations of anadromous species.

4. Further investigate and describe spatial and temporal patterns of habitat use and biological information on river herring (presented in Part II).

1.3 REPORT ORGANIZATION

For the purposes of this report, the migratory/mid-water finfish collected were classified into one of three groups: target migratory species (generally state managed), Essential Fish Habitat (EFH) managed species (federally managed), and other important/common migratory finfish species (including important forage species). The intent of this organization was to highlight species that were identified by resource agencies as important and to consider the relative abundance/contribution of each species in/to the Harbor's finfish community. Data analyses and treatment in the Discussion focus upon the target migratory finfish species. Species aggregations which include species that utilize the Harbor both temporally and spatially in a similar fashion are identified. The Results, Discussion, and Summary sections (Sections 3, 4, and 5) are provided in two parts. Part I covers common mid-water/migratory species collected in the Harbor and Part II focuses on river herring (blueback herring and alewife) in the Harbor. River herring serve an important ecological role as a prey resource and recent population declines throughout their historic range (ASMFC 2012) warrants developing a better understanding of where river herring migratory pathways occur and the timing of peak seasonal use (temporal and spatial patterns) within the Harbor.

Part I - Spatial and Temporal Trends in Abundance of Mid-water Species (MFS data). This section summarizes MFS results for all species across all years of sampling. Spatial and temporal patterns in abundance are examined relative to environmental factors (water temperature and freshwater discharge from major rivers). The results provide a synopsis of all four years (2006, 2011, 2012, and 2013) of MFS sampling and includes GIS figures that depict fish assemblage distributions, as well as maps of individual important species that have not been previously depicted in ABS and other USACE-NYD NY/NJ Harbor reports.

Part II – River Herring. This section focuses on identifying and describing spatial and temporal use of habitat by river herring within the Harbor. In addition to the mid-water sampling, data from ABS bottom trawl sampling were factored into this assessment. Large sample sizes of alewife (n = 11,669) and blueback herring (n = 7,072) were collected during the nine years of ABS bottom trawl sampling and these data are also used to define the timing and location of river herring occurrences in the Harbor.

Discussion sections include finfish use of the Harbor in terms of seasonal distribution/movements and habitat use throughout the Harbor. Migratory finfish survey results are discussed within the context of USACE-NYD's ongoing efforts to better understand potential impacts associated with exposure to total suspended solids (TSS) and underwater noise resulting from the HDP on fish behavior and migration within Harbor.

2.0 METHODS

2.1 STUDY AREAS AND SAMPLING LOCATIONS

During the 2011 through 2013 MFS, 20 fixed stations consistent with locations sampled in 2006 were sampled with the mid-water trawl (Figure I-1). Fewer stations were sampled in 2011-2013 than 2006 (26 stations), so that each station could be sampled more frequently (i.e., weekly during the peak spring and fall migration periods). Of these stations, 17 were located in channel areas and 3 were in non-channel areas. This distribution of sampling effort reflects the difficulty of sampling shallow water areas using a mid-water trawl, and a focus on sampling in the navigation channels where dredging occurs.

For spatial analysis, the Harbor was divided into four study areas representing distinct subsections of the Harbor in order to detect different usage by migratory species: the Arthur Kill/Kill Van Kull, Newark Bay, Upper Bay, and Lower Bay. These are interconnected areas of varying hydrodynamic and physical properties (such as differences in substrate and salinity/freshwater discharge). Sampling stations were distributed within each of the four study area as described in the following sub-sections.

2.1.1 Arthur Kill and Kill Van Kull (AK/KVK)

The Arthur Kill/Kill Van Kull study area is confluent with the Upper Bay to the east via the Kill Van Kull (a narrow, tidal strait) and with the Lower Bay and Raritan Bay via the Arthur Kill, also a narrow, tidal strait. This study area has a dynamic hydrology due to the variation in tidal velocity, amount of freshwater flow, and complex bathymetry, including connecting bays (i.e., Upper, Newark, and Raritan Bays). Due to the limited extent of shallow water habitat within this study area, six channel stations were sampled in this area using the mid-water trawl; four (MAK-1 to 4) were in the Arthur Kill and 2 (MKK-1 and 2) were in the Kill Van Kull. These were the same stations sampled during 2006, 2011 to 2013. Deep water channel stations were selected due to water depth and safety issues related to towing a mid-water trawl in a high vessel traffic area. The KVK channel stations were approximately 20 feet deeper than the AK channel stations.

2.1.2 Newark Bay (NB)

The Hackensack and Passaic River basins form the watershed of Newark Bay. The Newark Bay study area consists of broader expanses of open water than the Arthur Kill/Kill Van Kull, though it is not as large a body of water as the Upper or Lower Bay. Newark Bay contains deep water navigation channels, and its shorelines and shallow water habitats have been greatly modified by bulkheads, riprap, and historic fill. Four stations were sampled in Newark Bay using the mid-water trawl; all four (MNB-1, 2, 5, and 6) were in navigation channels. Stations MNB-5 and 6 were established at the mouths of the Passaic and Hackensack Rivers, respectively. Two non-channel stations (MNB-3 & 4) sampled in 2006 were not sampled during these follow-up surveys due to the decreased number of stations included in these programs.

2.1.3 Upper Bay (UB)

The Upper Bay study area is centrally located within NY/NJ Harbor, (a hub) connecting the three other study areas to the Hudson River. The Upper Bay begins at the mouth of the Hudson River and empties into the Lower Bay. It is connected to Newark Bay and the Arthur Kill via the Kill Van Kull to the west, and exchanges water with the East River and Long Island Sound. This study area contains extensive deep, open water channels and relatively few remaining areas of shallow water habitat due to historic shoreline modifications and development of port facilities.

Six stations were sampled in the Upper Bay using the mid-water trawl; five (MUB-1 through 3, 8 and 9) were in channels and one (MUB-11) was a non-channel station. Two non-channel stations (MNB-6 and 7) and three channel stations (MNB-4, 5, and 10) sampled in 2006 were not sampled during these follow-up surveys due to the decreased number of stations included in these programs.

2.1.4 Lower Bay (LB)

The Lower Bay study area contains expanses of both deep and shallow open water. Water quality is influenced by the Atlantic Ocean more so than the other three study areas. Four stations were sampled in the Lower Bay using the mid-water trawl; two (MLB-3 and 5) were channel areas and two (MLB-4 and 6) were non-channel areas. Two non-channel stations (MLB-1 and 2) sampled in 2006 were not sampled in 2011-2013. One channel station (MLB-5) and one non-channel station (MLB-6) were added to the 2011-2013 surveys to sample near shore areas where the Lower Bay constricts through the Narrows and into the Upper Bay.

2.2 ENVIRONMENTAL FACTORS

Dissolved oxygen, temperature, conductivity, and salinity were measured after each trawl using a calibrated YSI Pro2030 multi-parameter handheld meter. Water quality parameters recorded with mid-water trawls were taken at the sample depth, which varied based on station depth and location.

Because water temperature is an important environmental cue for migratory fish activity (e.g., Collette and Klein McPhee 2002, Loesch and Lund 1977), MFS Program temperature data were supplemented with data obtained from a NOAA gauge (station ID 8518750) located at the southern tip of Manhattan Island (the Battery, at 40°42.0′N, 74°0.8′W). This temperature sensor is located at 2.385 m below mean sea level (MSL) and provides a continuous record of water temperature, thus allowing an examination of the duration and magnitude of conditions experienced during critical periods of migratory activity, which is not possible using the bi-weekly water quality data collected during the MFS sampling.

Hudson River discharge data were obtained from records for United States Geological Survey (USGS) station 01358000 at Green Island in Albany County, New York for the years of sampling (2006 and 2011-2013). Flows can be used to help characterize estuarine conditions during spawning runs.

2.3 FINFISH SAMPLING

The U.S. Army Corps of Engineers' M/V (motor vessel) *Hudson* was the primary sampling vessel used for the mid-water trawl surveys. Surveys were scheduled during daylight hours (between one hour after sunrise and one hour before sunset). Mid-water and near bottom trawls were conducted using an 18-foot (5.5 m) balloon trawl, rigged for mid-water trawling. For transects less than 38 feet deep, a minimum cable length of 200 feet of tow cable was deployed to ensure the mid-water trawl extended beyond the *Hudson*'s wheel wash. The float cable length required to fish at mid depths down to 20 feet was determined using a chart of sample depth, float cable lengths, and tow speeds. For mid-water trawling at transects greater than 38 feet deep and for near bottom trawls, the tow cable length was determined from a chart of wire angle (target angle of approximately 80°) and sample depth to provide the amount of wire from the trawl doors to the water surface and to ensure the mid-water trawl was being towed below the *Hudson*'s wheel wash. For mid-water trawls based on wire angle and length to determine sample depth, the wire angle was measured using a mechanical inclinometer at the beginning of each tow. Mid-water trawls were towed into the prevailing current at a speed of approximately 6.6 ft/sec (200 cm/sec). Tow velocities were monitored using a General Oceanics electronic flowmeter and deck readout to ensure consistency of tow speed throughout the sampling program. Tidal current differences between the surface and mid-water, as indicated by wire angles deviating from approximately 80°, required slight adjustments in the *Hudson*'s speed through the surface water to maintain a target angle of approximately 80° (range between 78 and 82°).

Bottom trawls were conducted during the 2006 MFS Program and during the ABS Program from 2002 to 2010 using a 30-foot (9.1 m) otter trawl. A minimum ratio of tow cable length to maximum station water depth of 5:1 was maintained to ensure that the trawl was in contact with the bottom throughout each tow. Target tow duration for both methods was ten minutes, although tow times were adjusted as needed to account for obstructions, limited distances, commercial traffic, and other factors. Bottom trawls were towed at a speed of approximately 4.9 ft/sec (150 cm/sec) over the bottom against the prevailing current.

Mid-water and bottom trawl sampling stations were located using Global Positioning System (GPS) coordinates as well as aids to navigation, soundings, bottom type, and landmarks in the channel and shoal areas. GPS coordinates were recorded to the nearest one hundredth of a minute (e.g., 40° 35.56') at the start and end of each trawl transect. All pertinent sample information was recorded on a Field Data Sheet. Once the net and catch were on-board the survey vessel, dissolved oxygen, temperature, conductivity, and salinity were measured after each trawl using a calibrated YSI Pro2030 multi-parameter handheld meter with other available meters (YSI Model 85 Handheld Oxygen, Conductivity, Salinity and Temperature System) as back-up meters. Temperature was measured to the nearest +/- 0.3 °C; dissolved oxygen (+/- 0.3 mg/L); conductivity (+/- 1 µS [micro Siemens]/cm); and salinity (+/- 0.1 psu [practical salinity units]) and recorded on the Field Data Sheet. Water quality parameters recorded with mid-water trawls were taken at the sample depth. This sample depth varied based on station depth and location. During the ABS, surface, mid, and bottom water quality parameters were measured with each bottom trawl sample. Wet water samples were taken at least once during each survey date to check meter accuracy. Triplicate dissolved oxygen samples and a water sample for conductivity and salinity were collected, preserved, and analyzed under laboratory conditions. Dissolved oxygen samples were analyzed on return from the field using the Winkler Method and the conductivity and salinity samples were analyzed using a calibrated benchtop YSI conductivity meter. The temperature was checked immediately after collection with a calibrated thermometer.

Following each trawl, fish collected were identified, enumerated, measured for total length to the nearest millimeter, and returned to the water. The total lengths of up to 100 specimens of each target species (i.e., Atlantic menhaden, American shad, blueback herring, alewife and striped bass) were recorded. For all non-target species, total lengths of up to 25 specimens of each species were recorded for randomly selected individuals. After analysis, all live organisms were released at the collection site. As needed, one specimen of each new species collected was retained for confirmation of the field identification and quality control purposes.

2.4 DATA ANALYSIS

The temporal migratory patterns of target, EFH, and other common/important mid-water species moving within and through the Harbor were characterized. Seasonal movements included timing and duration of the upstream and downstream migrations of spawning adults and older juveniles and the downstream movement of young-of-the-year and yearlings/juveniles within the Harbor. Temporal occurrence information included multi-year analyses to determine whether the seasonal occurrence patterns of selected species were consistent across years. Potential associations with temperature thresholds and freshwater discharge from major rivers were examined.

Spatial distribution factors included depth and Harbor region usage by adults and juveniles. Harbor areas frequently used by common mid-water species and age groups were identified. The locations of pre-spawning adults were used to identify Harbor regions used during their spawning migrations. The consistency of spatial usage of the Harbor regions was examined across years.

2.4.1 Catch per Unit Effort

CPUE, defined for the purpose of this study as the number of fish collected per ten minutes of trawling, was determined for each mid-water trawl sample and was standardized to ten minutes using the following formula:

$$\text{CPUE} = \left(\frac{N}{T}\right) \times 10$$

Where:

N equals the number of fish collected during the trawl and *T* equals the actual tow time expressed in minutes.

Monthly mean CPUEs were calculated by averaging samples collected within a calendar month. Seasons were defined as spring (March through June), summer (July and August), and fall

(September through December). No mid-water trawl sampling was conducted in January or February, but where appropriate, ABS bottom trawl data were used to supplement the analysis for the winter period. ABS bottom trawl methodology was extensively described in USACE-NYD 2015b and in previous ABS reports.

2.4.2 Statistical Methods

Multivariate analyses were used to examine the degree to which the taxonomic composition of mid-water fish assemblages varied among years. Analysis of Similarities (ANOSIM) was used (PRIMER version 7.0, Clark *et al.*, 2014) to test for interannual differences using ranked similarity matrices based on Bray-Curtis similarity measures of log (x+1) transformed data. Separate analyses were conducted for each season. Similarity percentages (SIMPER) were used to identify fish taxa contributing to any differences that were detected. Multivariate analyses also were used to examine how fish assemblages varied spatially within the Harbor within each season. Arthur Kill and Newark Bay were grouped into a single Harbor subarea (Arthur Kill/Newark Bay) to maintain consistency with the USACE-NYD ABS reports which also provide figures showing finfish assemblages in the Harbor collected by bottom trawl (USACE-NYD 2015b).

Mean monthly CPUEs were plotted for target migratory species (alewife, American shad, Atlantic menhaden, blueback herring, and striped bass), four common EFH managed species (Atlantic herring, bluefish, Atlantic butterfish, and silver hake), and important forage species (bay anchovy, striped anchovy, and Atlantic silverside). Size frequency distributions were plotted by season (or year) for species with sufficient sample sizes.

3.0 RESULTS

3.1 ENVIRONMENTAL FACTORS

Temperature differences among years during the migratory finfish sampling were most pronounced in the winter and spring, with extreme cold temperatures in 2011 and relatively mild winter/spring temperatures in 2012 (Figure I-2). The time at which water temperatures exceeded

10°C, an approximate temperature threshold for river herring spawning migrations (Kahnle and Hattala 2010), occurred as early as late March in 2012 and as late as late April in other years (Figure I-3b). Late summer and fall temperatures were less variable among years (Figure I-3a).

Hudson River discharge was typically high in the spring, followed by lower summer flows (Figure I-4). In 2006 and 2013, however, highest flows occurred later in June. Highest flows occurred in 2011, with both a spring peak discharge and high flows in September. In 2012, flows were low throughout the year (Figure I-4).

Mean salinities in each Harbor area corresponded to previously observed trends of lowest salinities in Arthur Kill/Newark Bay intermediate salinities in Upper Bay, and highest salinities in Lower Bay (Figure I-5a). Temporal variation in salinity was consistent across Harbor areas and corresponded to the temporal variation in river discharge. For instance, salinities were highest in 2012, when freshwater inflows were lowest. Likewise, salinities were generally lower in 2011, when river discharges were the highest. Dissolved oxygen concentrations were above 5 mg/L throughout the estuary year-round and did not vary appreciably among years (Figure I-5b). Seasonal fluctuations reflected a common tendency for DO concentrations to decrease with increasing temperatures, and thus, lowest values were recorded in the summer in all Harbor areas. Anoxic or hypoxic (< 3.0 mg/l) conditions were not indicated for any Harbor area.

3.2 FINFISH

The number of mid-water trawls conducted each year ranged from 311 to 440 (total of 1,617 for the entire program), collecting from 23 to 38 species each year (Table I-1). Of the five target migratory species, blueback herring (n = 43,375) and alewife (n = 6,081) were collected in the highest numbers (Table I-2) and are the subject of Part II of this report. American shad (n = 372) and Atlantic menhaden (n = 1,468) were collected in all four years of the MFS. Striped bass (n = 38) were collected in only three of the four program years and are not reliably collected by mid-water trawl, therefore analyses for this species used bottom trawl data collected during the ABS (2002 – 2010). Twelve EFH species were collected, with Atlantic herring (n = 6,008), Atlantic butterfish (n = 628), bluefish (n = 207), and silver hake (n = 182) collected in the greatest abundances (Table I-2) and are therefore detailed in this report. The remaining eight EFH species (n = 17) were collected in extremely low numbers (from 1 – 5 fish over the four years) and were only present in one or two years of the MFS with 2011 having the most occurrences (five of the eight species). These eight species are demersal species briefly discussed in more detail in this report; however they have been discussed in previous reports including USACE-NYD 2013 and USACE-NYD 2015b.

Important forage fish included bay anchovies, which were the numerically dominant species (n = 192,139) and striped anchovies (n = 1,740). Other relatively common species that were collected in all four years of the MFS included Atlantic moonfish (n = 75), Atlantic silversides (n = 80), lined seahorse (n = 42), and spotted hake (n = 216). Atlantic thread herring (n = 99), gizzard shad (n = 267), weakfish (n = 65), white mullet (n = 59), and white perch (n = 48) were relatively common some years but were not present in all years of the MFS. The following subsections describe spatial variation in mid-water fish assemblages and temporal occurrences and spatial distributions of target migratory, EFH, and important forage species.

3.3 SEASONAL MID-WATER FINFISH ASSEMBLAGES

Fall mid-water fish assemblages differed among years ($R = 0.23$, $p < 0.001$, Figure I-6a) and were similar among Harbor areas ($R = 0.05$, $p > 0.1$). The annual differences were most pronounced between the fall of 2006 and 2011 ($R = 0.61$, $p = 0.001$) due to higher abundances of bay anchovy, blueback herring, alewife and American shad in 2011 (Table I-3). The latter three species are migratory and juveniles enter the estuary from upstream locations in the fall. The differences in abundance between 2006 and 2011 may be due to the timing of sampling coinciding (or not) with migratory runs. Alternatively, environmental conditions for these species may have been more favorable in 2011. Of those environmental factors examined in this study, only river discharge differed appreciably in the fall of the two years, with higher inflows in September of 2011.

Spring mid-water fish assemblages were very similar among Harbor areas ($R = 0.01$, $p > 0.4$) and among years ($R = 0.02$, $p > 0.3$; Figure I-6b). Bay anchovy, blueback herring, Atlantic herring, alewife, spotted hake and Atlantic butterfish accounted for over 99% of fish collected.

Summer mid-water fish assemblages were very similar among Harbor areas ($R = -0.13$, $p > 0.8$) and among years ($R = -0.11$, $p > 0.8$; Figure I-6c). Bay anchovy, Atlantic butterfish, Atlantic menhaden and striped anchovy accounted for over 99% of fish collected in the summer.

Bay anchovy, blueback herring, alewife, and Atlantic herring form mid-water species aggregations throughout the Harbor during spring with some additional species (Atlantic butterfish, Atlantic menhaden) occurring in specific Harbor regions (Figures I-30 – I-33). Bay anchovy dominate (92%) the Lower Bay species assemblages. Atlantic herring commonly co-occur in the Arthur Kill/Kill Van Kull, Newark Bay and Upper Bay and are present in the Lower Bay. Atlantic butterfish commonly co-occur in the Lower Bay and Upper Bay and are present in the Arthur Kill/Kill Van Kull and Newark Bay. Atlantic menhaden are present in the Upper Bay and Newark Bay and uncommon in the Arthur Kill/Kill Van Kull and Lower Bay. During summer, bay anchovy dominate (range from 91 – 99%) all species assemblages, they co-occur with Atlantic butterfish in the Upper Bay and Lower Bay. During the fall, bay anchovy continued to dominate (58% to 81%) collections in all Harbor regions along with blueback herring (15 -35%). Other species included Atlantic menhaden, Atlantic butterfish, alewife, and striped anchovy.

Mid-water trawl data, winter-spring fish assemblages were primarily composed of Atlantic herring, alewife, blueback herring, and bay anchovy with Atlantic menhaden, Atlantic butterfish, American shad, and spotted hake common or present in most Harbor regions (Figures 30 -33). Lined seahorse were collected in low numbers during winter in all four Harbor regions. Bay anchovy became more numerous in late spring to summer as Atlantic herring, alewife, and blueback herring numbers decreased. Bay anchovy dominated the summer aggregations with other species including Atlantic menhaden, Atlantic butterfish, bluefish, and striped anchovy common or present in most Harbor regions. A few alewife, blueback herring, and weakfish were collected in some Harbor regions during summer. Bay anchovy continued to be the dominant species in fall aggregations; other common species included alewife and blueback herring. American shad, Atlantic butterfish, Atlantic menhaden, Atlantic moonfish, bluefish, silver hake, and weakfish were collected in some Harbor regions during the fall.

Overall percent composition of Arthur Kill/Kill Van Kull winter-spring mid-water fish assemblages suggest Atlantic herring, bay anchovy, alewife, and blueback herring co-occurred in the Arthur Kill/Kill Van Kull during winter - spring (Figure I-30). A few bluefish, striped bass, Atlantic butterfish, Atlantic menhaden, American shad, sliver hake, Atlantic tomcod, spotted hake, and lined seahorse were also present. By summer, bay anchovy dominated collections (approximately 99% of the catch) along with Atlantic butterfish, Atlantic menhaden, and striped anchovy were also present, as well as a few blueback herring. Bay anchovy dominated collections into the fall with alewife and blueback herring as these young-of-the-year moved downriver into the Harbor. Atlantic menhaden, silver hake, striped anchovy, gizzard shad, and American shad were also present and a few Atlantic butterfish, Atlantic moonfish, Atlantic silverside, bluefish, and weakfish were collected during the fall.

Overall percent composition of Newark Bay winter-spring mid-water fish assemblages suggest that Atlantic herring, bay anchovy, alewife, and blueback herring co-occurred in the Arthur Kill/Kill Van Kull during winter - spring (Figure I-31). A few Atlantic menhaden, white perch, striped bass, Atlantic butterfish, American shad, silver hake, spotted hake, northern pipefish, and lined seahorse were also present. By summer, bay anchovy dominated collections (approximately 97% of the catch) with Atlantic butterfish, Atlantic menhaden, bluefish, blueback herring and striped anchovy also present in low numbers. Bay anchovy continued to dominate collections into the fall, co-occurring with increasing numbers of blueback herring and alewife as the young-of-the-year of these anadromous species emigrated downriver into the Harbor. Atlantic menhaden were common and Atlantic butterfish, Atlantic moonfish, Atlantic silverside, bluefish, gizzard shad, striped anchovy, and American shad were also present.

Overall percent composition of Upper Bay winter-spring fish assemblages suggest that Atlantic herring, bay anchovy, alewife, and blueback herring co-occurred in Upper Bay during winter-spring (Figure I-32). A few Atlantic menhaden, white mullet, banded killifish, bluefish, Atlantic butterfish, American shad, silver hake, spotted hake, smallmouth flounder, Atlantic tomcod, and lined seahorse were also present. By summer, bay anchovy dominated collections (approximately 90% of the catch), co-occurring with Atlantic butterfish, inland silverside, northern stargazer, bluefish, and blueback herring. A few striped anchovy, alewife, and lined seahorse were also present in low numbers. Bay anchovy continued to dominate collections into the fall, co-occurring with blueback herring and alewife as the young-of-the-year of these anadromous species emigrated downriver into the Harbor as young-of-the-year. Atlantic butterfish, striped anchovy, and American shad were also present with a few Atlantic moonfish, Atlantic menhaden, and weakfish.

Overall percent composition of Lower Bay winter-spring fish assemblages suggest that finfish assemblages in the Lower Bay channels are dominated by bay anchovy, co-occurring with Atlantic herring, Atlantic butterfish, and blueback herring, and to a lesser extent, bluefish, alewife, and lined seahorse (Figure I-33). A few American shad, spotted hake, and Atlantic menhaden were also present in low numbers. By summer, bay anchovy dominated collections (over 99% of the catch), co-occurring with Atlantic butterfish, bluefish, and striped anchovy. Bay anchovy continued to dominate collections into the fall co-occurring with blueback herring as young-of-the-year of this anadromous species emigrated downriver into the Harbor. Striped anchovy, alewife, Atlantic thread herring, American shad, and Atlantic butterfish were also present.

3.4 TARGET, EFH, AND IMPORTANT FORAGE SPECIES

3.4.1 Alewife (*Alosa pseudoharengus*)

The alewife and closely related blueback herring are anadromous species with similar distributions, ecological roles and environmental requirements. Alewife range from the Gulf of Saint Lawrence to South Carolina, with peaks between the Gulf of Maine and the Chesapeake Bay. Alewife enter estuaries on their annual spawning runs during the spring. Within the Hudson River, alewife spawn primarily in the Catskill and Albany regions beginning in April, Yolk-sac and post-yolk-sac larvae are most abundant in the upper estuary, and the larvae eventually disperse downriver. Alewife distributions in the Harbor are summarized in the following paragraphs and are further examined and discussed in Part II of this report. A total of 6,081 alewife were collected during the MFS; yearly totals ranged from a low of 252 in 2013 to a high of 4,276 in 2011, and totaled 1,061in 2006 and 492 in 2012 (Table I-2). Alewife were primarily collected in the Upper Bay, Newark Bay, and the Arthur Kill/Kill Van Kull during 2011; peak

CPUEs (near 30) occurred in the Upper Bay during the spring of 2011 (Figure I-18). Newark Bay collections peaked during the fall of 2011 with a CPUE of approximately 25 followed by the Arthur Kill/Kill Van Kull with a CPUE near 10. The Upper Bay fall of 2011 CPUE was just above 5 and this was below the Upper Bay fall CPUE of about 12 during 2006. Summer CPUEs remained near 0 for all Harbor regions during the four years. Lower Bay collections remained near 0 for all years, except for the fall CPUE about 2.5 in 2012. Alewife generally occurred with blueback herring, Atlantic herring, and bay anchovy during the spring and with blueback herring and bay anchovy during the fall in all four Harbor regions (Figures I-30 – I-33). Alewife were also well-represented in bottom trawl collections (see also Part II).

3.4.2 American shad (*Alosa sapidissima*)

American shad is an anadromous species occurring along the Atlantic coast from the St. Lawrence River in Canada, to the St. Johns River in Florida, with high concentrations in the area from Connecticut to North Carolina. Spawning occurs in the tidal freshwater portion of the Hudson River from March to June (Limburg 1996). Larvae and juveniles move downstream in response to currents and changes in water temperature but remain in brackish waters until the fall. Young-of-the-year shad emigration occurs as a gradual seaward movement over several months, and is dependent on age and size, typically starting at a length of approximately 75-100 mm. American shad were collected during the MFS in the spring from March through May and from August through December, with peak collections in November (Figure I-7). The majority of American shad (371 of the 372 collected) were juveniles. The size distributions of juvenile shad collected in the spring were similar among all years, whereas, young-of-the-year fish collected in the fall of 2011 were smaller and more numerous than young-of-the-year fish collected in the fall of other years (Figure I-8). Shad collected in the Harbor in the fall were primarily 100 – 180 millimeter (mm) total length (TL) (Figure I-8), reflecting continued growth as the out-migration occurs. In 2011, young-of-the-year shad occurred in the Harbor in September, with abundances increasing through November in greater numbers in comparison to other years (Figure I-9). The earlier arrival of shad in the fall of 2011 may be related to high September Hudson River discharge (Figure I-4) and correspondingly low salinities (Figure I-5a).

One adult American shad (> 380 mm TL) was collected during the MFS by mid-water trawl sampling in October of 2006 at the non-channel station MLB-2 in Lower Bay. A single adult (540 mm TL) was collected using a bottom trawl during ABS sampling at a non-channel station in Arthur Kill (AK-1) in June 2008.

A total of 372 American shad (371 juveniles) were collected during the MFS; yearly totals ranged from a low of 18 in 2013 to a high of 259 in 2011, and totaled 40 in 2006 and 55 in 2012 (Table I-2). Juvenile American shad were primarily collected in the Upper Bay, followed by Newark Bay and the Arthur Kill/Kill Van Kull during the fall of 2011 (Figure I-19). Peak CPUEs (near 2.2) occurred in the Upper Bay during the fall of 2011with high CPUEs of just over 0.5 in the Arthur Kill/Kill Van Kull and about 0.5 in the Lower Bay and Newark Bay. Overall, juvenile American shad were present in all four Harbor regions during spring and fall, and few were collected during summer. Summer CPUEs remained near 0 for all regions during the four years. American shad generally occurred with blueback herring, alewife, Atlantic herring, and bay anchovy during the spring and with blueback herring, alewife, and bay anchovy during the fall in all four Harbor regions (Figures I-30 – I-33).

3.4.3 Atlantic butterfish (*Peprilus triacanthus*)

Atlantic butterfish range from Florida to Newfoundland, but are primarily found from Cape Hatteras to the Gulf of Maine. They are a pelagic species, occurring in the estuaries and near coastal waters during the fall, Larvae, juveniles and adults occur in both shallow and deep waters (Cross *et al.* 1999). Butterfish occur in the Hudson River Estuary during late spring through fall. Spawning occurs from June through August. Atlantic butterfish were collected during the MFS in mid-water trawls in all years from the spring through the fall (Figure I-7). In the spring, size distributions were bimodal (Figure I-10), reflecting the occurrence of both young-of-the-year (<85 mm TL) and adults (> 120 mm TL). Juveniles were relatively abundant in the spring and summer of 2006 and in the fall of 2013 (Figure I-10). Adult butterfish were collected during all three seasons (Figure I-10). Butterfish were collected in all Harbor areas (Figure I-20). Because butterfish are euryhaline (5-32 psu) and eurythermal (4 – 22 ^{o}C), many Harbor areas provide suitable habitat.

A total of 628 Atlantic butterfish were collected during the MFS, yearly totals ranged from a low of 82 in 2013 to a high of 322 in 2006, and totaled 135 in 2011 and 89 in 2012 (Table I-2). Atlantic butterfish were primarily collected during the summer in all four Harbor regions (Figure I-19). Peak CPUEs (near 9) occurred in the Arthur Kill/Kill Van Kull during the summer of 2006 followed by CPUEs of about 3.5, 2, and 1.5 in Newark Bay, Upper Bay, and Lower Bay, respectively. Spring 2006 CPUEs reached just above 1.5 and just over 1 in the Lower Bay and Upper Bay, respectively. CPUEs of about 3.5 occurred in the Lower Bay during the summer of 2012. Fall CPUEs remained near 0 for all regions during the four years and spring CPUEs remained near 0 in the Arthur Kill/Kill Van Kull and Newark Bay and fluctuated between 0 and 1.5 in the Lower Bay and Upper Bay. Atlantic butterfish generally occurred with Atlantic menhaden, striped anchovy, bluefish, and bay anchovy during the summer in all four Harbor regions (Figures I-30 – I-33).

3.4.4 Atlantic cod (*Gadus morhua*)

The Atlantic cod is widely distributed in the northwest Atlantic Ocean from Greenland to Cape Hatteras, North Carolina. Overall, densities are highest off Newfoundland, in the Gulf of St. Lawrence and on the Scotian Shelf (Lough 2004). In U.S. waters, densities are highest on Georges Bank and the western Gulf of Maine. Off New England, Atlantic cod typically move into coastal waters during the fall and then retreat into deeper waters during spring. Spawning occurs near bottom and year-round, with a peak in winter and spring. Principal spawning areas include the Northeast Peak of Georges Bank, the perimeter of the Gulf of Maine, and over the inner half of the continental shelf off southern New England (Hutchings *et al.* 1993). Atlantic cod spawning is related to environmental conditions. It is delayed until spring when winters are severe and peaks in winter when they are mild (Colton 1978).

Atlantic cod were collected in three samples during the MFS. In 2006, cod were collected in two bottom trawl samples conducted in August in Upper Bay and averaged 116 ± 3 mm TL. The only other sample containing Atlantic cod was a mid-water trawl conducted in April 2013 in Upper Bay in which two fish (26 and 32 mm TL) were collected. This difference in body size between fish collected by mid-water vs. bottom trawls is consistent with their transition from a pelagic juvenile stage to a demersal stage as older juveniles and adults.

3.4.5 Atlantic herring (*Clupea harengus*)

Atlantic herring juveniles and adults of the George's Bank stock use the New York Bight as a wintering area between December and April, and this is when they are likely to occur in Upper New York Bay (Kornfield *et al.* 1982). Atlantic sea herring are primarily pelagic but may also be found in shallow, nearshore areas. Atlantic herring were collected during the MFS in the early spring (March and April; Figure I-7) and were primarily between 50 and 70 mm TL (Figure I-11), which corresponds to juveniles soon after metamorphosis. Juvenile herring, which feed on zooplankton, were concentrated in the Arthur Kill/Kill Van Kull, Newark Bay and Upper Bay, whereas the few adults collected occurred almost exclusively in Upper Bay (Figure I-21).

A total of 6,008 Atlantic herring were collected during the MFS; yearly totals ranged from a low of 116 in 2011 to a high of 3,853 in 2012, and totaled 618 in 2006 and 1,421 in 2013 (Table I-2). Atlantic herring were most common during the spring of 2012 in the Newark Bay and the Arthur Kill/Kill Van Kull with CPUEs of around 26 and 48, respectively. Atlantic herring juveniles were primarily collected in the Arthur Kill/Kill Van Kull and Newark Bay during 2012; peak CPUEs (near 50) occurred in the Arthur Kill/Kill Van Kull during the spring of 2012 with high collections of about 26 in Newark Bay and low CPUE of about 6 in the Upper Bay (Figure I-21). Upper Bay, Newark Bay, and Arthur Kill/Kill Van Kull CPUEs were similar during the spring of 2013 at approximately 10. In 2006, Newark Bay and Arthur Kill/Kill Van Kull CPUEs were similar during the spring of 2006 at approximately 10, followed by the Upper Bay with a low CPUE of about 4. Atlantic herring were generally absent from collections during the summer and fall in all Harbor Regions with CPUEs at or near 0. Juvenile Atlantic herring generally occurred with alewife, blueback herring, and bay anchovy during the spring in Upper Bay, Newark Bay, and Arthur Kill/Kill Van Kull aggregations, a few Atlantic herring occurred with these species in the Lower Bay (Figures I-30 – I-33). Throughout the MFS, Atlantic herring did not occur in summer or fall samples from any of the four Harbor regions.

3.4.6 Atlantic menhaden (*Brevoortia tyrannus*)

The Atlantic menhaden is a seasonally abundant clupeid, occurring in large schools in coastal bays and estuaries. Atlantic menhaden migrate seasonally along the Atlantic coast from Maine to central Florida, moving north through the Mid-Atlantic Bight during spring and south during fall to overwinter in waters south of Cape Hatteras (Able and Fahay 1998). Atlantic menhaden spawn in continental shelf waters along the U.S. Atlantic coast, although some spawning activity is reported to occur in the lower reaches of estuaries and coastal bays (Dovel 1971). Larval migration into estuaries occurs during October to June and large schools of juvenile Atlantic menhaden use estuaries as nurseries during the summer before migrating offshore in the fall. Atlantic menhaden were most abundant during the MFS in the late summer and fall (Figure I-7). In the spring, a strong juvenile cohort was collected in 2012 (Figure I-12) and a strong juvenile cohort occurred in the summer of 2006 (Figure I-12). Larger juveniles were collected in the fall of 2006 and 2012, reflecting growth of these two cohorts. Adult menhaden were collected in all years and seasons.

A total of 1,468 Atlantic menhaden were collected during the MFS; yearly totals ranged from a low of 16 in 2013 to a high of 1,153 in 2006, and totaled 29 in 2011 and 270 in 2012 (Table I-2). Atlantic menhaden were primarily collected from the Arthur Kill/Kill Van Kull and Newark Bay regions during the summer and fall of 2006 (Figure I-22). Peak CPUEs (near 20) occurred in Newark Bay during the fall of 2006 followed by CPUEs of just over 5 in the Arthur Kill/Kill Van Kull. High CPUEs (just above 10) occurred in the Arthur Kill/Kill Van Kull during the summer of 2006 followed by CPUEs of just under 5 in Newark Bay. CPUEs remained near 0 during the spring in all Harbor regions and in the Lower Bay and Upper Bay during all seasons and years. CPUEs also remained near 0 for the summer and fall seasons in the Arthur Kill/Kill Van Kull and Newark Bay for 2011, 2012, and 2013.

Atlantic menhaden sporadically occurred with Atlantic butterfish, striped anchovy, bluefish, and bay anchovy during the summer and during the spring and fall (along with blueback herring and alewife) primarily in the Arthur Kill/Kill Van Kull and Newark Bay (Figures I-30 – I-33).

3.4.7 Black sea bass (*Centropristis striata*)

Black sea bass are a demersal species that is associated with structures, such as rocky outcroppings and reefs, ranging from Cape Canaveral, Florida, to Cape Cod, Massachusetts. In the vicinity of the Harbor Estuary, juvenile and adult black sea bass move inshore from July through September (Steimle *et al.* 1999). Adults migrate south and offshore (to the Chesapeake bight) during fall/winter. Spawning occurs on the continental shelf from April through October

Peak spawning in the New York Bight occurs in August. Seabass abundances during the MFS were highest in 2006 bottom trawl sampling, in which 42 fish were collected from all Harbor areas from August to November and represented both juveniles (< 190 mm TL) and adults. Mid-water sampling yielded two black sea bass, a juvenile in October 2011 and an adult in November 2013.

3.4.8 Blueback herring (*Alosa aestivalis*)

Blueback herring (and closely related alewife) are anadromous species with similar distributions, ecological roles and environmental requirements. Blueback herring inhabit coastal and estuarine waters from Nova Scotia to Florida, with concentrations in the Middle and South Atlantic Bight. Blueback herring enter estuaries on their annual spawning runs during the spring. Within the Hudson River, blueback herring spawn primarily in the Catskill and Albany regions beginning in April. Yolk-sac and post-yolk-sac larvae are most abundant in the upper estuary, and the larvae eventually disperse downriver.

Blueback herring distributions in the Harbor are summarized in the following and further examined and discussed in Part II of this report. A total of 43,375 blueback herring were collected during the MFS; yearly totals ranged from a low of 1,213 in 2006 to a high of 31,576 in 2012, and totaled 6,578 in 2011 and 4,008 in 2013 (Table I-2). Blueback herring were primarily collected in the Upper Bay and Lower Bay during the fall of 2012, with CPUEs of 225 and 180 in the Upper Bay and Lower Bay, respectively (Figure I-23), Arthur Kill/Kill Van Kull CPUEs reached a high of about 80 during the fall of 2012 while Newark Bay CPUE was just below 50 during the fall of 2012, and both spring and fall CPUEs were near 40 during 2013. Spring collections were low for all regions except Newark Bay during 2013 when the CPUE was just under 50. Summer CPUEs remained near 0 for all regions during the four years. Blueback herring generally occur with alewife, Atlantic herring, and bay anchovy during the spring and with alewife and bay anchovy during the fall in all four Harbor regions (Figures I-30 – I-33). Blueback herring were also well represented in bottom trawl collections (see also Part II).

3.4.9 Bluefish (*Pomatomus saltatrix*)

Bluefish are a pelagic, marine species, using estuaries as nursery areas. Along the eastern Atlantic coast, they range from Nova Scotia to Argentina (Collette and Klein-MacPhee 2002). Juveniles typically inhabit estuaries from May to October. Adults form large schools and are highly migratory, with a seasonal occurrence in the Harbor Estuary and lower Hudson River from April to October. Spawning in the Mid-Atlantic takes place during summer from May through September over the continental shelf. Adults migrate to the Mid-Atlantic Bight during the spring and move south and/or offshore during the fall (Pottern *et al.* 1989).

Bluefish were collected in the Harbor during the MFS from May to October (Figure I-7) and were collected in all Harbor areas. Larger bluefish (>100 mm TL) were collected in the spring in 2011 (Figure I-13) and may have either overwintered in the estuary during a particularly cold winter or reentered the estuary early in the spring. Spring-spawned juveniles (< 60 mm TL) were especially abundant during the later months of the spring 2013 sampling season (Figure I-13), whereas juvenile recruits from the summer-spawned cohort were evident in 2006 and 2013 (Figure I-13). Growth of bluefish within the estuary is evident by fall, with many juveniles reaching sizes over 100 mm TL. Most young-of-the-year bluefish have emigrated from estuaries in the mid-Atlantic Bight at sizes less than 240 mm TL by the fall (Able and Fahay, 1998, Able *et al.* 2003).

A total of 207 bluefish were collected during the MFS; yearly totals ranged from a low of 20 in 2012 to a high of 86 in 2013, and totaled 29 in 2006 and 72 in 2011 (Table I-2). Bluefish were primarily collected during the summer from Newark Bay in 2006, 2011, and 2013; from the Arthur Kill/Kill Van Kull in 2011 and 2013; from the Lower Bay in 2012 and 2013; and from the Upper Bay in 2013 (Figure I-24). Peak CPUEs (near 1) occurred in Newark Bay during the summer of 2013 and in the Lower Bay during the summer of 2012. Peak spring CPUEs of just under 0.6 occurred in the Arthur Kill/Kill Van Kull during 2013 and peak fall CPUEs of about 0.7 occurred in Newark Bay during 2011. CPUEs remained between 0 and 0.2 during the spring in all Harbor regions (except as noted above) and between 0 and 0.1 during the fall in all Harbor regions except Newark Bay, as noted above.

Bluefish sporadically occurred with Atlantic butterfish, Atlantic menhaden, striped anchovy and bay anchovy primarily during the summer in the Arthur Kill/Kill Van Kull and Newark Bay (Figures I-30 – I-33).

3.4.10 Pollock (*Pollachius virens*)

Pollock are a boreal species occurring on both sides of the North Atlantic. Along the northwestern Atlantic coast, they range from Cape Hatteras, North Carolina to western Greenland, however they are generally uncommon south of New Jersey (Able and Fahay 2010). In the Gulf of Maine spawning (typically involving very large aggregations of fish) occurs from November to February, peaking in December (Collette and Klein- MacPhee 2002). On the Scotian Shelf, spawning occurs from September to April and peaks from December to February (Clay *et al.* 1989). Limited spawning activity has been documented in the mid-Atlantic Bight. Young of the year pollock may be present during winter in oceanic waters of the mid-Atlantic Bight, and in both inshore and offshore waters during early summer (Able and Fahay 2010).

One juvenile pollock (< 70 mm) was collected in a mid-water trawl during May 2011 in Newark Bay.

3.4.11 Red hake (*Urophycis chuss*)

Red hake are seasonally abundant in the Hudson-Raritan Estuary from November to May. They undertake seasonal migrations in response to changing water temperatures, inhabiting shallow water in the spring and summer and moving to deeper, offshore waters to over-winter. Eggs and larvae are pelagic and typically occur in deeper waters of the inner continental shelf (Able and Fahay 1998). Red hake (n=2) were collected in mid-water trawls only during May 2011 in the Upper Bay region; these fish were 118 and 168 mm TL, which roughly corresponds to one-year-old fish (Able and Fahay, 1998).

3.4.12 Scup (*Stenotomus chrysops*)

Scup are found in marine waters from Nova Scotia to Cape Hatteras, North Carolina, occuring inshore in spring and summer and moving offshore during the fall (Collette and Klein-MacPhee 2002). Spawning occurs close to shore, during daylight hours, from May to August, with peaks in May and June. One scup (140 mm TL) was collected in a mid-water trawl during May 2011 in the Upper Bay region, which roughly corresponds to a one-year-old fish (Able and Fahay, 1998).

3.4.13 Silver hake (*Merluccius bilinearis*)

Silver hake are distributed on the continental shelf of the northwest Atlantic Ocean from Cape Hatteras, North Carolina to the Gulf of St. Lawrence and the southern edge of the Grand Banks, Newfoundland, Canada; they are especially abundant along the Scotian Shelf, the Gulf of Maine, Georges Bank, and the Mid-Atlantic Bight off Long Island, New York (Almeida 1987). Juveniles and adults migrate to deeper waters of the continental shelf as water temperatures decline in the autumn and return to shallow waters in spring to spawn, beginning as early as January in the Mid-Atlantic Bight and continuing north to Georges Bank by May. During spring and summer, silver hake move inshore and northward in the Middle Atlantic Bight (Collette and Klein-MacPhee 2002).

Silver hake were collected during the MFS in May and during the fall (October – December; Figure I-7). Juvenile silver hake were collected in 2011 (n = 180) and 2012 (n = 2). Fish collected in 2011 ranged from 50 to 150 mm TL (Figure I-14). The two silver hake juveniles collected in the fall of 2012 were within the size distribution of the 2011 cohort (94 mm and 107 mm TL).

A total of 182 silver hake were collected during the MFS; yearly totals ranged from lows of 0 in 2006 and 2013 to a high of 180 in 2011, and totaled 2 in 2012 (Table I-2). Silver hake were primarily collected during the fall from the Arthur Kill/Kill Van Kull in 2011 (peak CPUE of about 2.2) with a few also collected from Newark Bay and the Upper Bay, and a few were also collected during the spring of 2011 (Figure I-25). Except as noted, spring and fall CPUEs remained at or near zero. Summer collections remained at or near 0 in all Harbor regions and years and Lower Bay CPUEs remained at or near 0 for all seasons and years of the MFS.

Silver hake sporadically occurred in 2011 with Atlantic menhaden, striped anchovy, alewife, blueback herring, and bay anchovy during the fall in the Arthur Kill/Kill Van Kull and in the spring with blueback herring, alewife, Atlantic herring, Atlantic menhaden, and bay anchovy in the Arthur Kill/Kill Van Kull and Newark Bay, with some occurrences in the Upper Bay (Figures I-30 – I-33).

3.4.14 Spanish mackerel (*Scomberomorus spp.*)

Spanish mackerel occur from the Florida Keys to New York, wintering in the warmer waters off Florida and moving northward to North Carolina in early April and to New York waters in June (Desfosse *et al.* 1999). Two juvenile Spanish mackerel were collected during the MFS in August 2006 at station MAK-3. These fish were 38 and 91 mm TL.

3.4.15 Striped bass (*Morone saxatilis*)

Striped bass is an important, commercially and recreationally-harvested, anadromous species that declined along the U.S. Atlantic coast in the 1980s due to overfishing, decreased juvenile production (primarily among the Chesapeake Bay and Roanoke River-Albemarle Sounds stocks) and stress from degraded environmental conditions (Boreman and Austin 1985, Richards and Deuel 1987). Striped bass is a long-lived species with life spans that approach 30-years. Adults occur in estuarine and nearshore environments, moving seasonally north and south along the coast and migrating up rivers to spawn in the spring. Post-larvae drift downriver and juveniles remain in estuaries for two to four years (Fay *et al.* 1983). The Hudson-Raritan Estuary is recognized as an important spawning and nursery habitat for striped bass, contributing up to 10% of the entire western Atlantic coastal stock (McLaren *et al.* 1981; Waldman 1990). In contrast to the Chesapeake and Roanoke stocks, the Hudson River stock maintained high levels of juvenile production throughout the 1970s and 1980s; however the commercial fishery for this species in the Hudson was closed in 1976 due to high levels of PCB contamination throughout the Hudson River and estuary (Richards and Deuel 1987).

Striped bass were collected during the MFS in mid-water trawls in relatively low abundances compared to bottom trawls (USACE-NYD 2015b, Part C), therefore winter and spring striped bass abundances in the Harbor are characterized using ABS data. Overall, striped bass abundances declined from January through June (Figure I-15a), with considerable inter-annual variation in the timing of peak abundances based upon the ABS bottom trawl data (Figure I-15b, I-15c). Especially high abundances occurred in March of 2004; most of these were yearlings (< 130 mm TL).

Juvenile striped bass were abundant in Arthur Kill channels in the winter (Figure I-16a) and larger individuals were more common in non-channel habitat in the spring (Figure I-16b). In Newark Bay, larger fish were more commonly collected at channel stations in the winter (Figure I-16c) and non-channel stations in the spring (Figure 16d). Juvenile striped bass size distributions and abundances were very similar between channel and non-channel stations in Upper Bay in the winter (Figure I-16e). Overall abundances were lower in the spring and small juveniles were more common at Upper Bay non-channel stations (Figure I-16f). Few striped bass were collected in Lower Bay in either the winter or spring (Figure I-16 g and h). Adult striped bass were collected in Lower Bay channels in the winter and were more common at non-channel stations in the spring.

Of the 4,876 striped bass measured during ten years of ABS sampling, only 35 individuals were adults (> 500 mm TL). Adult striped bass were collected in every Harbor area (Figure I-16) and collections occurred at bottom water temperatures ranging from 2.7 to 6.8^{o}C during the winter and between 7.1 and 19.9 ^{o}C during the spring. Because adults overwinter in the Harbor channels and adult abundances were relatively low during the spring, it is not clear when spawning migrations occurred each year. Adults were collected in non-channel areas of Newark Bay and Upper Bay in April and May when water temperatures ranged from 10.5 to 17.9 ^{o}C.

During the MFS, striped bass peak mid-water trawl CPUEs of 0.4, 0.1, and <0.1 occurred in the spring of 2011 in the Arthur Kill/Kill Van Kull, Newark Bay and Upper Bay regions, respectively (Figure I-26a). CPUEs were at or near 0 in all other years and Harbor areas. Peak winter CPUEs for bottom trawls of 42 and 36 occurred in the Arthur Kill and Newark Bay regions, respectively (Figure I-26b). Striped bass abundances were highest during ABS sampling in the Harbor in January, declining throughout the spring to few fish present in June (Figure I-15). Winter striped bass abundances were concentrated in channel stations of the Arthur Kill and Newark Bay and secondarily in Upper Bay (Figure I-26b). In the spring, abundances were lower and more localized at both channel and non-channel stations in Arthur Kill/Newark Bay and Upper Bay. Although they are one of the more common coastal migratory species along the northeast and mid-Atlantic shorelines, very few striped bass were collected in the Lower Bay region.

3.4.16 Windowpane (*Scopthalmus aquosus*)

Windowpane flounder are widely distributed along the U.S. eastern seaboard, from the Gulf of Saint Lawrence to Florida. They occur at all depths in the Harbor Estuary; but juveniles and adults are seasonally most abundant in deeper channels. Spawning begins in late winter or early spring and peaks in May. Eggs and larvae are pelagic and occur in the polyhaline portion of the estuary, primarily in spring (Able and Fahay 1998). Five juvenile windowpane (46 – 76 mm TL) were collected by mid-water trawl during the MFS in the spring of 2011. These collections occurred during four sampling periods in all Harbor areas (stations MLB-4, MUB-9, MNB-5, MKK-2, and MAK-3). This flatfish species is more commonly collected by bottom trawl, therefore it is not known whether these collections represent off-bottom movements of the individual fish or if the fish were collected during a portion of the trawl collection that was near the bottom.

3.4.17 Winter flounder (*Pseudopleuronectes americanus*)

Winter flounder range along the Atlantic coast of North America from Labrador, south to North Carolina and Georgia. Adults spawn in late winter through spring and all life stages (egg, larval, juvenile and adult) inhabit shoals and subtidal areas (< 6 meters) over sand, mud and gravel substrate in the Harbor. An adult winter flounder (229 mm TL) was collected during the MFS by mid-water trawl at non-channel station MLB-2 in October 2006 and another adult (278 mm TL) was collected in October 2012 at non-channel station MUB-11. On both occasions, water temperatures at the time and location of sampling were 17^{o}C. Collections of adult winter flounder in pelagic habitat are consistent with recent research conducted by the University of New Hampshire, in which off-bottom movements of tagged pre-spawning winter flounder were observed (E. Fairchild, pers. comm. 2014). Because these observations, which were made exclusively at night, occurred during the spawning season, when flounder do not feed, it is unlikely the off-bottom movements were associated with foraging activity. Alternatively, movement into pelagic habitat may reflect selective tidal transport (E. Fairchild, pers. Comm. 2014).

3.5 IMPORTANT FORAGE SPECIES

3.5.1 Atlantic silverside (*Menidia menidia*)

Atlantic silversides are small schooling fish that frequent tidal marshes, seagrass beds and shallow shore areas, ranging from Nova Scotia to central Florida, along the U.S eastern seaboard. They occur in dense schools and represent an important prey resource for larger predatory fishes, including striped bass, bluefish, and weakfish (Conover and Murawski 1982). During winter months, Atlantic silverside migrate out of estuaries and occupy deeper coastal waters (Conover and Ross 1982). Eggs are deposited in the intertidal zone above the mean low water mark on stems or roots of salt marsh cordgrass (*Spartina alterniflora*) or on mats of detritus (Conover and Kynard 1984). Atlantic silversides were collected during the MFS in April and in increasing abundances from September to December (Figure I-7). Silversides ranged from 55 to 118 mm TL.

A total of 80 Atlantic silversides were collected during the MFS, yearly totals ranged from a low of 6 in 2011 to a high of 50 in 2013, and totaled 9 in 206 and 15 in 2012 (Table I-2). Atlantic silverside were primarily collected during the fall (Figure I-27). Peak CPUEs (just over 0.5) occurred in Newark Bay and at about 0.4 in the Arthur Kill/Kill Van Kull during the fall of 2013. Spring and fall CPUEs remained between 0 and 0.1. Atlantic silversides sporadically occurred with blueback herring, alewife, Atlantic butterfish, Atlantic menhaden, striped anchovy, bluefish, and bay anchovy during the fall (Figures I-30 – I-33).

3.5.2 Bay anchovy (*Anchoa mitchilli*)

The bay anchovy is one of the most abundant species in Atlantic coast estuaries and is an important prey resource for larger, predatory fishes, including striped bass, bluefish, and weakfish. Adults are abundant in a variety of coastal habitats, including near-shore waters off sandy beaches, submerged aquatic vegetation beds, and shallow to deep offshore waters (Morton 1989). During spring, individuals that have wintered in the deep channels of the Harbor Estuary move shoreward or upstream into shoal areas. In the northern range of the bay anchovy, spawning occurs from May to September in waters less than 20 meters in depth (Zastrow *et al.* 1991). Bay anchovies were collected in all months of the MFS and were highly abundant in the summer, with peak abundances in August (Figure I-7). Bay anchovies ranged in size from 13 to 105 mm TL (Figure I-17a). One-year-old fish (< 65 mm TL) were abundant in the Harbor, unlike the age structure of populations surveyed in the Hudson River, in which fish were larger (Bassista and Hartman 2005).

A total of 192,139 bay anchovy were collected during the MFS, yearly totals ranged from a low of 24,791 in 2006 to a high of 82,785 in 2012, and totaled 57,183 in 2011 and 27,380 in 2013 (Table I-2). Bay anchovy were primarily collected during the summer in the Lower Bay and Arthur Kill/Kill Van Kull, followed by Newark Bay, and relatively few were collected in the Upper Bay where CPUEs were near 0 for all years (Figure I-28). Peak CPUEs were over 2000 in the Lower Bay during 2012; over 1500 in the Arthur Kill/Kill Van Kull during 2006, about 1200 in the Arthur Kill/Kill Van Kull in 2012; and about 700 in the Lower Bay during 2013. Except for the peaks noted, summer CPUEs generally ranged from near 0 to less than 300 throughout the Harbor. Spring CPUEs were generally less than 20 in all years and Harbor regions except in the Lower Bay in 2011when the CPUE was approximately 150. Fall CPUEs ranged from near 0 to less than 400 in the Harbor.

Bay anchovy generally occurred with Atlantic menhaden, Atlantic butterfish, striped anchovy, bluefish, and bay anchovy during the summer in all four Harbor regions (Figures I-30 – I-33). During the fall they occurred with alewife, blueback herring, and striped anchovy in all four Harbor regions.

3.5.3 Striped anchovy (*Anchoa hepsetus*)

The striped anchovy closely resembles the bay anchovy, but is larger, often exceeding 10 cm in length. This species has a more southerly range than the bay anchovy, commonly occurring from Chesapeake Bay south along the Atlantic seaboard to the West Indies and Uruguay. Strays are occasionally encountered as far north as Maine and Nova Scotia (Collette and Klein-MacPhee 2002). Striped anchovy are oceanic spawners; most spawning activity in mid-Atlantic and southeastern Atlantic water takes place from April through September. Both juveniles and adults frequent polyhaline bays, estuaries and tidal creeks. Out-migrating adults concentrate in shallow waters of the inner continental shelf during fall and are virtually absent from inshore/shelf waters during winter (Able and Fahay 2010).

Striped anchovies were collected during the MFS only in August, September, and October, with peak abundances in September (Figure I-7). Striped anchovies were smaller in 2012 than in other years (Figure I-17b).

A total of 1,740 Striped anchovy were collected during the MFS, yearly totals ranged from a low of 33 in 2006 to a high of 1,493 in 2012, and totaled 125 in 2011 and 89 in 2013 (Table 2). Striped anchovy were primarily collected during the summer and fall of 2012 from the Lower Bay and during the summer from the Arthur Kill/Kill Van Kull and Newark Bay; they were also present but not common in the Arthur Kill/Kill Van Kull and in Newark Bay during the summer of 2011 (Figure 29). CPUEs remained at or near 0 during the spring of all survey years in all Harbor Regions and during 2006 and 2013 for all seasons and Harbor regions. Upper Bay CPUEs remained at or near 0 for all seasons and years of the MFS.

Striped anchovy sporadically occurred with Atlantic butterfish, Atlantic menhaden, bluefish, and bay anchovy during the summer primarily in the Arthur Kill/Kill Van Kull and Newark Bay Harbor regions (Figures I-3 - I-33). During the fall they occurred sporadically with alewife, blueback herring, and bay anchovy, primarily in the Lower Bay as well as in the other Harbor regions.

4.0 DISCUSSION

4.1 SPATIAL AND TEMPORAL PATTERNS AND POTENTIAL MOVEMENT CORRIDORS

The MFS provides area/region-specific life history information for key migratory species that occur in the Harbor. The program’s five target species (alewife, American shad, Atlantic menhaden, blueback herring, and striped bass) use the Harbor in a variety of ways, including as a pre-spawning staging area, as a corridor to access spawning habitat in the Hudson River or other tributaries, and as foraging grounds, nursery habitat, and overwintering habitat for juveniles. Information gained from this study can be used to better assess potential interactions between dredging operations and migratory species as they move through the Harbor complex. The spatial and temporal information from the MFS should be used to review and recommend modifications to current conservation recommendations for migratory finfish (NMFS 2015) in conjunction with any other data available. Since aggregations of multiple species can be predicted both temporally and spatially with some degree of confidence based upon the current data, measures that protect one species may often protect others as well.

Twelve EFH species were collected in the MFS; however only three (Atlantic butterfish, Atlantic herring and bluefish) were collected in all four years of the MFS. The remaining nine species were represented in one or two years of the MFS, with six of these nine species present in 2011 compared to only two in 2006 and 2012 and three in 2013. Of these, eight are demersal species and would not be well represented in mid-water trawls and have previously been discussed in USACE-NYD 2013 and USACE-NYD 2015b, the other (Spanish mackerel) is a pelagic/mid-water species and is not generally present in the Harbor. These species are not included in the discussion section of this report.

Forty additional species were collected throughout the MFS; however only eight (Atlantic moonfish, Atlantic silverside, bay anchovy, lined seahorse, northern pipefish, spotted hake, striped anchovy, and striped searobin) were collected in all four years of the MFS. Relatively common species collected each year of the MFS included bay anchovy, striped anchovy, spotted hake, Atlantic silverside, Atlantic moonfish and lined seahorse. Other relatively common species that were not present all four years of the MFS included Atlantic thread herring, gizzard shad, weakfish, white mullet, and white perch.

The migratory finfish community of the Harbor is dynamic, differing in species composition among Harbor regions and seasons. Since species collections are composed primarily of juveniles (young-of-the-year and yearlings), the prior year or years production influences the abundance, and also in part the distribution, of various migratory species. Many fish species that are abundant in the Harbor are not federally managed (EFH) or listed as a state-managed species by the Atlantic States Marine Fisheries Commission, but they are ecologically important, serving as important predators and/or prey for other fish species. Many have strong ecological dependence on freshwater habitats (obligate estuarine-dependent species) such as alewife, blueback herring, and striped bass, all of which spawn in freshwater and migrate through the Harbor Estuary to near-shore oceanic habitat as juveniles (Able 2005). Older juveniles and adults spend most of their life at sea before migrating through the Harbor to spawn in upstream freshwater habitats. Other species enter the Harbor during yearly movements and their densities in the Harbor may be influenced by year-class strength, freshwater flows, salinities, water temperatures, predator-prey relationships, and other factors; these species may be facultative, indicating they often use estuaries but are not dependent on them.

4.2 FISH ASSEMBLAGES

During the summer and spring, the seasonal compositions of fish assemblages were fairly homogenous within the harbor, i.e., they did not differ among harbor areas or among years (Figure I-6). During the fall, however, fish assemblages differed among years, most notably because of higher abundances of bay anchovy, blueback herring, alewife, and American shad in 2011, a year with high fall Hudson River discharge (Figure I-4). The seaward migration of juvenile alewives is triggered, in part, by increased stream flows (Gahagan *et al.*2010), thus, the higher abundances of blueback herring, alewife, and American shad in 2011 may reflect their response to higher river discharge.

Based on the 2006, 2011-2013 MFS mid-water trawl data, winter-spring fish assemblages were primarily composed of Atlantic herring, alewife, blueback herring, and bay anchovy with Atlantic menhaden, Atlantic butterfish, American shad, and spotted hake common or present in most Harbor regions (Figures I-30 through I-33). Lined seahorses were also present in low numbers during the winter in all four Harbor regions. Bay anchovy became more numerous in late spring to summer as Atlantic herring, alewife, and blueback herring numbers decreased. Bay anchovy dominated the summer aggregations with other species including Atlantic menhaden, Atlantic butterfish, bluefish, and striped anchovy common or present in most Harbor regions. A few alewife, blueback herring, and weakfish were present in some Harbor regions during summer. Bay anchovy continued to be the dominant species in fall aggregations; other common species included alewife and blueback herring. American shad, Atlantic butterfish, Atlantic menhaden, Atlantic moonfish, bluefish, silver hake, and weakfish were present in some Harbor regions during the fall.

Species assemblages were composed of both obligate and facultative estuarine-dependent species as defined and identified in Able 2005. Many of these species (American shad, Atlantic menhaden, Atlantic silversides, alewife, blueback herring, and lined seahorse) are obligate estuarine-dependent species and others including Atlantic butterfish, bay anchovy, bluefish, striped anchovy, and weakfish are facultative (Able 2005). Atlantic herring, Atlantic moonfish, and silver hake are likely facultative.

Four target species (anadromous species) migrated through the Harbor during their spring spawning migration. Alewife and blueback herring are discussed further in Part II of this report. The other two, American shad and striped bass were collected in low numbers during the MFS mid-water trawl surveys and no adults of either species were collected. Juvenile American shad were collected from April to May and in the fall from September through December. Juvenile striped bass were collected from April to May and in the fall during September and December. During the ABS bottom trawl surveys, striped bass were collected from January through May. Striped bass overwintering locations are influenced by temperature and salinity (Hurst and Conover 2002). Under relatively warm winter conditions, young-of-the-year fish survive over a wider (5 to 35 psu) range of salinities than when temperatures are cold ($1^{o}C$; 10 to 25 psu). In the field, recruitment to Age-1 is negatively correlated with severity of winter (Hurst and Conover 1998). Overwintering mortality is not caused by exposure to lethal temperatures alone, but may result from a combination of low temperatures and unfavorable salinities in the wintering grounds (Hurst and Conover 2002). Overwintering striped bass utilize an optimal salinity range along the river axis (Hurst and Conover 2002). This optimum salinity range shifts/moves up or down river with changes in the freshwater discharge and tidal cycles. As a result overwintering striped bass may be carried into or out of the Harbor area (Upper Bay), resulting in varying yearly winter residence periods within the Harbor.

Atlantic menhaden, a target species, was collected in April and May and August to November, with the majority collected in August, October, and November. Atlantic butterfish were collected from May through October, with the majority collected in June, July, and August. Atlantic herring were collected during March, April and May, with the majority collected in March and April. Bluefish were collected from May to October, with the majority collected in June, July, August, and September. Silver hake were sporadically collected in May, November, and December, most were collected in November. Bay anchovy were collected from May to December, with the majority collected in July, August, September, and October. Striped anchovy were collected from August to September, most were collected in September. Atlantic silverside were collected in April, November and December, with most collected in December.

4.2.1 Temporal Occurrence within the Harbor and Location within the Water Column

Several species were collected in both the MFS mid-water trawls and ABS bottom trawls, suggesting that they are distributed over a wide range of depths. Alewife, American shad, and Atlantic silverside were common in both mid-water and bottom trawl samples and may have demonstrated a slight preference for use of near bottom waters during winter and spring. Blueback herring and bay anchovy were collected by bottom trawl, but were more common in the mid-water trawl samples than in the bottom trawl samples, which suggested a preference for use of mid-waters during winter and spring.

American shad juveniles were collected in the Harbor from January to June during the 2002 to 2010 ABS bottom trawl surveys and during April and May and September through December during the 2006 and 2011 through 2013 MFS mid-water trawl program. The majority of American shad were collected as one year old juveniles from January through April and as young-of-the-year juveniles from October to December. Peak years when American shad were collected as one year old juveniles included 2006, followed by 2004 and 2002 during the ABS and 2011 and 2012 during the MFS. Fall collections were only made during the MFS, 2011 was the peak year for young-of-the-year juveniles. In 2011, young-of-the-year shad occurred in the Harbor in September, with abundances increasing through November in greater numbers in comparison to 2006, 2012 and 2013 (Figure I-9). The earlier arrival of shad in the fall of 2011 may be related to high September Hudson River discharge (Figure I-4) and correspondingly low salinities (Figure I-5a). American shad were also present in the ABS bottom trawl collections, with a peak average winter CPUE of 2 in the Upper Bay followed by CPUEs of about 1 in the Lower Bay and Arthur Kill (USACE-NYD 2015b – Figure C-6). American shad spring bottom trawl CPUEs were about 1.3 in the Arthur Kill compared to CPUEs of about 0.5 in the Upper

Bay and Newark Bay (using USACE-NYD 2015b - Figure C-6). During the MFS mid-water trawl surveys, the peak spring CPUEs were < 0.3 in the Harbor (Figure I-19). This seems to indicate that American shad may be more evenly distributed in the water column using both mid and near bottom waters during their winter-spring migration through the Harbor.

Atlantic menhaden were collected in the Harbor from January to June during the 2002 to 2010 ABS bottom trawl surveys and during April and May and August through November during the 2006 and 2011 through 2013 MFS mid-water trawl program. The majority of Atlantic menhaden were collected as juveniles in January, February, August, October, and November. Peak years when Atlantic menhaden juveniles were collected included 2008, followed by 2010 and 2006 during the ABS and 2006 during the MFS. Atlantic menhaden were also present in the ABS bottom trawl collections, with a peak average CPUE of just over 2 and 2.5 in the Lower Bay during spring and winter, respectively (USACE-NYD 2015b, Figure C-8). Atlantic menhaden bottom trawl CPUEs were below 0.5 for all other Harbor regions and seasons (using USACE-NYD 2015b, Figure C-8). For the MFS mid-water trawl surveys, the peak spring CPUEs were 10 in the Arthur Kill/Kill Van Kull and about 5 in Newark Bay during 2006, CPUEs remained at or near 0 for all other Harbor regions (Figure I-22). Spring CPUEs were low and remained near 0 for all Harbor regions during 2011 through 2013. Although Atlantic menhaden were collected from mid-water as well as near bottom portions of the water column during spring, there is some indication that Atlantic menhaden may be more bottom-oriented during winter and spring then they are from summer through fall.

Atlantic silverside were collected in the Harbor from January to March during the 2002 to 2010 ABS bottom trawl surveys and during November and December during the 2006 and 2011 through 2013 MFS mid-water trawl program. The majority of Atlantic silverside were collected in January and February during the ABS, and in December during the MFS. Peak years when Atlantic silverside were collected included 2010, followed by 2008, 2007, and 2009 during the ABS, and during the MFS, catches were small with CPUEs the fall of 2013 nearing 0.5. Atlantic silverside were also present in the ABS bottom trawl collections, with a peak average CPUE of just over 12 in the Lower Bay during winter (USACE-NYD 2015b, Figure C-8). Atlantic silverside bottom trawl CPUEs were below 2 for all other Harbor regions and seasons (using

USACE-NYD 2015b, Figure C-9). For the MFS mid-water trawl surveys, the peak spring CPUE was under 0.1 in Newark Bay during 2011, spring CPUEs remained at or near 0 for the Upper and Lower Bay regions (Figure I-27). Atlantic silverside appear to be more bottom-oriented during the spring.

Bay anchovy were collected in the Harbor in May and June during the 2002 to 2010 ABS bottom trawl surveys and during May to December during the 2006 and 2011 through 2013 MFS mid-water trawl program. The majority of bay anchovy were collected in May and June during the ABS and July through October during the MFS. Peak years when bay anchovy were collected included 2006 followed by 2008, and 2005 and 2009 during the ABS and 2012 followed by 2006 and 2013 during the MFS. Bay anchovy were also commonly collected in the ABS bottom trawl surveys, with a peak average CPUE of about 150 in the Upper Bay during spring, the lowest spring CPUE was 10 for the AK (USACE-NYD 2015b, Figure C-11). Other CPUEs near 70 occurred during the spring in the Lower Bay and Newark Bay. For the mid-water trawl surveys, the peak spring CPUE was near 200 in the Lower Bay during 2011 and CPUEs remained near 0 for other years and for other Harbor regions and all years. This may indicate that bay anchovy may be more common near bottom than at mid-water during the winter and spring.

Silver hake were also present in the ABS bottom trawl collections, with a peak average CPUE of about 3.5 and 1.8 in the Lower Bay during spring and winter, respectively (USACE-NYD 2015b – Figure C-13). Silver hake bottom trawl CPUEs were below 0.5 for all other Harbor regions and seasons (using USACE-NYD 2015b, Figure C-13). For the MFS mid-water trawl surveys, the peak spring CPUE was about 0.3 in Arthur Kill/Kill Van Kull during 2011, Except for 2011, Spring CPUEs remained at or near 0 for the other years and all Harbor regions (Figure I-25). These data suggest that silver hake are more bottom-oriented and less likely to be collected in mid-water trawls.

Spotted hake were also present in the ABS bottom trawl collections, with CPUEs highest in the spring in the Arthur Kill (48) & Newark Bay (43) followed by the Upper Bay (37) and Lower Bay (15), winter CPUE ranged from 2 to 13 (USACE-NYD 2015b - Figure C-16). MFS CPUEs were lower, suggesting that spotted hake are more bottom-oriented and less likely to be collected in mid-water trawls.

Striped bass were also present in the ABS bottom trawl collections, with high winter CPUEs of 42 and 36 occurred in the Arthur Kill and Newark Bay regions, respectively (Figure I-26b). Fewer striped bass were collected in Upper Bay (10) during winter and spring collections in these Harbor areas ranged from 5 to 15 compared to very low CPUEs in Lower Bay during winter and spring (Figure I-26b). During the MFS, peak mid-water trawl CPUEs of 0.4, 0.1, and <0.1 occurred in the spring of 2011 at the Arthur Kill/Kill Van Kull, Newark Bay and Upper Bay, respectively (Figure I-26a). CPUEs were at or near 0 in all other years and Harbor areas. These data suggest that striped bass are more bottom-oriented and less likely to be collected in mid-water trawls.

4.3 DREDGING AND MIGRATORY FINFISH

Developing an understanding of where migratory pathways occur and the timing of peak seasonal use (temporal and spatial patterns) can improve effective management of dredging activities within the Harbor while protecting this resource. The hypothetical impact of dredging operations, particularly the potential effects of noise, vibration or turbidity presenting a possible barrier to migratory fishes in NY/NJ Harbor, was cited as a concern in NMFS (2015) and subsequent consultations with NMFS have discussed the application of MFS and ABS data as well as other NYD studies to refine these recommendations within the Harbor.

Conservation Recommendations for striped bass designate a seasonal dredging restriction from November 15 to April 15 to protect fish that are overwintering in the Buttermilk, Red Hook and Bay Ridge Channels of the Upper Bay, and inshore areas of Upper and Lower Bay near the pierheads from the lower East River to the Port Jersey Channel. Overwintering locations are dependent on temperature and salinity; therefore, locations fluctuate with the tide, with overwintering striped bass remaining within an optimum salinity range of between 10 and 25 psu when water temperatures are cold (Hurst and Conover 2002). Striped bass CPUEs were highest in January and February (Figure I-15a) and striped bass were concentrated in Upper Bay, Newark Bay and Arthur Kill in the winter.

The 2015 Conservation Recommendations also include a seasonal dredging restriction from March 1 to June 30 to allow anadromous fish to pass through the Harbor to upstream spawning areas in the Hudson River, Hackensack River, and Passaic River. In downstream areas, including Kill Van Kull, Arthur Kill and Newark Bay, the dredging restriction ends on May 31st because it is expected that most fish would have passed through these areas by this time.

The results of multiple plume dynamic surveys conducted during the deepening of NY/NJ Harbor demonstrated that under most dredging scenarios, TSS concentrations decay rapidly within relatively short distances down-current from the dredge. Plumes descend in the water column to form bottom-oriented features that did not extend beyond the channel boundaries in most cases (USACE-NYD 2015a). These results suggest that even in a relatively "confined" waterway, such as the Arthur Kill or Kill Van Kull, suspended sediment plumes would not extend bank to bank, or the entire depth of the water column, and therefore would not create an obstacle to fish migrations.

Moreover, several studies suggest that dredging has no demonstrable effect on migratory fishes including runs of clupeid fishes in the Hudson River (Talbot 1954, Summers *et al.* 1985, Summers *et al.* 1987, Rose and Summers 1992). Talbot (1954) examined the historical stock assessment data for shad in the Hudson River and tributaries in relation to the incidence of dredging activities during extensive channel improvement projects and found no evidence of effects on recruitment. In several later analyses, Summers *et al.* (1985, 1987) and Rose and Summers (1992) included the incidence of dredging in a number of estuaries in the northeast as a parameter investigated as a potential influence on migratory fish abundance. They found no indication that dredging posed a risk as opposed to the dominant factors of water temperature and river discharge.

Potential impacts of underwater noise also are cited as a concern in NMFS (2015) which states "concerns about noise effects comes from an increased awareness that high-intensity sounds have the potential to harm both terrestrial and aquatic vertebrates." The scientific literature pertaining to effects of underwater sound is expanding rapidly. In contrast to investigations of pile driving, seismic exploration sounds, and military sources, few studies dedicated to assessing the impacts of dredging-related sounds have been performed or documented. However, several pertinent studies have been conducted characterizing dredging sound for operations in NY/NJ Harbor (Reine *et al.* 2014a) and coastal waters (WODA 2013, Reine *et al.* 2014b). Backhoe and cutterhead dredging operations in NY/NJ Harbor, even when engaged in fracturing and removing hard rock substrate, proved to be no louder in the dominant low frequency ranges detected by fishes than other sources in the harbor, including the widespread contributed sounds of vessel traffic.

A consensus is emerging among bioacousticians that typical dredging sounds, as opposed to pile driving, blasting or other sources of intense impulsive sounds, are not of sufficient intensity to cause permanent injury or permanent changes in auditory capability. Behavioral effects may occur, particularly in the form of startle responses upon initial detection of dredging sounds. Because dredging sounds are acknowledged to consist primarily of continuous sounds (Normandeau Associates 2012, WODA 2013, Popper *et al.* 2014, Hawkins *et al.* 2015), highly motivated migratory fishes would be very likely to rapidly habituate to those sounds. Because bucket and backhoe mechanical dredges and hydraulic pipeline cutterhead dredges represent relatively stationary sound sources over short time spans, habituation would occur as fishes approached the source. The occurrence of habituation would also be influenced by the ambient soundscape. Dredging sounds occur against a background of other sources of natural (e.g., hydrodynamic, wind-wave, biological) as well as anthropogenic (e.g., deep and shallow draft vessels, high speed ferries) origins. Migratory fishes would encounter underwater sounds of equal or greater intensity than those radiating from dredges long before encountering dredging sounds. As in the case of plumes, it should also be recognized that dredging sounds would not occur continuously but on an intermittent basis. Unless bucket dredging were to be conducted in a very confined waterway where passageways would be restricted, it is unlikely that either suspended sediment plumes or radiated sounds would represent a migratory barrier.

In summary, dredging-related sounds are very similar to multiple sound sources in urbanized, industrialized estuaries such as NY/NJ Harbor and are not more problematic than ship and ferry traffic sources that occur more continually throughout the year. Based on these considerations, the conservation recommendations outlined in NMFS (2015) for the protection of migratory finfish species are overly conservative and/or unnecessary for most waterways and typical dredging projects in NY/NJ Harbor. Based on the timing and occurrence of river herring migration discussed further in Part II of this report, USACE-NYD has requested modification to the migratory finfish window to no longer include May in the Kill Van Kull, Arthur Kill and Newark Bay regions of the Harbor. Coordination with NMFS is ongoing with regards to the draft 2015 Conservation Recommendations.

5.0 REFERENCES

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6.0 TABLES (PART I)

Table I-1. Summary of mid-water trawl sampling program targeting migratory finfish.

Sampling	**2006**	**2011**	**2012**	**2013**
Months	Apr-May, Aug-Nov	Apr- May Jul-Dec	Mar.-Dec.	Mar.-Dec.
# Mid-water stations	26	26	20	20
# Mid-water trawls	311	426	440	440
Total # Fish	29,329	69,613	119,951	33,203
# Species	26	38	33	23

Table I-2. Total number of fish collected from mid-water trawls during each year of migratory finfish sampling.

Target Species	Scientific Name	2006	2011	2012	2013	Total
Alewife	*Alosa pseudoharengus*	1,061	4,276	492	252	6,081
American shad	*Alosa sapidissima*	40	259	55	18	372
Atlantic menhaden	*Brevoortia tyrannus*	1,153	29	270	16	1,468
Blueback herring	*Alosa aestivalis*	1,213	6,578	31,576	4,008	43,375
Striped bass	*Morone saxatilis*	1	34	3	0	38
EFH Species	**Scientific Name**	**2006**	**2011**	**2012**	**2013**	**Total**
Atlantic butterfish	*Peprilus triacanthus*	322	135	89	82	628
Atlantic cod	*Gadus morhua*	0	0	0	2	2
Atlantic herring	*Clupea harengus*	618	116	3,853	1,421	6,008
Black sea bass	*Centropristis striata*	0	1	0	1	2
Bluefish	*Pomatomus saltatrix*	29	72	20	86	207
Pollock	*Pollachius virens*	0	1	0	1	2
Red hake	*Urophycis chuss*	0	2	0	0	2
Scup	*Stenotomus chrysops*	0	1	0	0	1
Silver hake	*Merluccius bilinearis*	0	180	2	0	182
Spanish mackerel	*Scomberomorus spp.*	2	0	0	0	2
Windowpane	*Scopthalmus aquosus*	0	5	0	0	5
Winter flounder	*Pseudopleuronectes americanus*	1	0	1	0	2

Table I-2 continued. Total number of fish collected from mid-water trawls during each year of migratory finfish sampling.

Other Species	Scientific Name	2006	2011	2012	2013	Total
American eel	*Anguilla rostrata*	0	4	0	1	5
American sandlance	*Ammodytes americanus*	4	0	1	17	22
Atlantic croaker	*Micropogonias undulatus*	0	15	1	0	16
Atlantic cutlassfish	*Trichiurus lepturus*	1	0	0	0	1
Atlantic moonfish	*Selene setapinnis*	10	58	3	4	75
Atlantic silverside	*Menidia menidia*	9	6	15	50	80
Atlantic thread herring	*Opisthonema oglinum*	0	1	98	0	99
Atlantic tomcod	*Microgadus tomcod*	0	14	5	0	19
Bay anchovy	*Anchoa mitchilli*	24,791	57,229	82,785	27,380	192,185
Blue runner	*Caranx crysos*	0	0	2	0	2
Boxfishes	*Ostraciidae*	1	0	0	0	1
Conger eel	*Conger oceanicus*	0	1	1	0	2
Feather blenny	*Hypsoblennius hentzi*	0	0	1	0	1
Fourbeard rockling	*Enchelyopus cimbrius*	1	0	0	0	1
Gizzard shad	*Dorosoma cepedianum*	0	267	0	0	267
Grubby	*Myoxocephalus aenaeus*	1	0	0	0	1
Hickory shad	*Alosa mediocris*	5	0	0	0	5
Inland silverside	*Menidia beryllina*	0	0	18	0	18
Lined seahorse	*Hippocampus erectus*	9	19	11	3	42
Lookdown	*Selene vomer*	2	0	0	0	2
Naked goby	*Gobiosoma bosc*	0	2	0	0	2
Northern pipefish	*Syngnathus fuscus*	4	3	5	6	18
Northern puffer	*Sphoeroides maculatus*	0	0	3	0	3
Northern searobin	*Prionotus carolinus*	0	1	0	1	2
Northern stargazer	*Astroscopus guttatus*	7	0	10	0	17
Oyster toadfish	*Opsanus tau*	0	5	0	0	5
Pinfish	*Lagodon rhomboides*	0	3	0	0	3
Silver perch	*Bairdiella chrysoura*	0	9	0	0	9
Skilletfish	*Gobiesox strumosus*	0	0	2	0	2
Smallmouth flounder	*Etropus microstomus*	0	10	0	0	10
Spotfin butterflyfish	*Chaetodon ocellatus*	0	0	0	1	1
Spotted hake	*Urophycis regia*	10	52	9	145	216
Striped anchovy	*Anchoa hepsetus*	33	125	1,493	89	1,740
Striped cusk-eel	*Ophidion marginatum*	0	1	0	0	1
Striped searobin	*Prionotus evolans*	1	1	1	4	7
Threespine stickleback	*Gasterosteus aculeatus*	0	0	1	0	1
Weakfish	*Cynoscion regalis*	0	57	8	0	65
White mullet	*Mugil curema*	0	0	59	0	59
White perch	*Morone americana*	0	40	6	2	48

Table I-3. Fall mean CPUE of fish contributing at least 5% to dissimilarities among years. Fish assemblage composition did not differ among years in the spring or summer.

Species	2006	2011	2012	2013
Bay anchovy	17.5	186.0	211.4	77.7
Blueback herring	3.5	17.8	139.0	7.5
Alewife	5.3	9.8	2.1	0.1
American shad	0.2	1.1	0.2	<0.1
Atlantic menhaden	6.2	0.1	0.7	<0.1
Atlantic butterfish	0.2	0.3	<0.1	0.2

7.0 FIGURES (PART I)

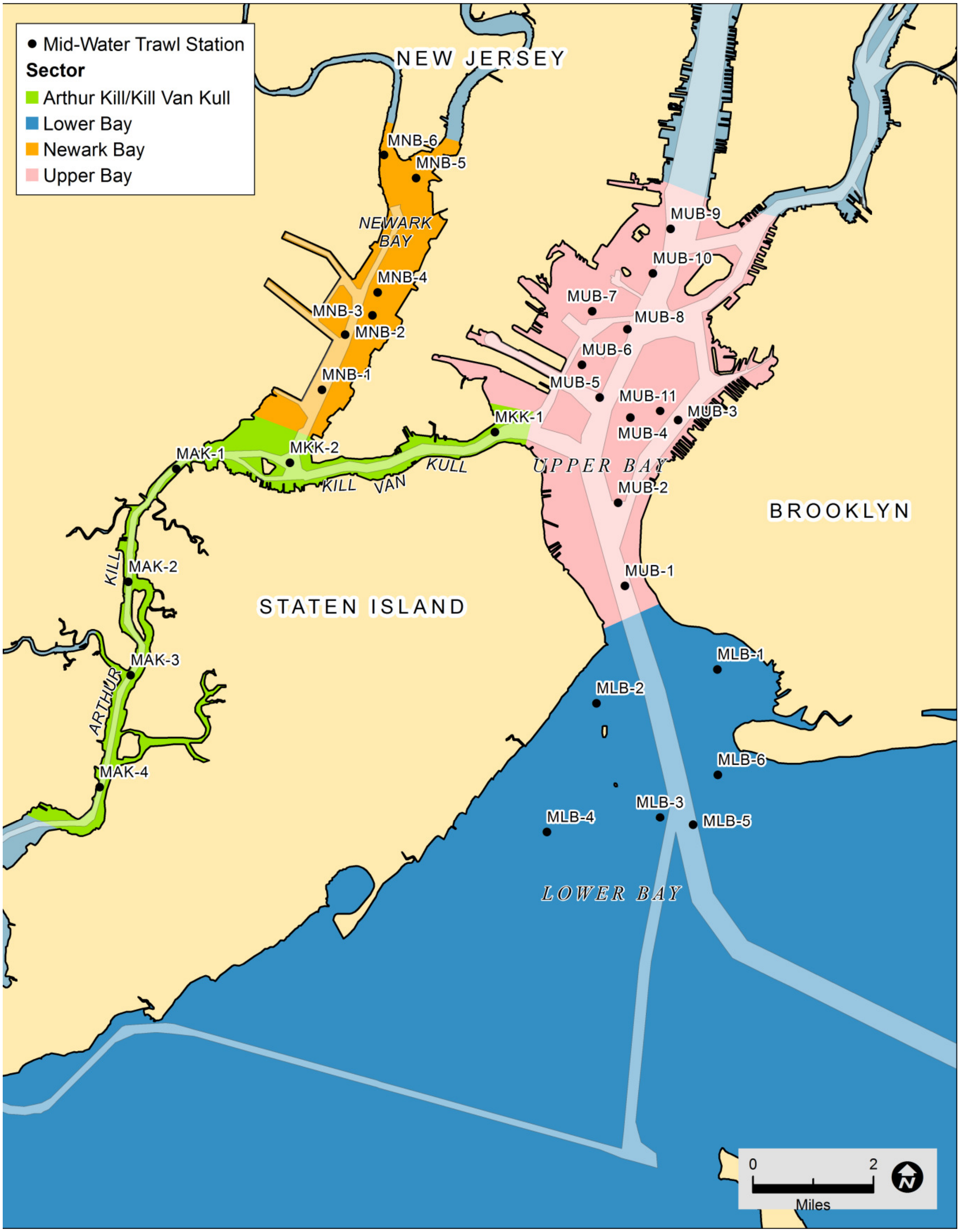


Figure I-1. Migratory Finfish Sampling Program (2006 and 2011-2013) mid-water trawl locations.

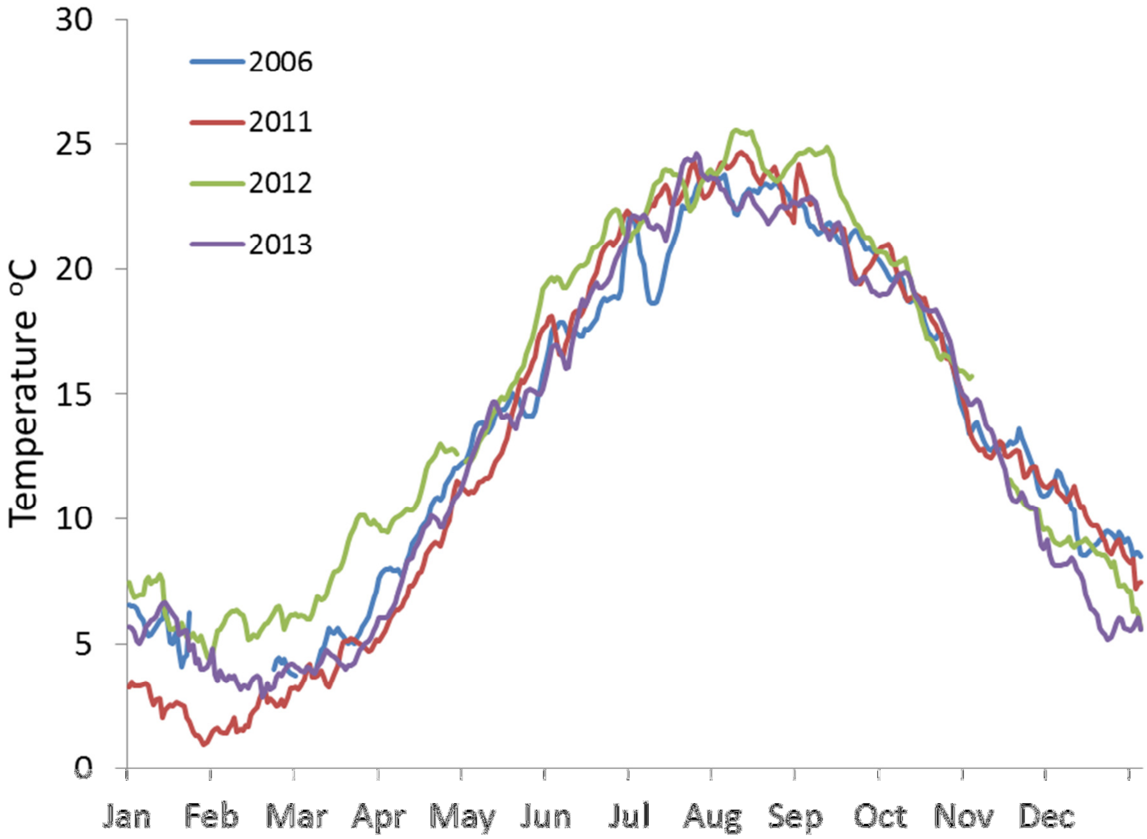
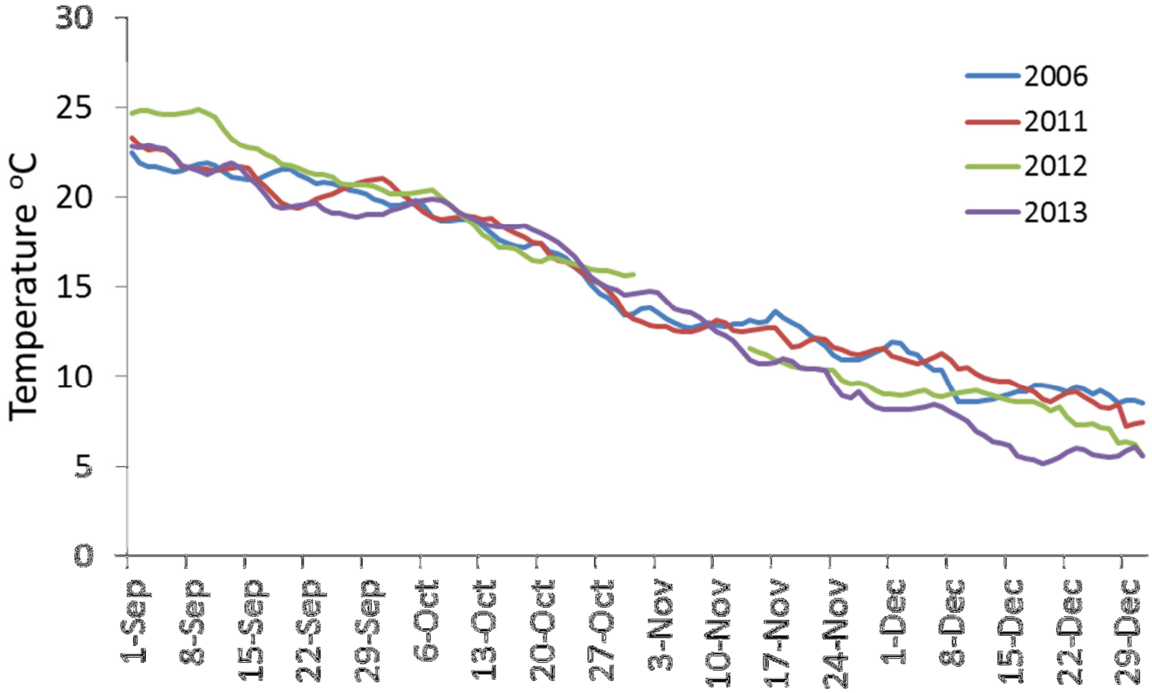


Figure I-2. Mean daily water temperatures recorded at NOAA gauge (station ID 8518750) located at the southern tip of Manhattan Island (the Battery) for the years of sampling (2006 and 2011-2013).



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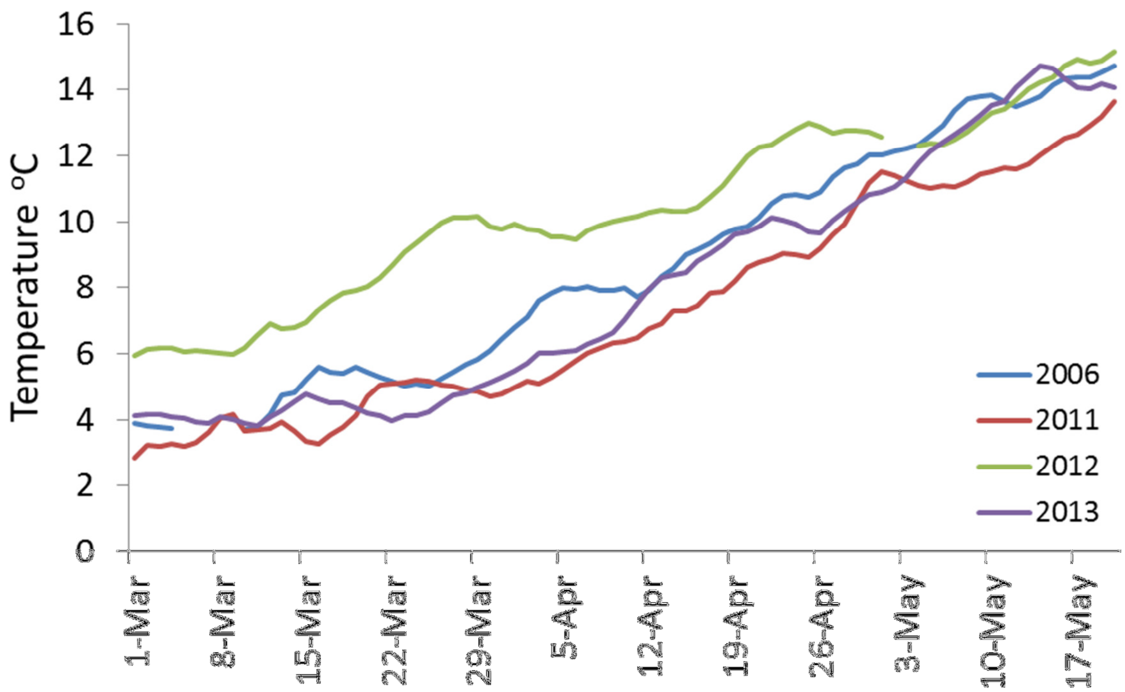


b)

Figure I-3. Fall (a) and spring (b) daily water temperatures for each year of sampling (2006 and 2011-2013).

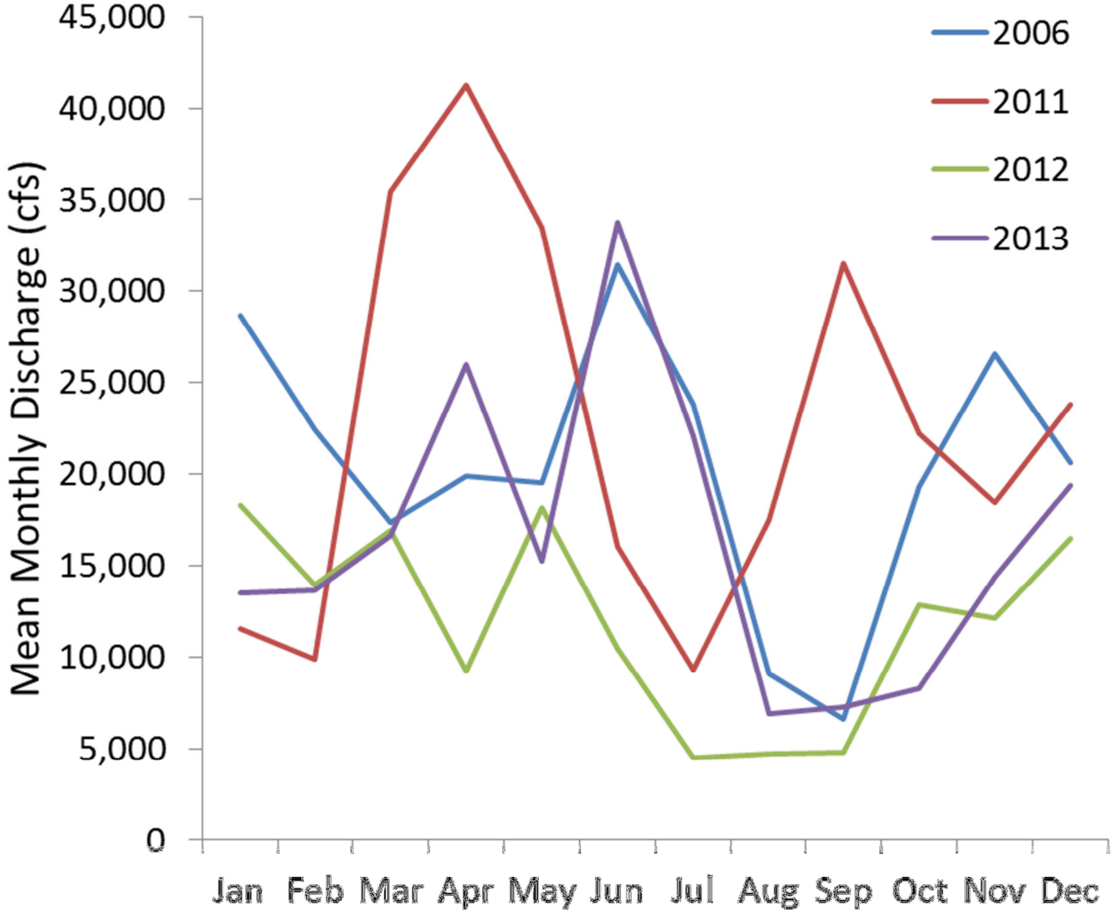


Figure I-4. Mean monthly Hudson River discharge data recorded at USGS station 01358000 at Green Island, which is just upstream from the Troy Lock and Dam for the years of sampling (2006 and 2011-2013).

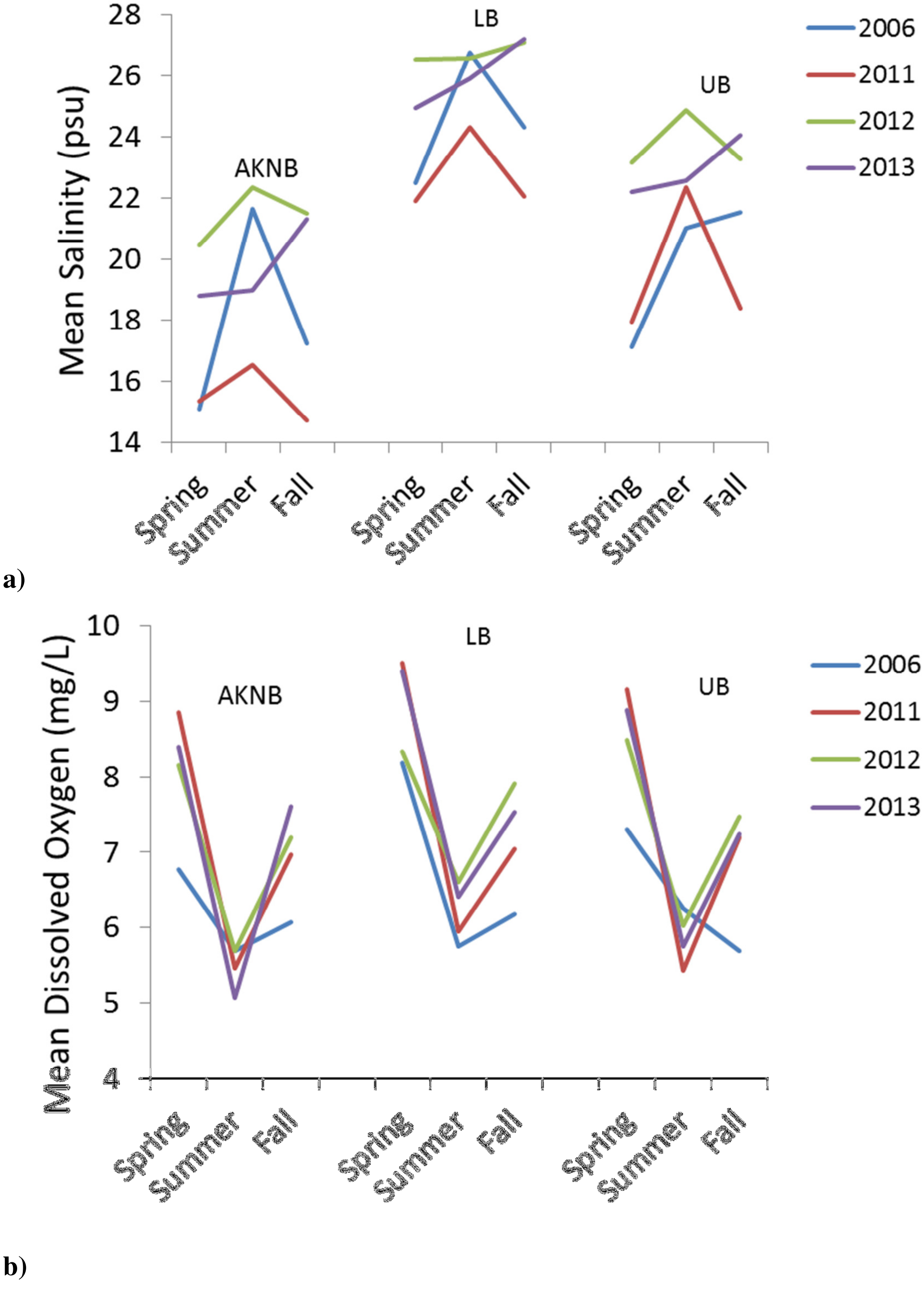
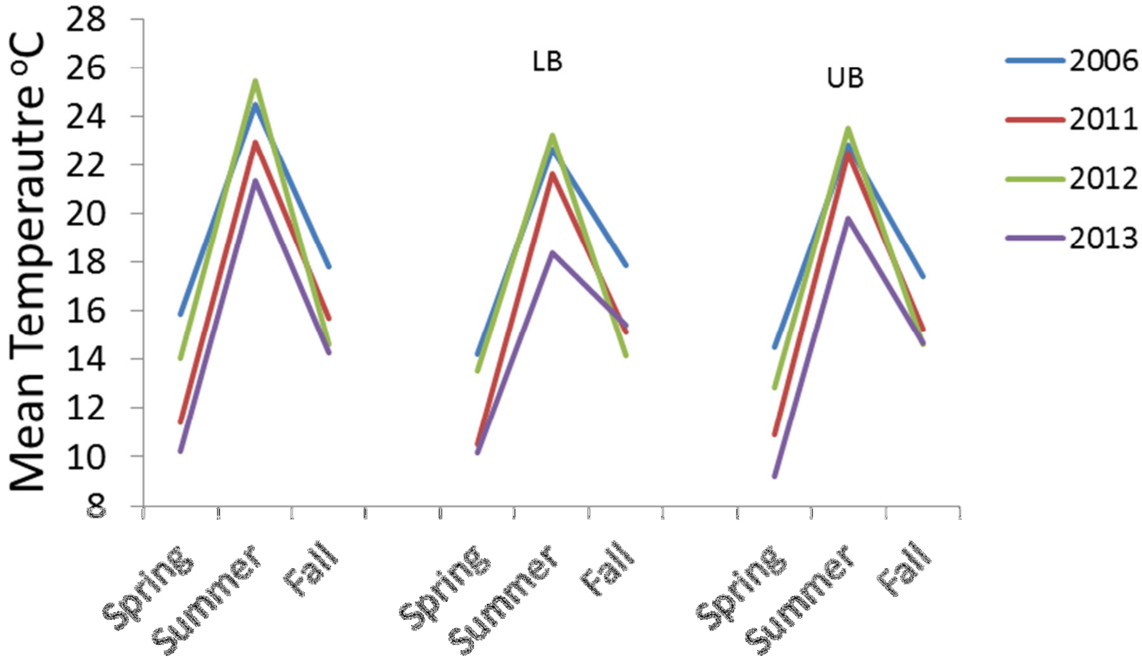
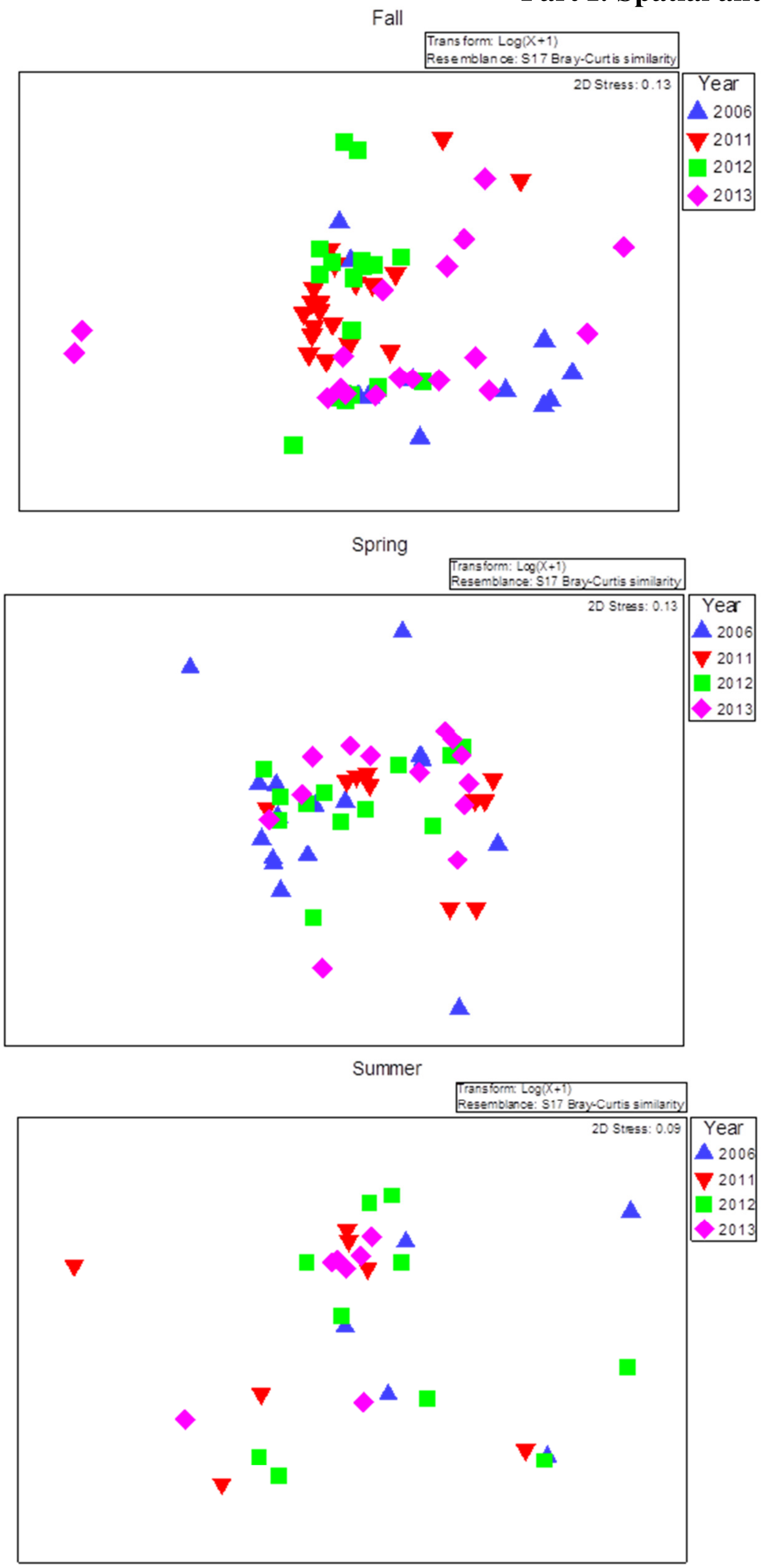


Figure I-5. Mean seasonal mid-water salinities (a) and dissolved oxygen concentrations (b) in each year of Migratory Finfish Sampling in the Arthur Kill/Newark Bay (AKNB), Lower Bay (LB), and Upper Bay (UB).



c)

Figure I-5 (continued). Mean seasonal mid-water temperatures (c) in each year of Migratory Finfish Sampling in the Arthur Kill/Newark Bay (AKNB), Lower Bay (LB), and Upper Bay (UB).



a)

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Figure I-6. Non-metric multidimensional scaling plots of mid-water fish assemblages collected in the fall (a), spring (b), and summer (c) for each year of sampling.

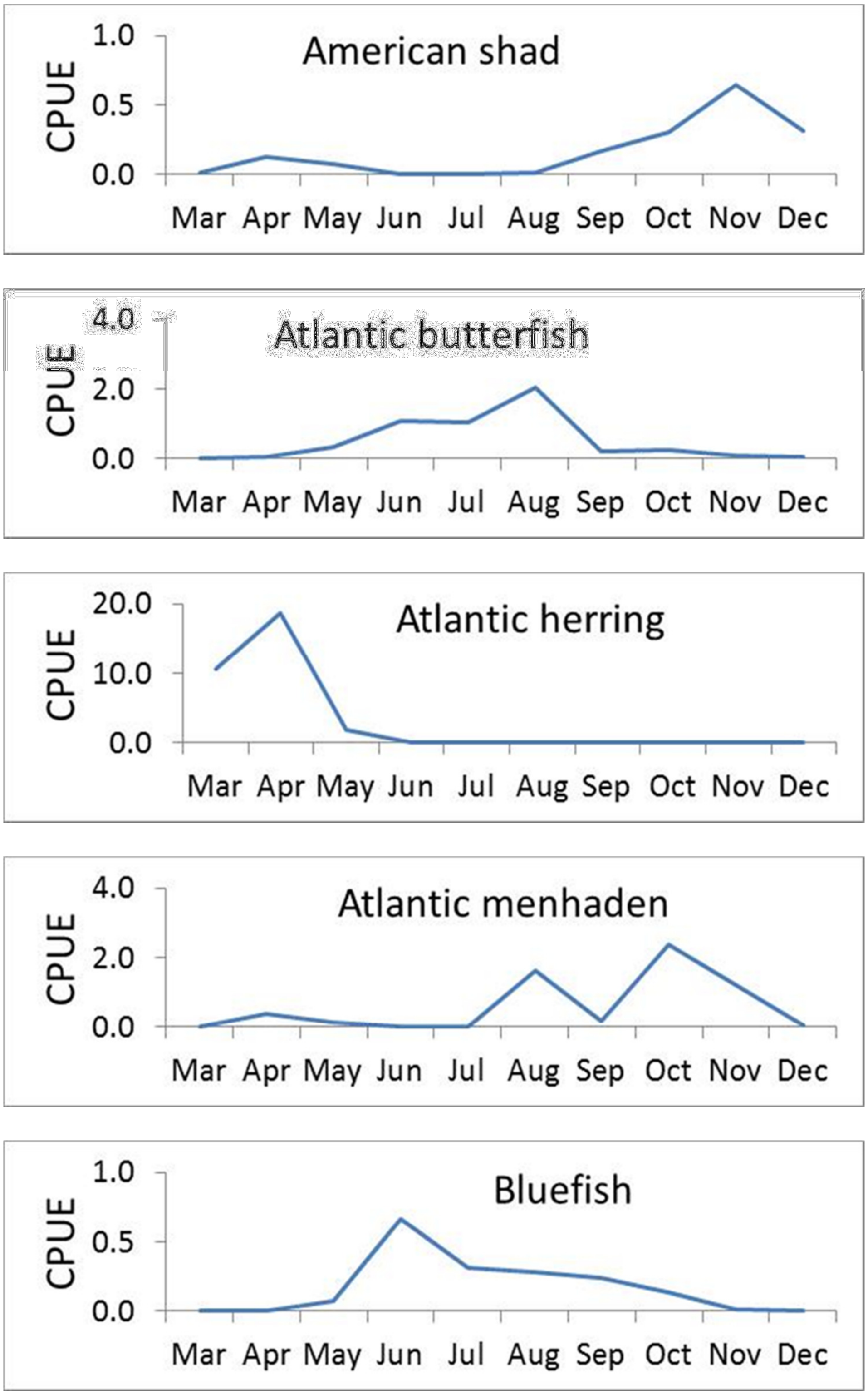


Figure I-7. Mean monthly CPUE for target, EFH and important forage species collected by mid-water trawl in the four years of Migratory Finfish Sampling (2006, 2011-2013).

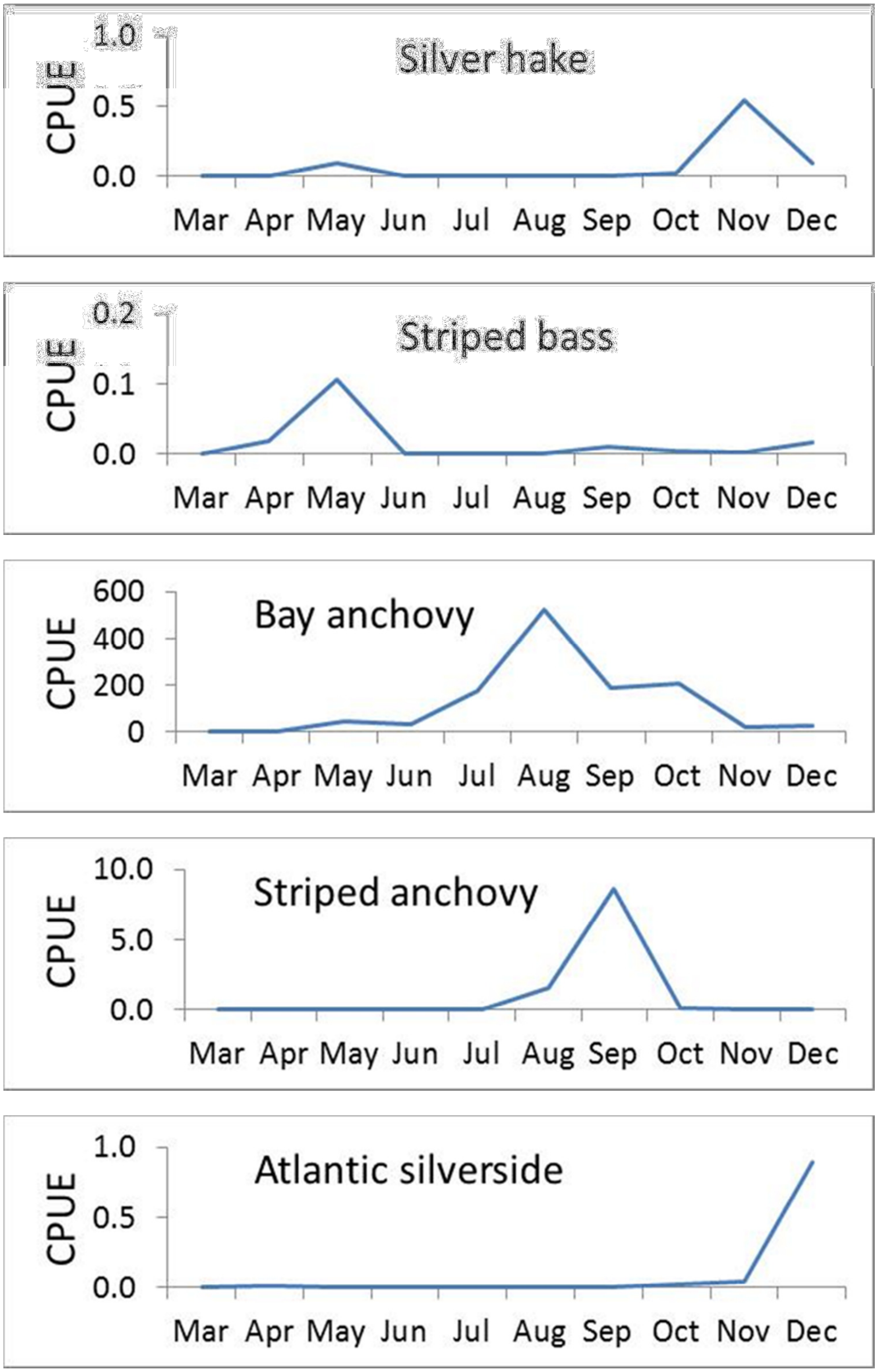
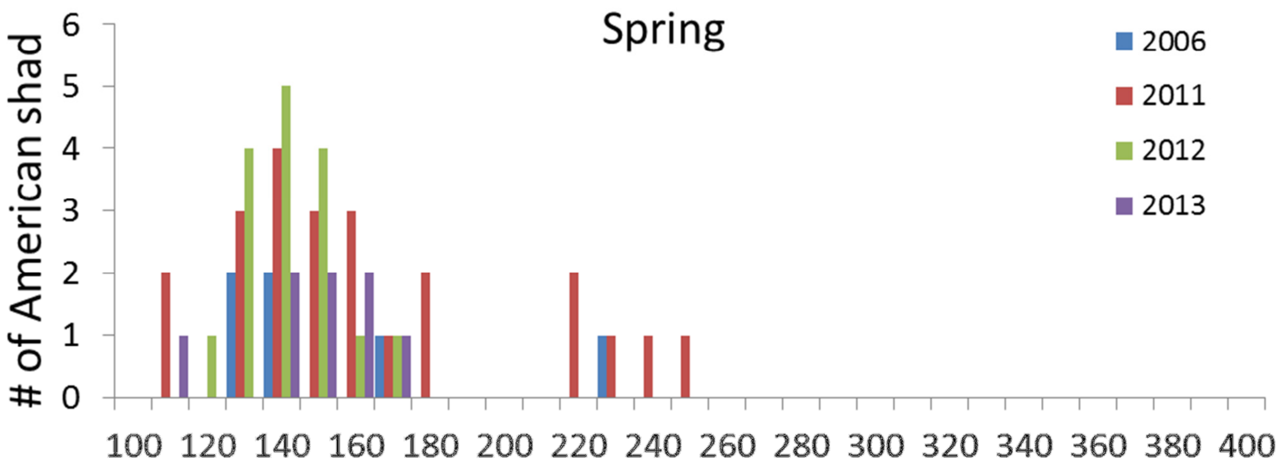
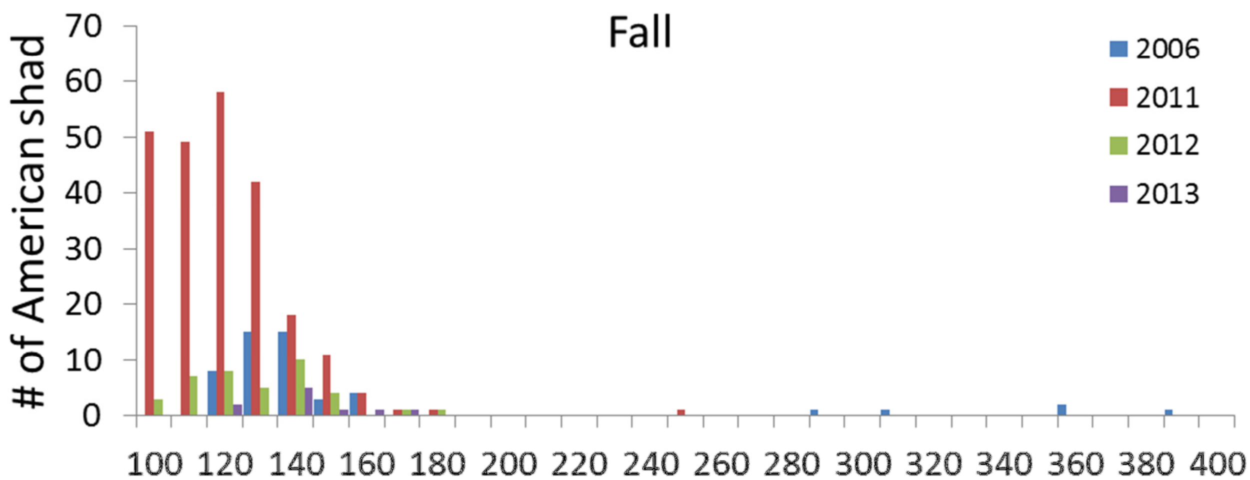


Figure I-7 (continued). Mean monthly CPUE for target, EFH and important forage species collected by mid-water trawl in the four years of Migratory Finfish Sampling (2006, 2011-2013).



a)



b)

Figure I-8. Size frequency distribution (mm) of American shad collected in the spring (a) and fall (b) for each year of Migratory Finfish Sampling. The total number of fish measured is given.

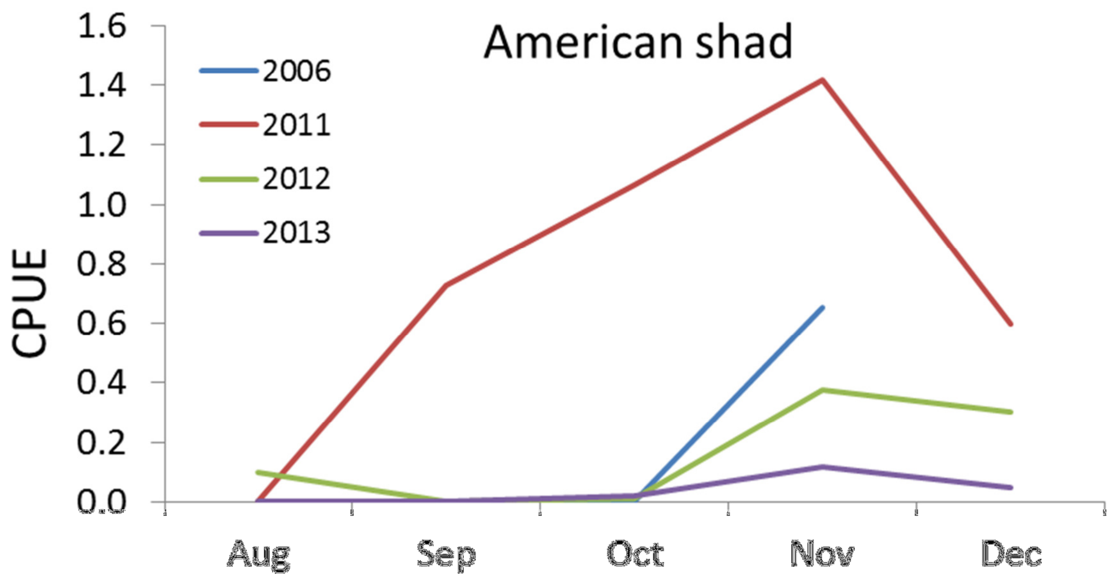
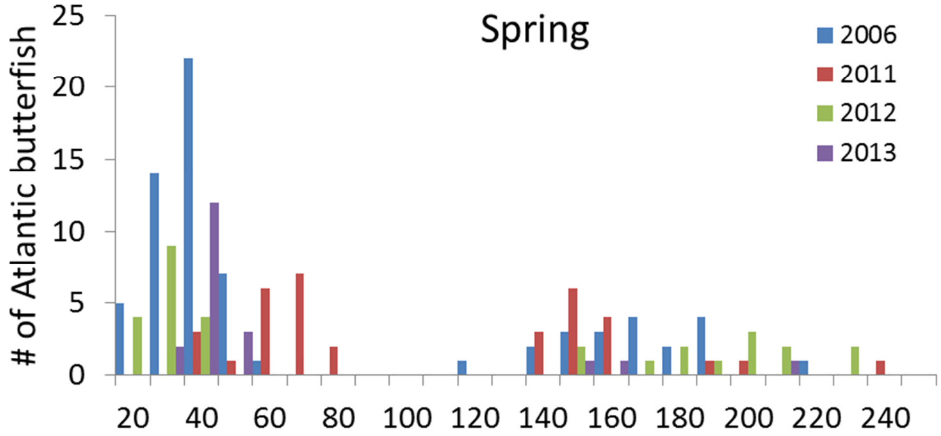
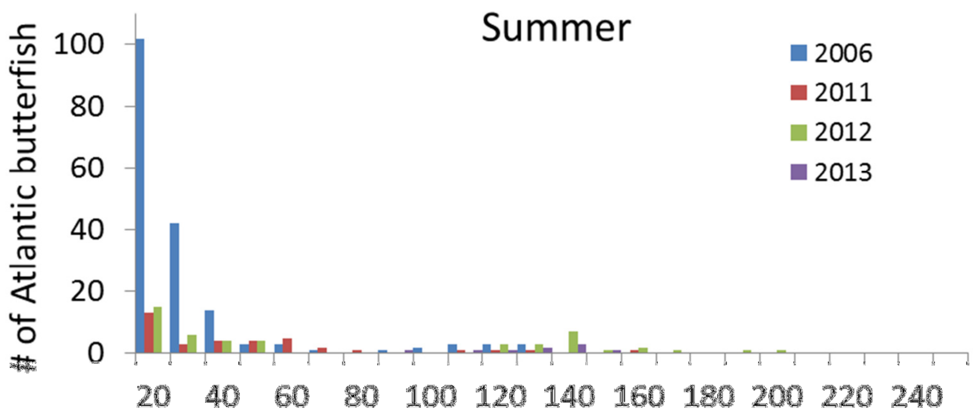


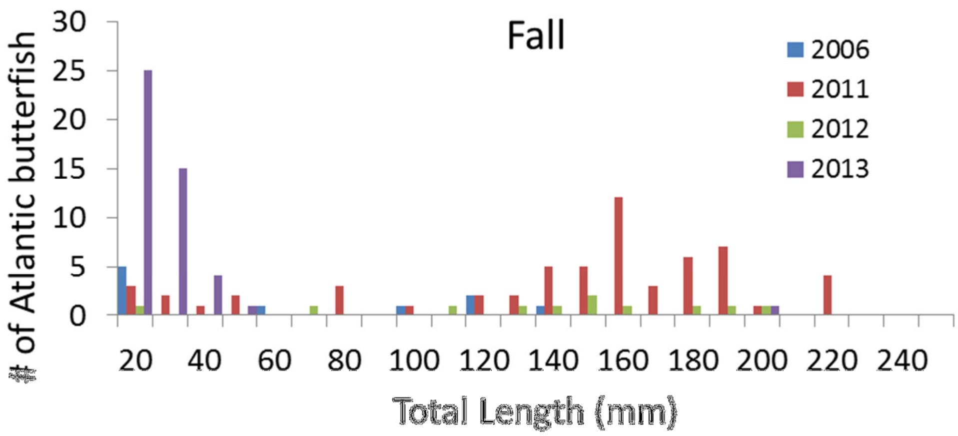
Figure I-9. Mean monthly CPUE by year for American shad collected by mid-water trawl.



a)



b)



c)

Figure I-10. Size frequency distribution of Atlantic butterfish in the spring (a), summer (b), and fall (c) for each year of Migratory Finfish Sampling.

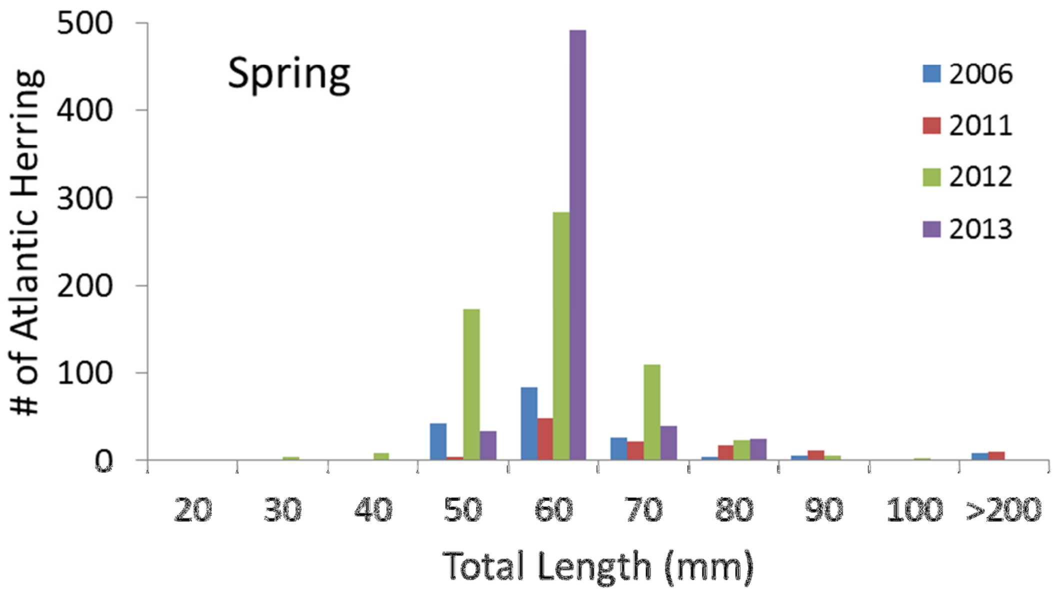
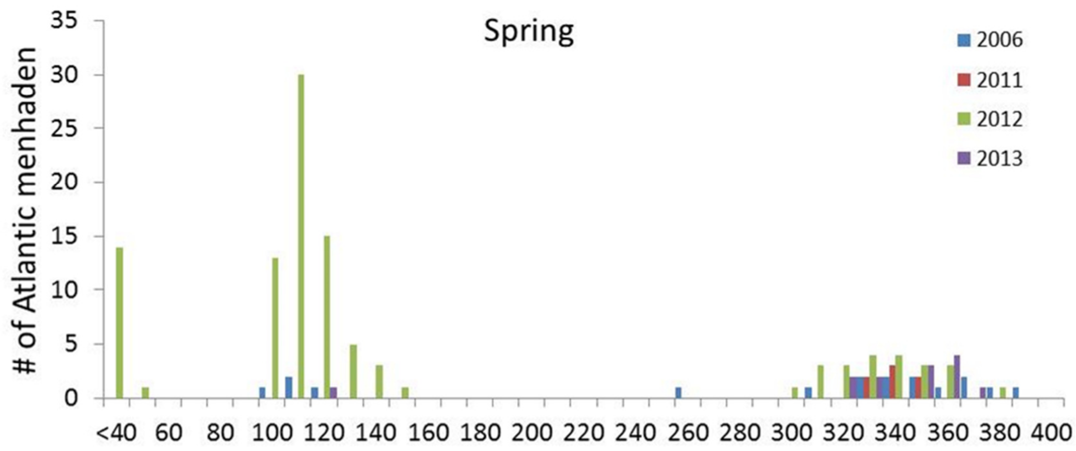
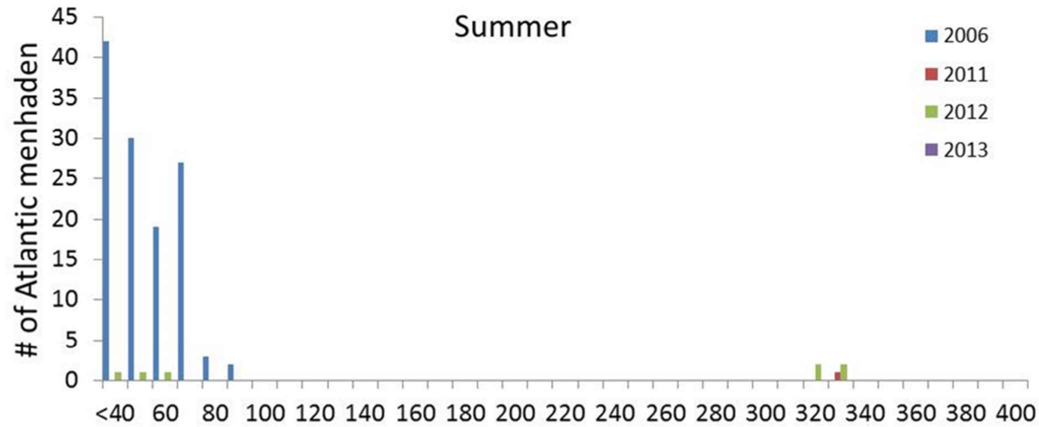


Figure I-11. Size frequency distribution of Atlantic herring in the spring, when peak abundances occurred, for each year of Migratory Finfish Sampling.



a)



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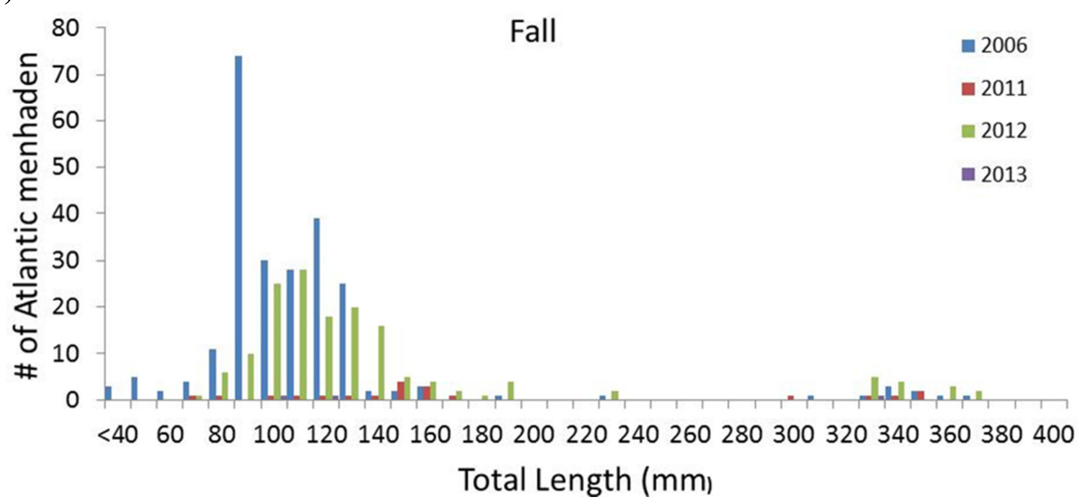

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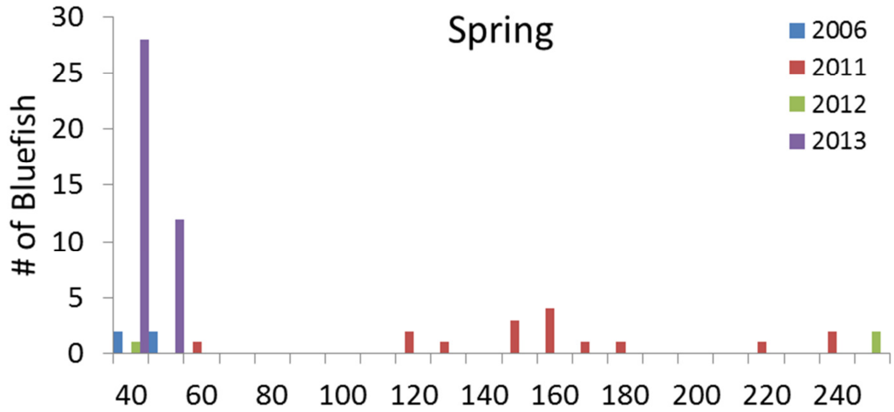

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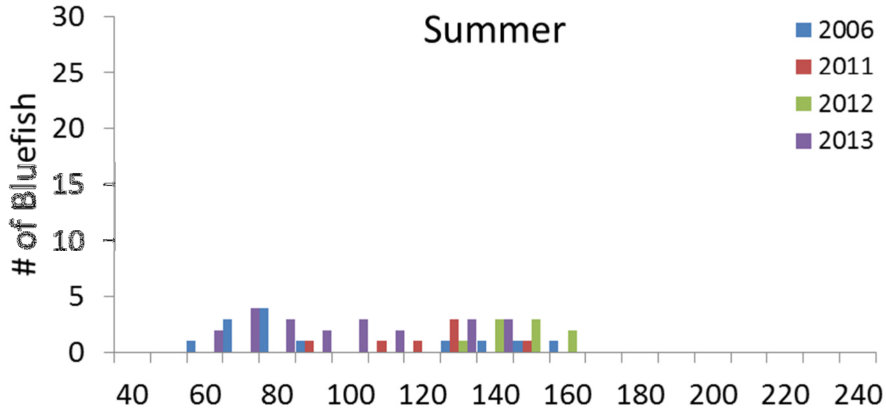

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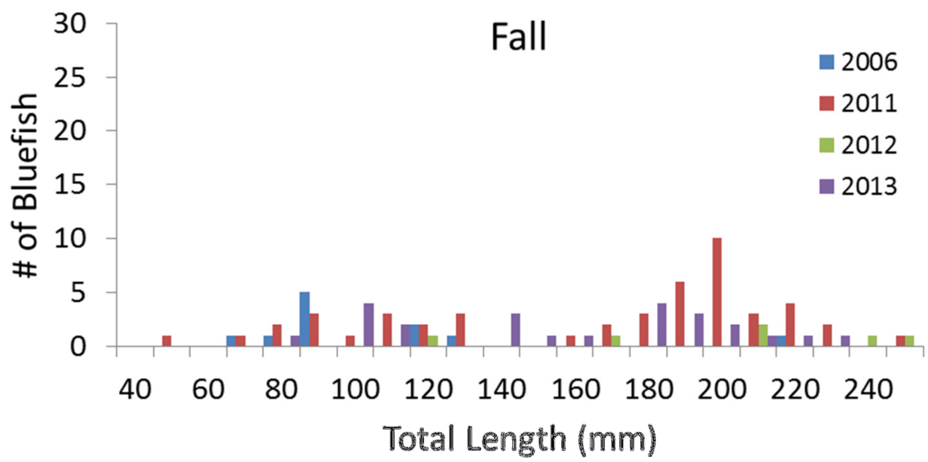

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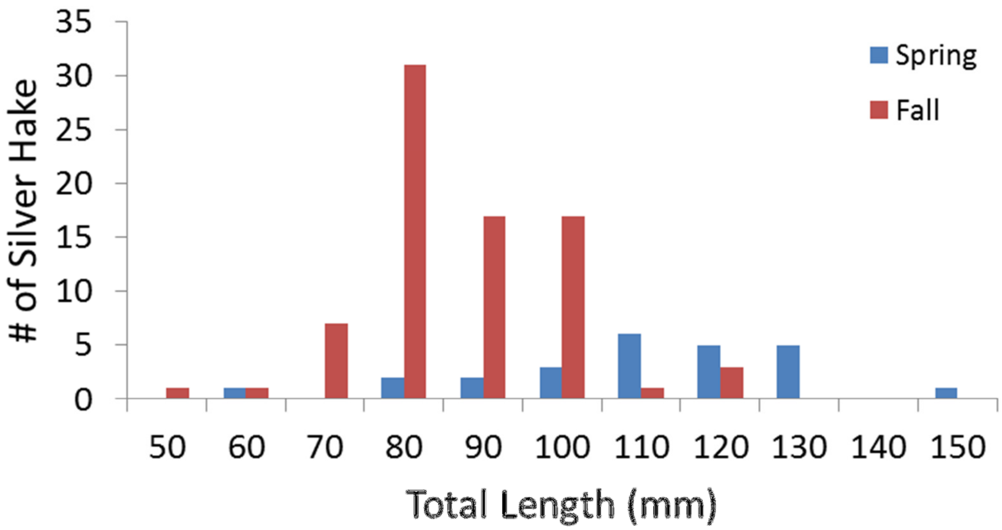

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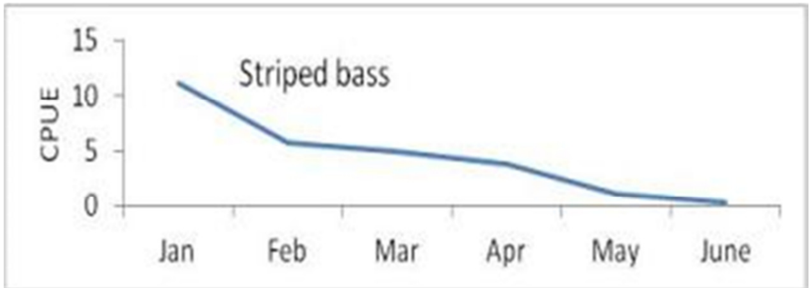

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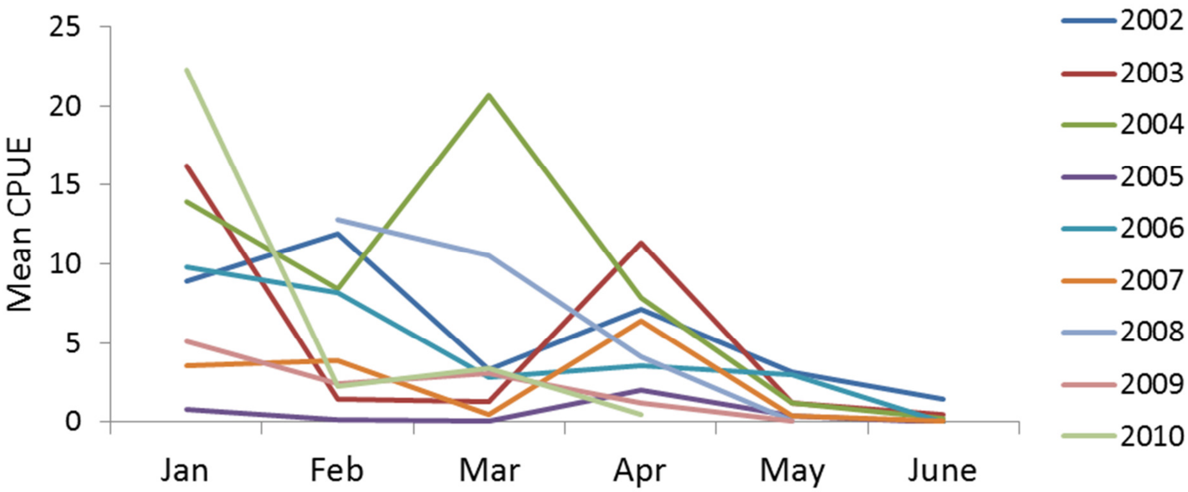

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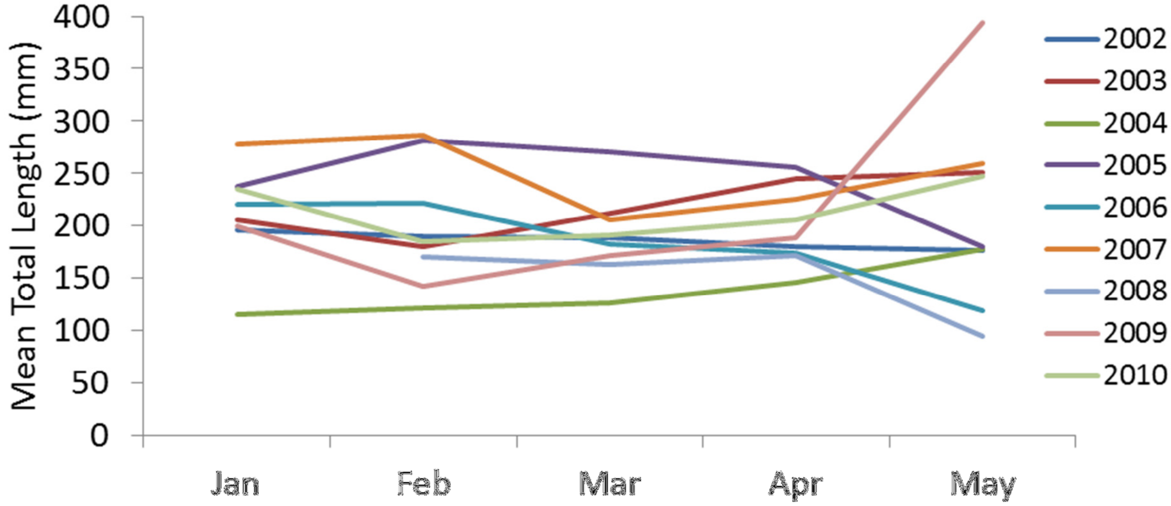

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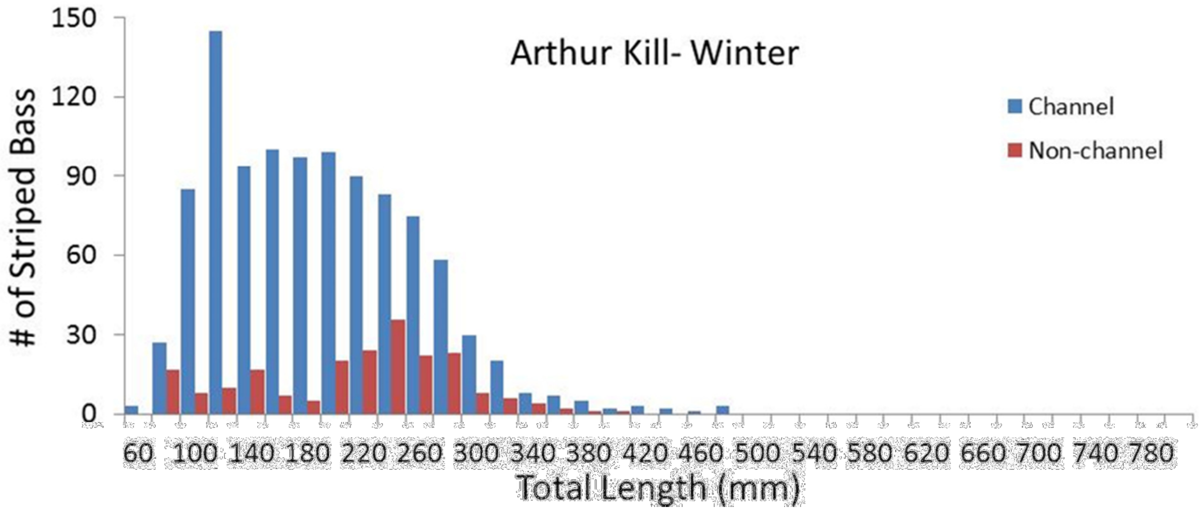

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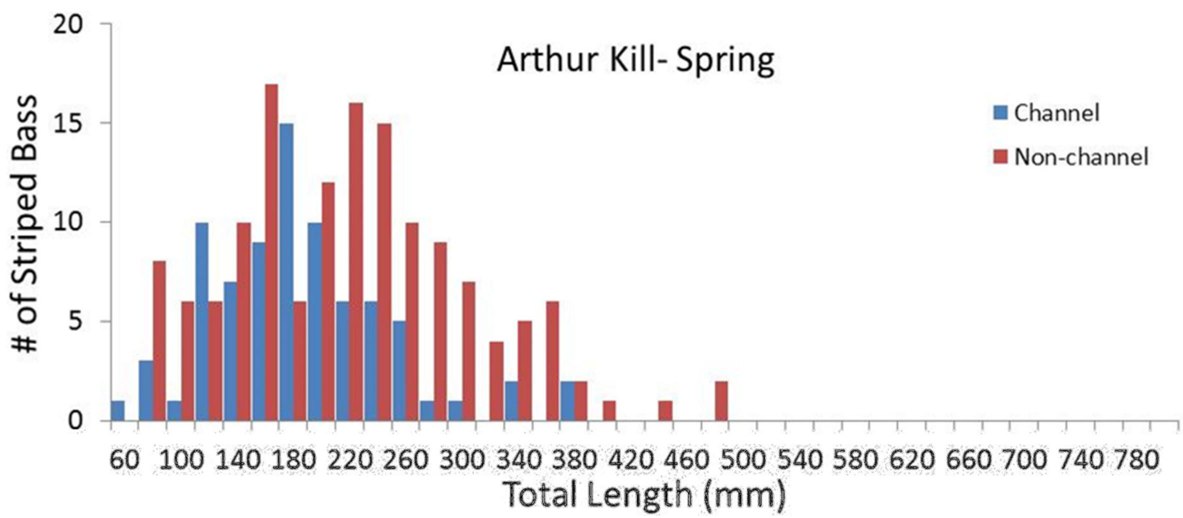

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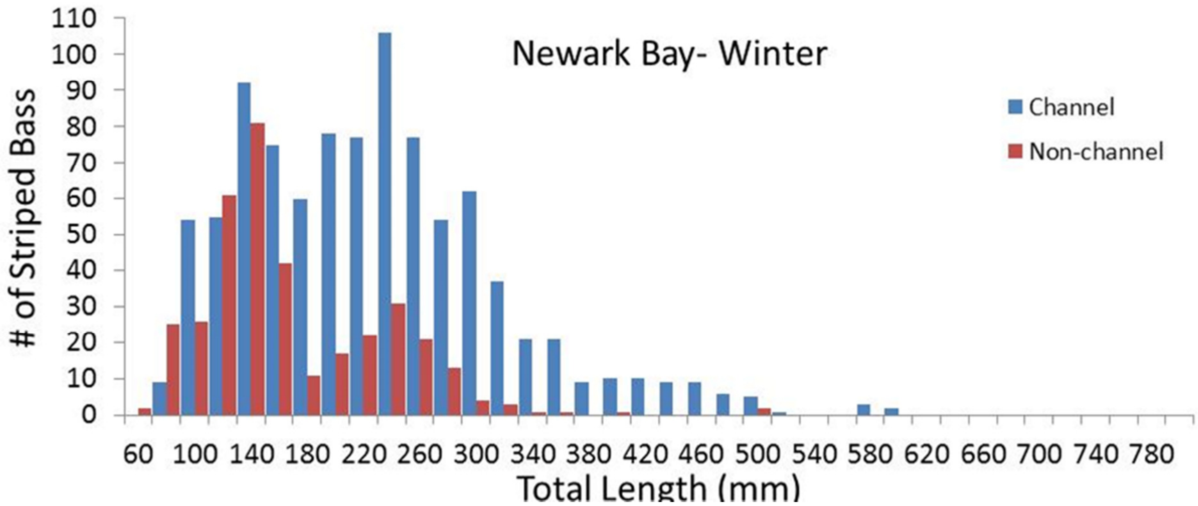

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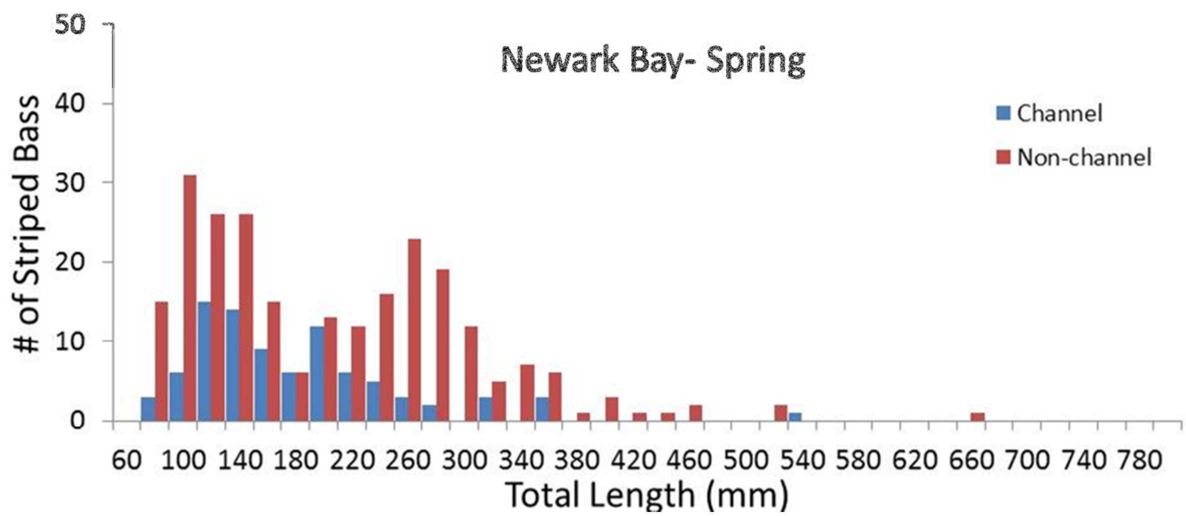

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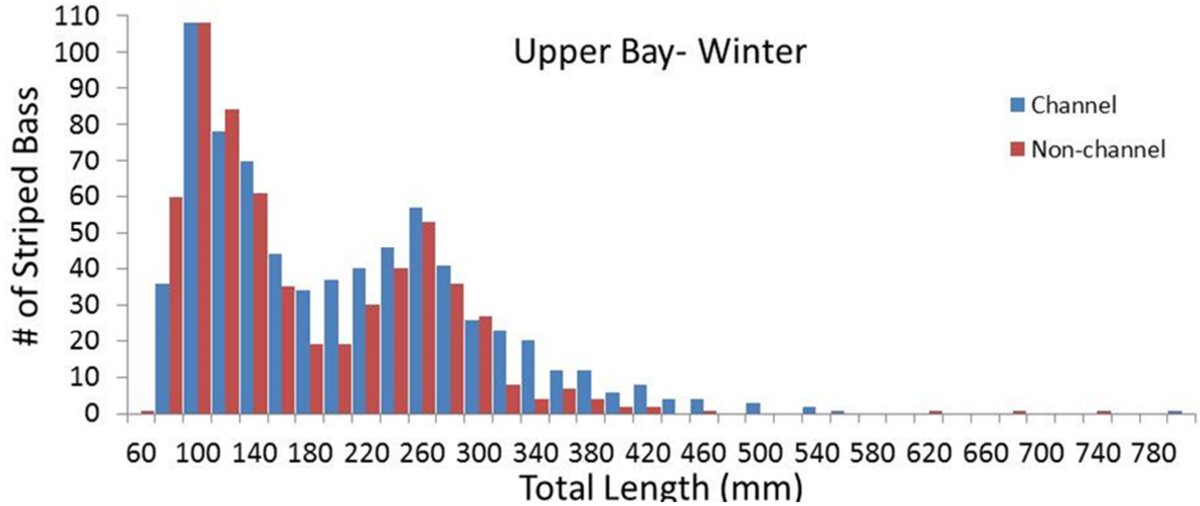

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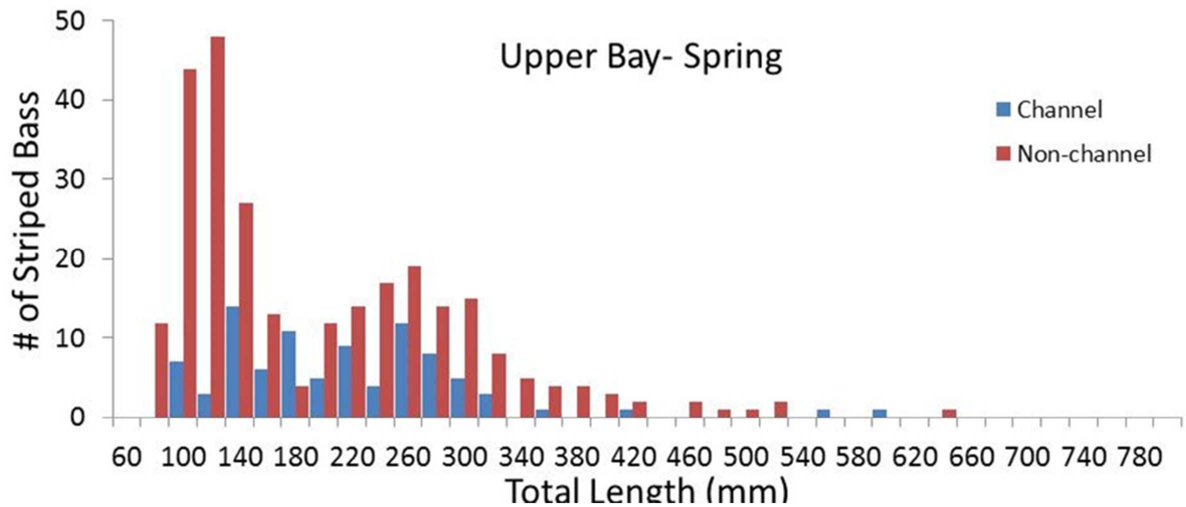

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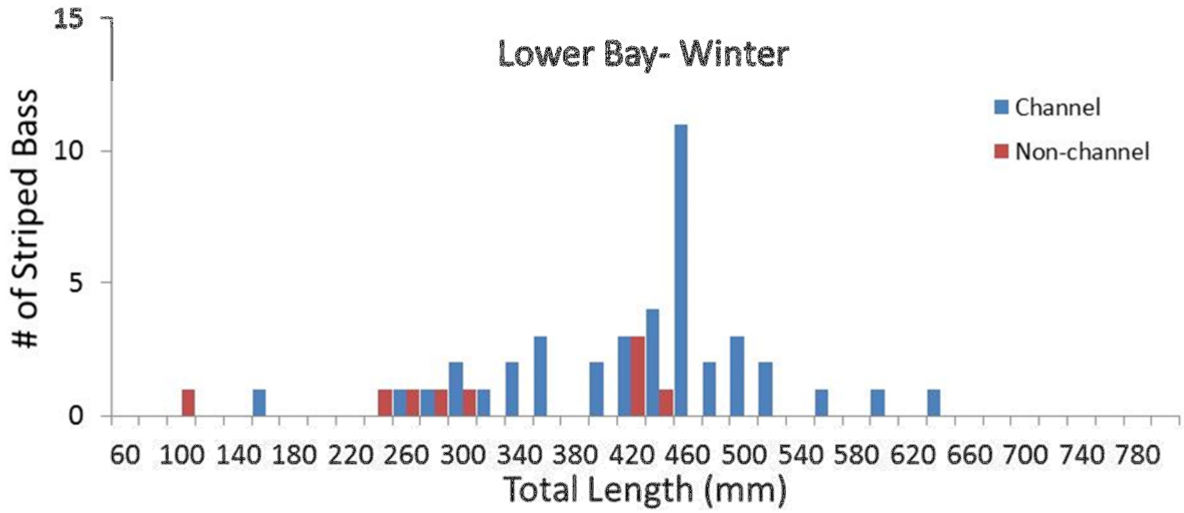

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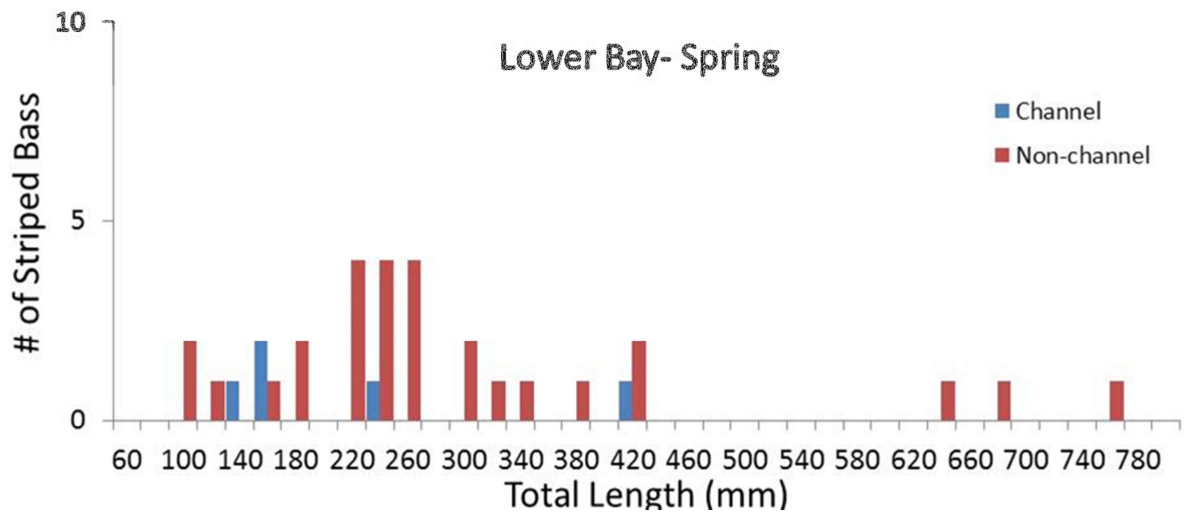

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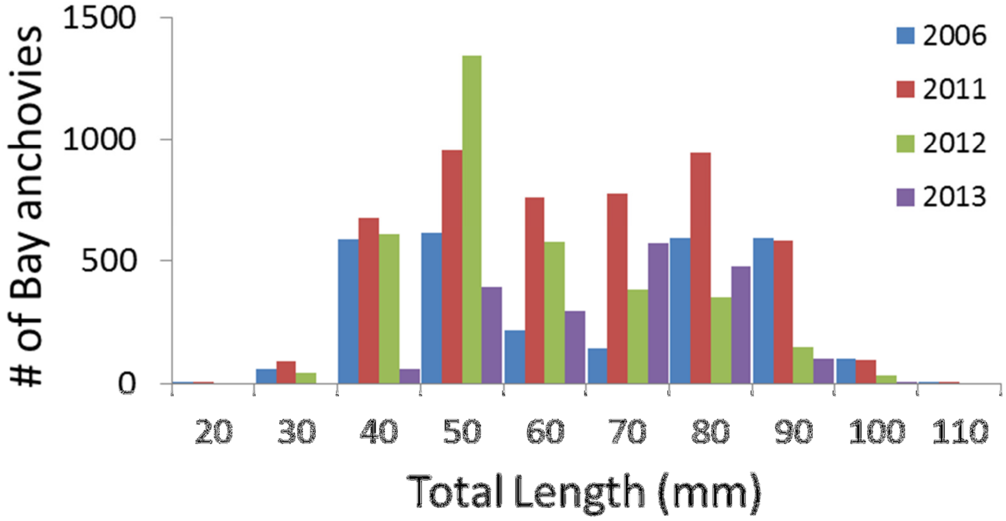

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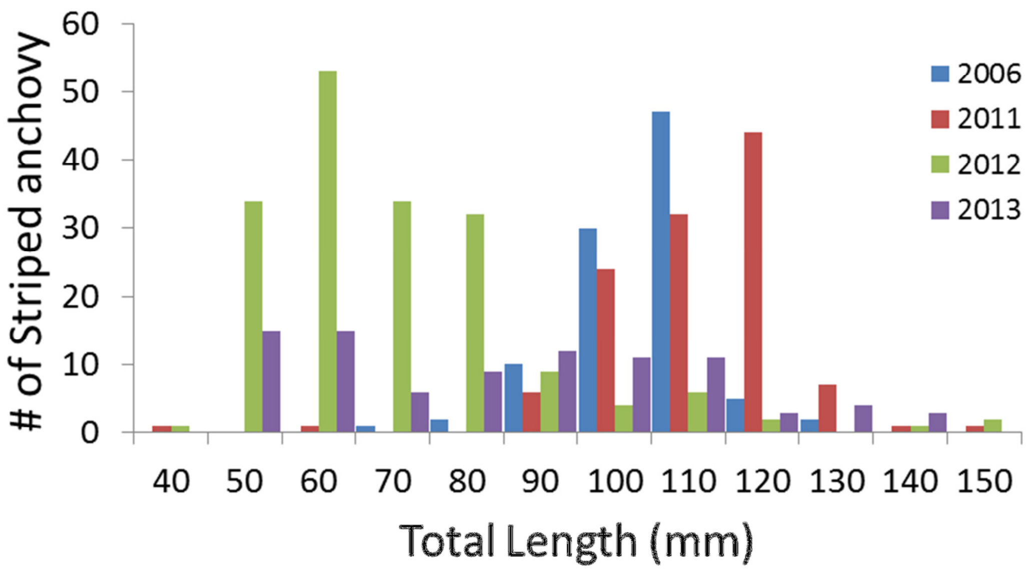

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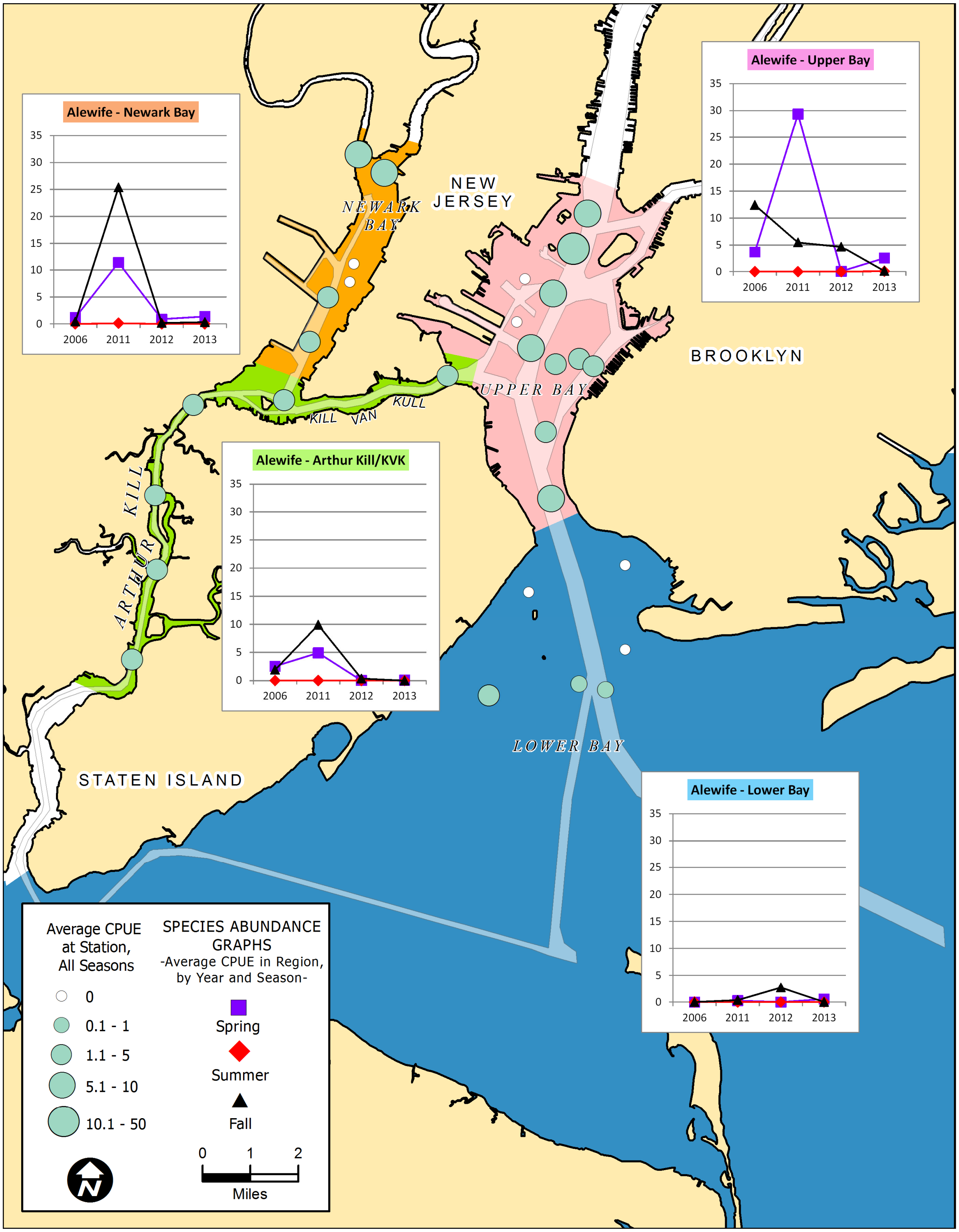

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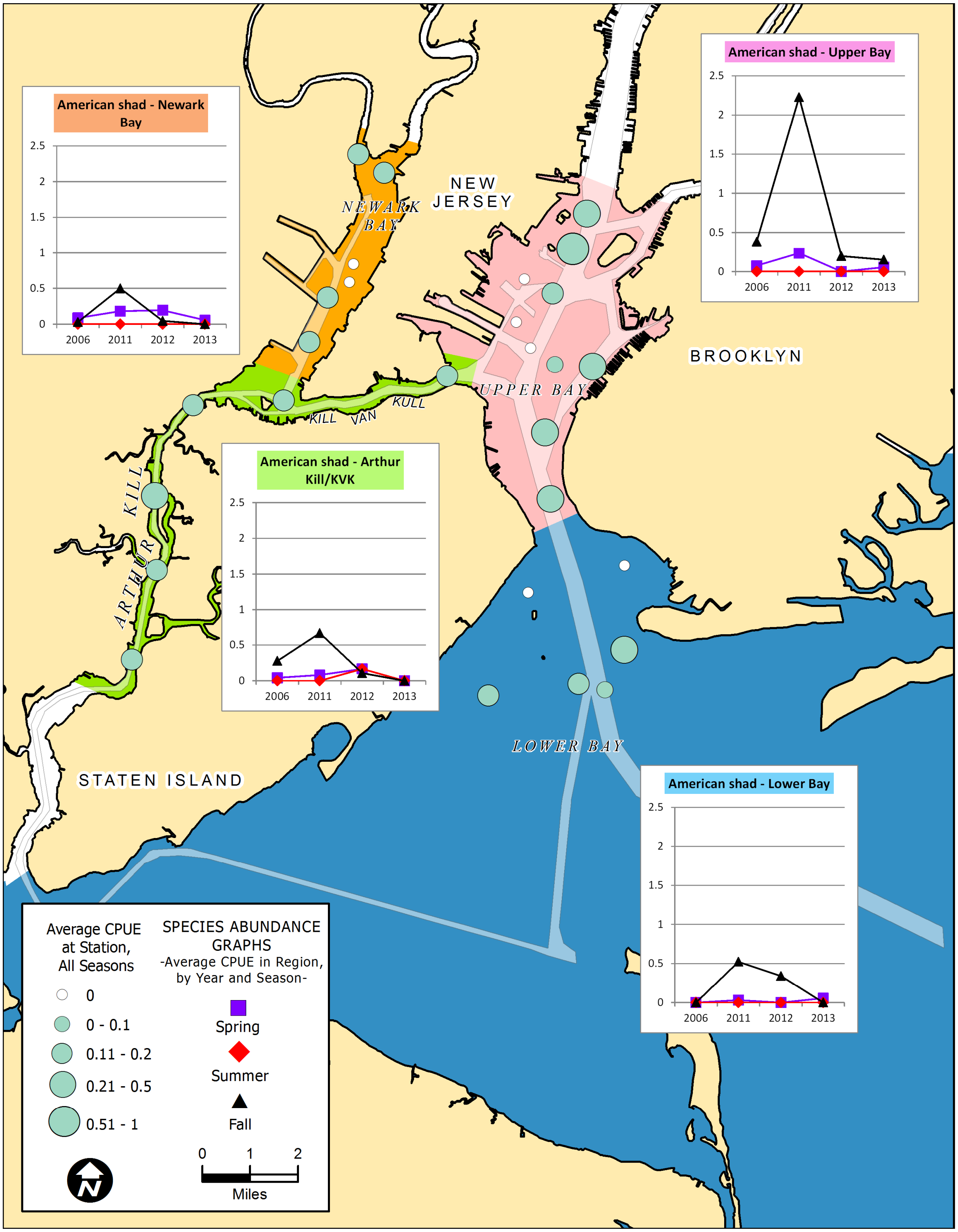

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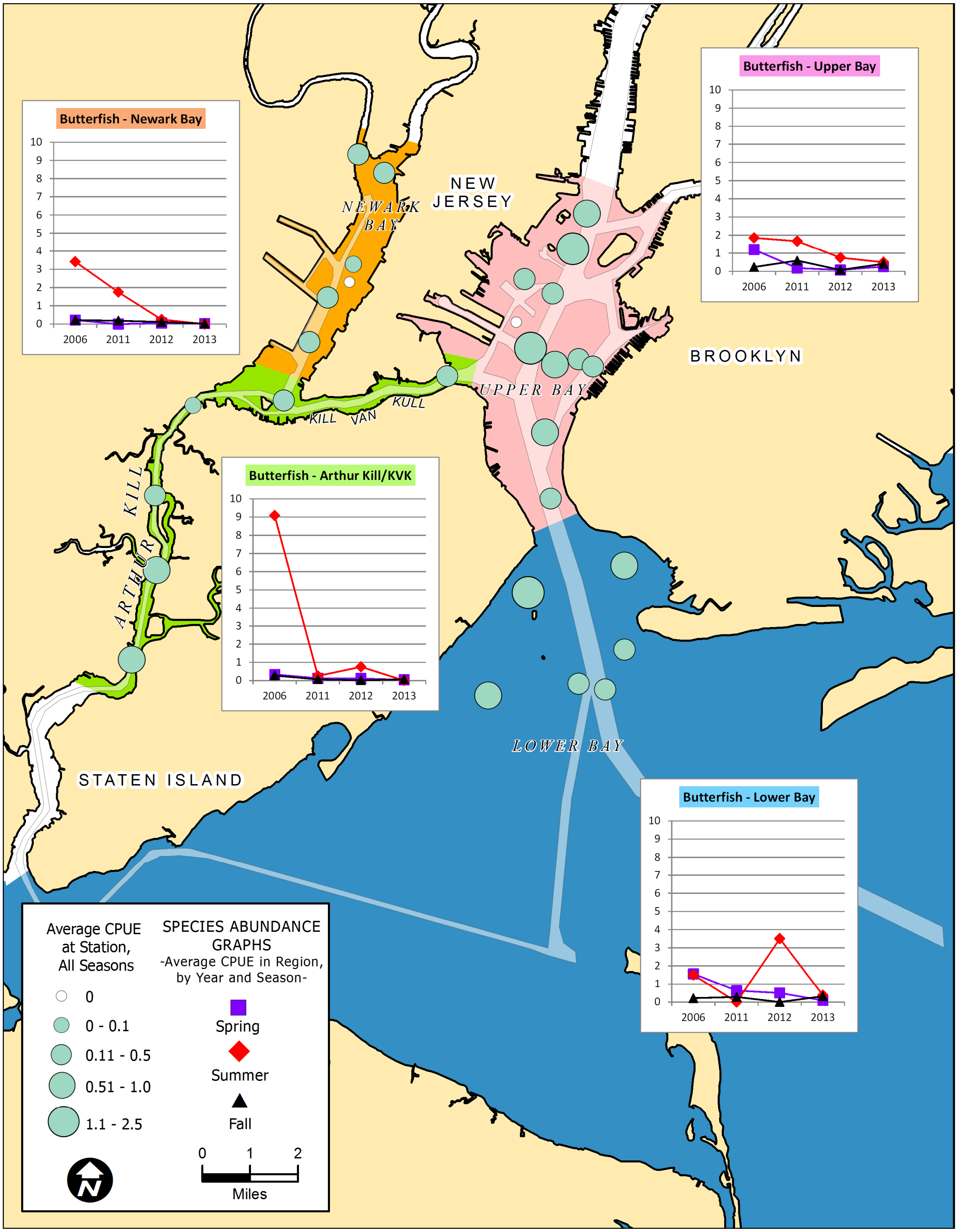

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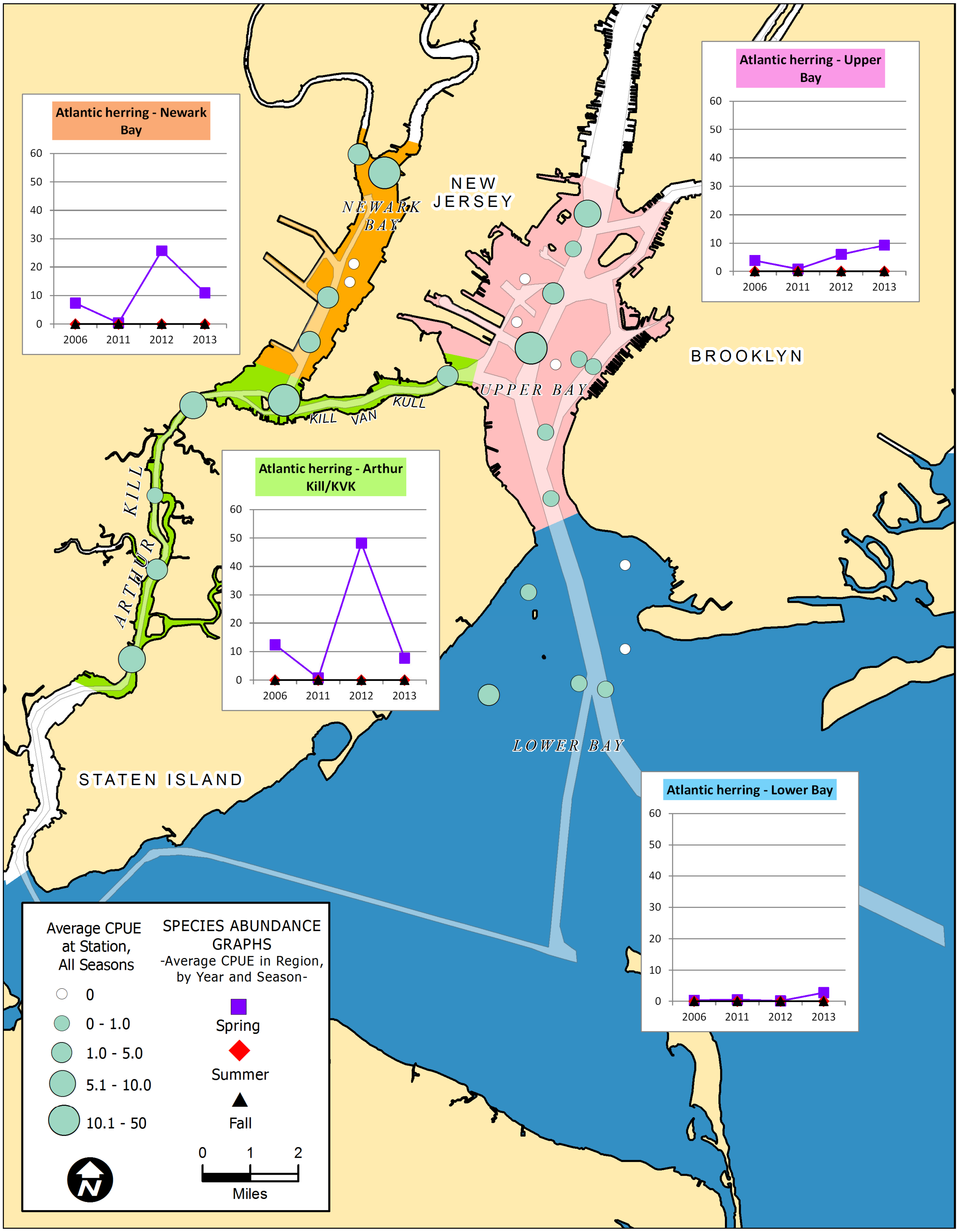

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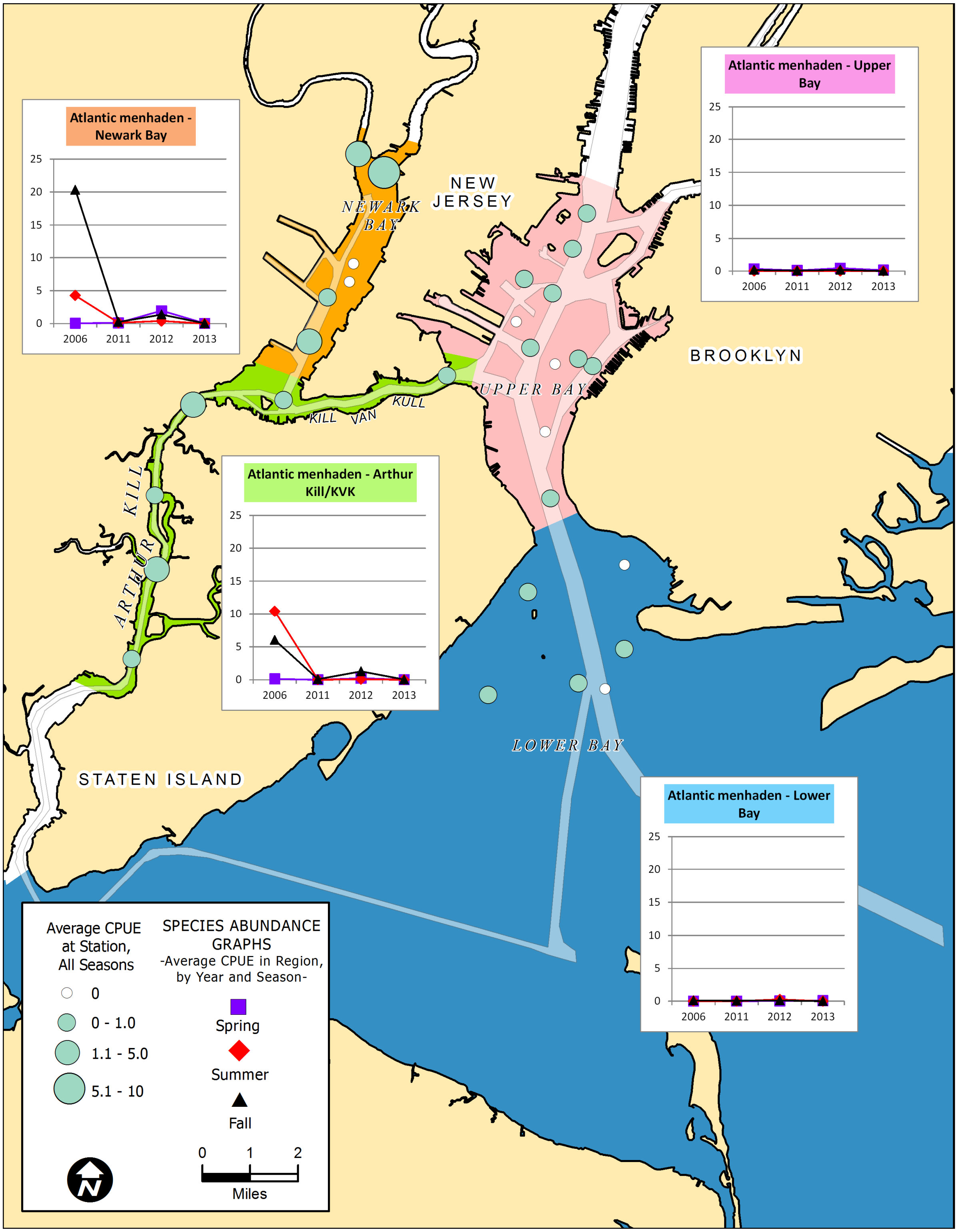

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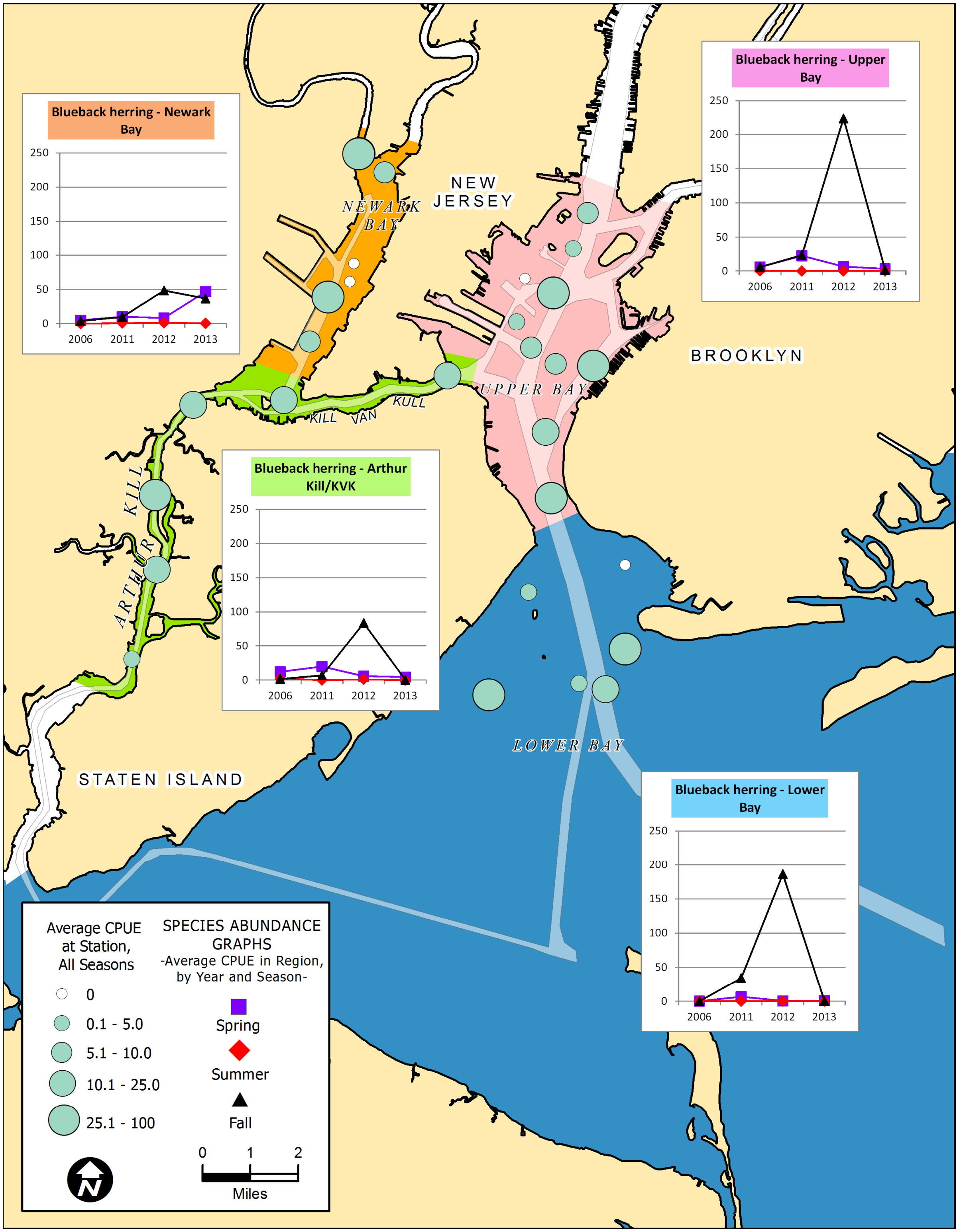

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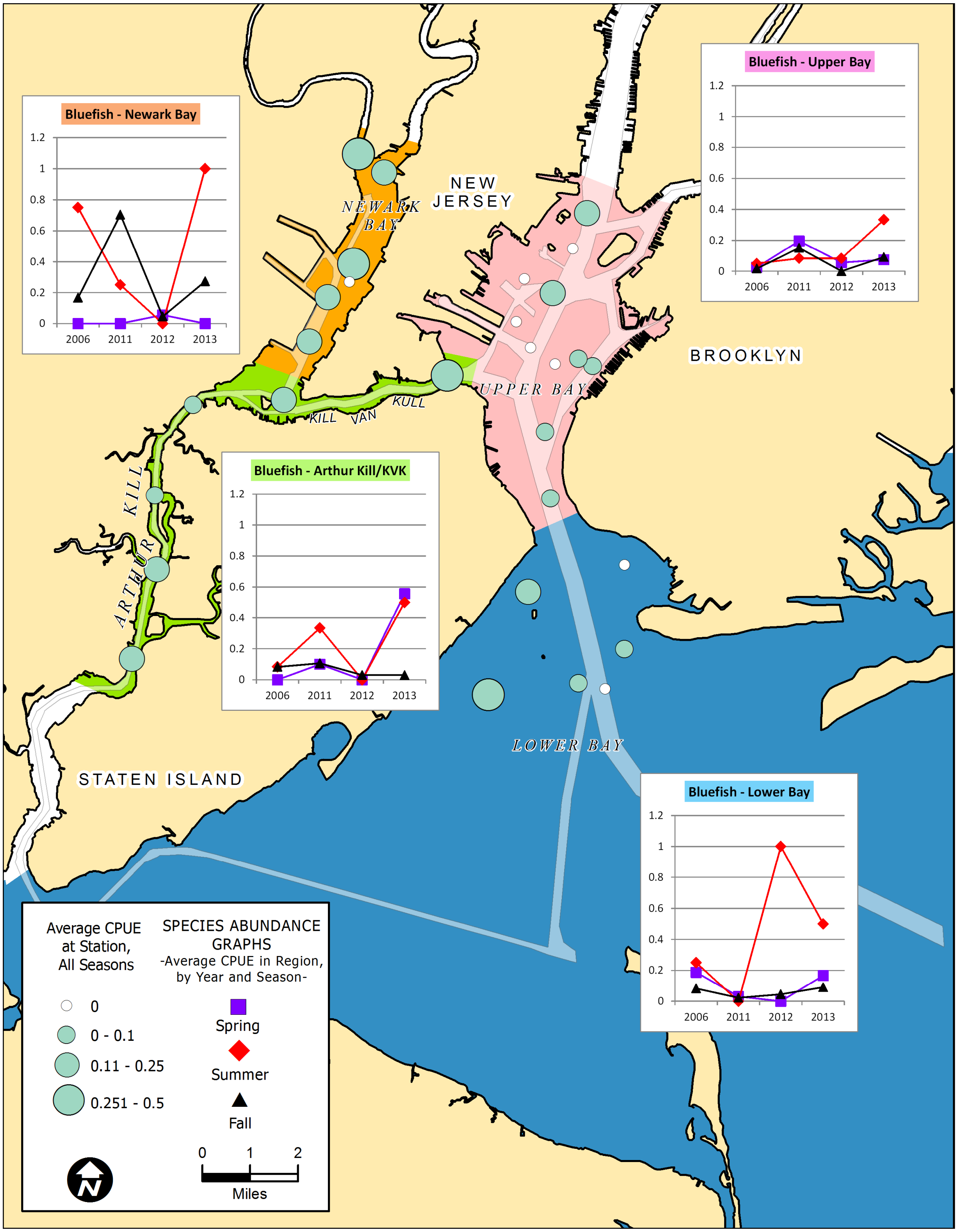

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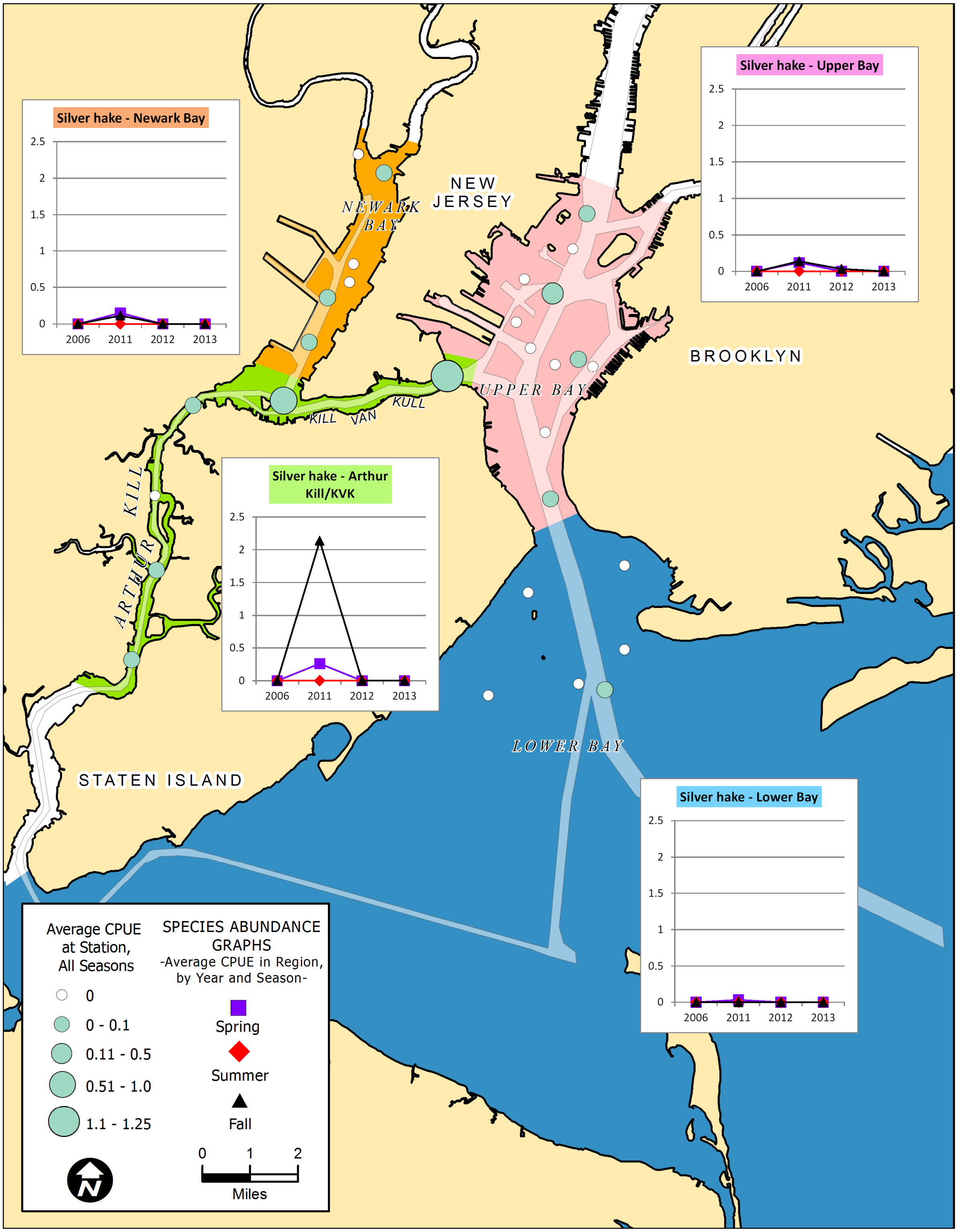

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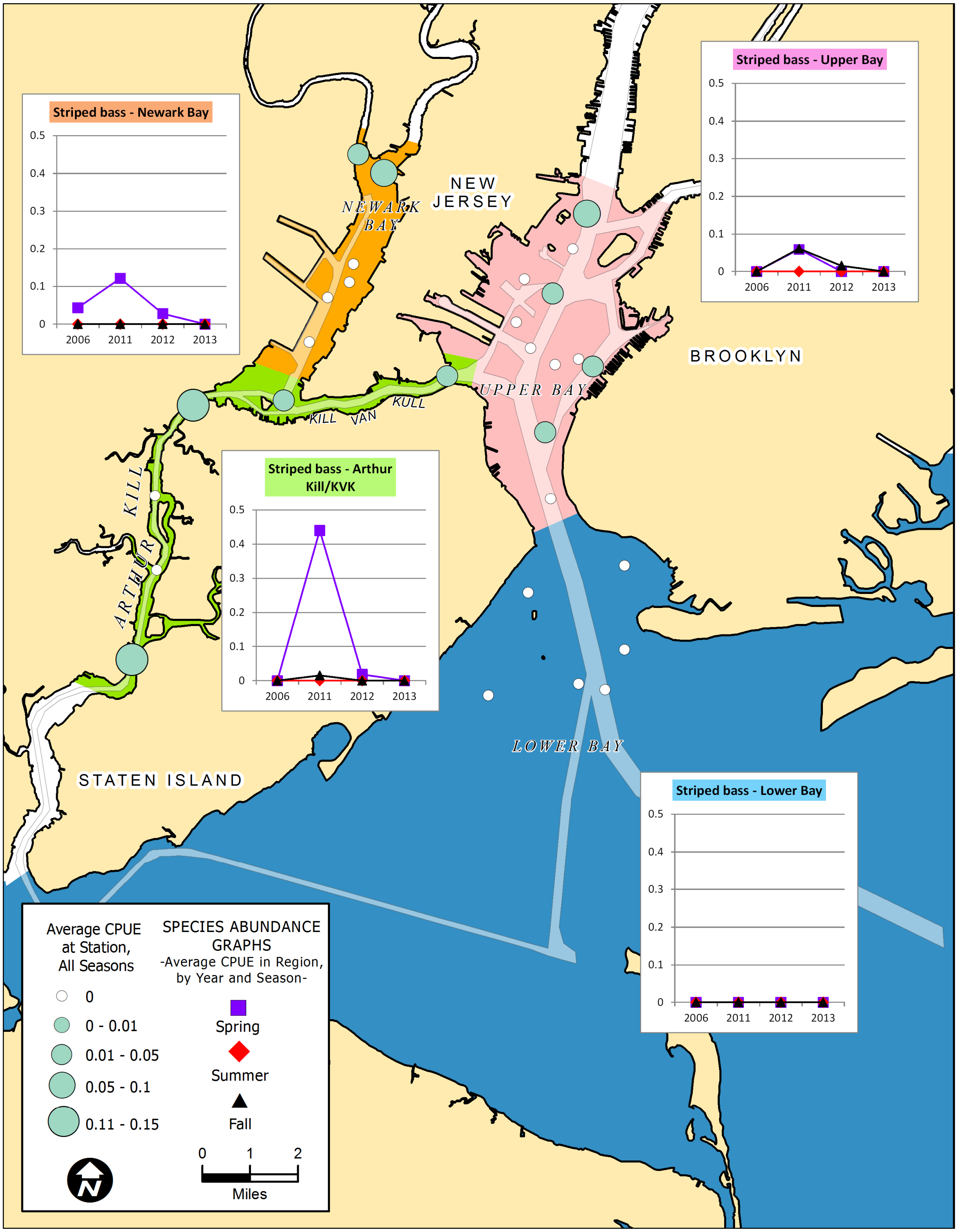

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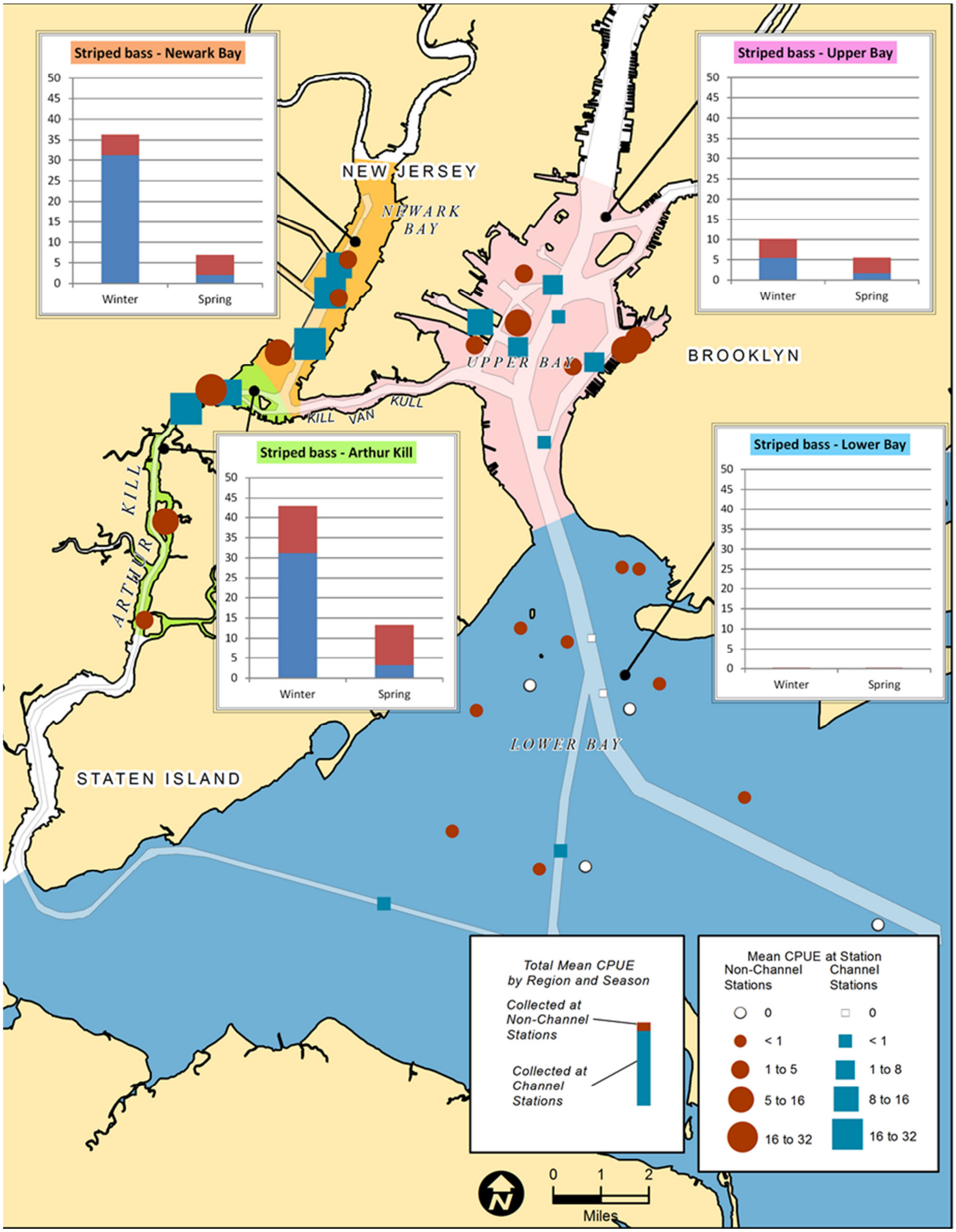

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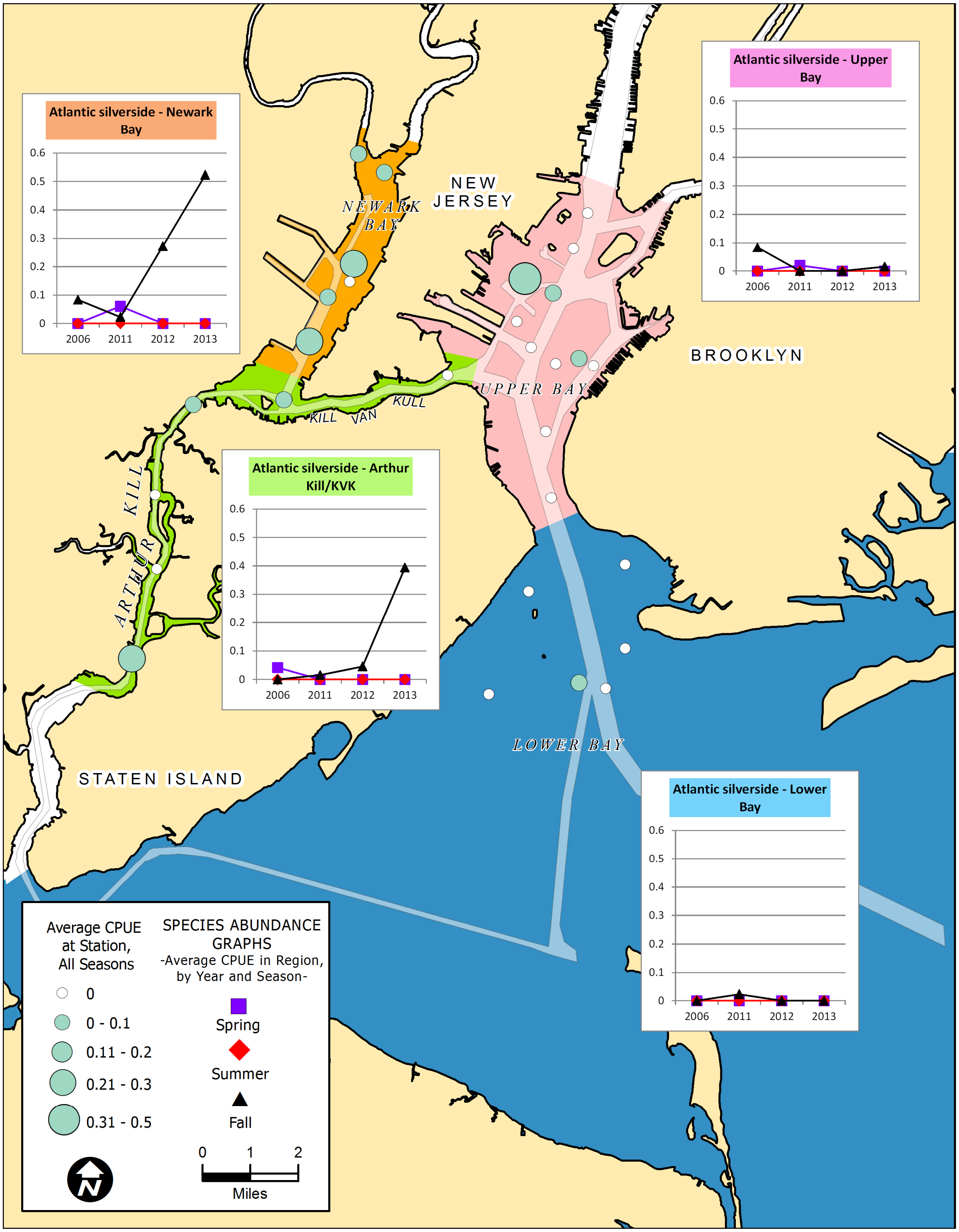

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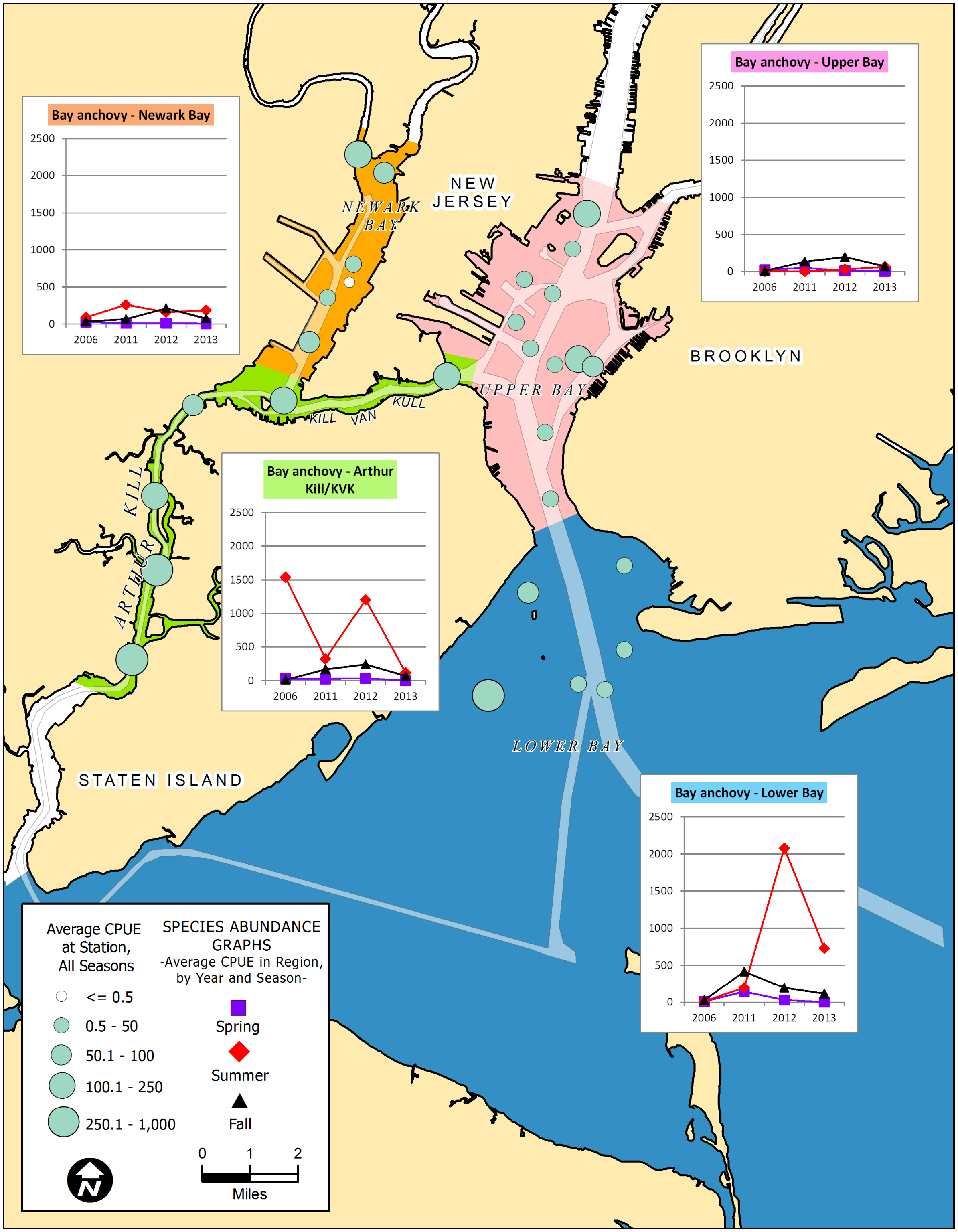

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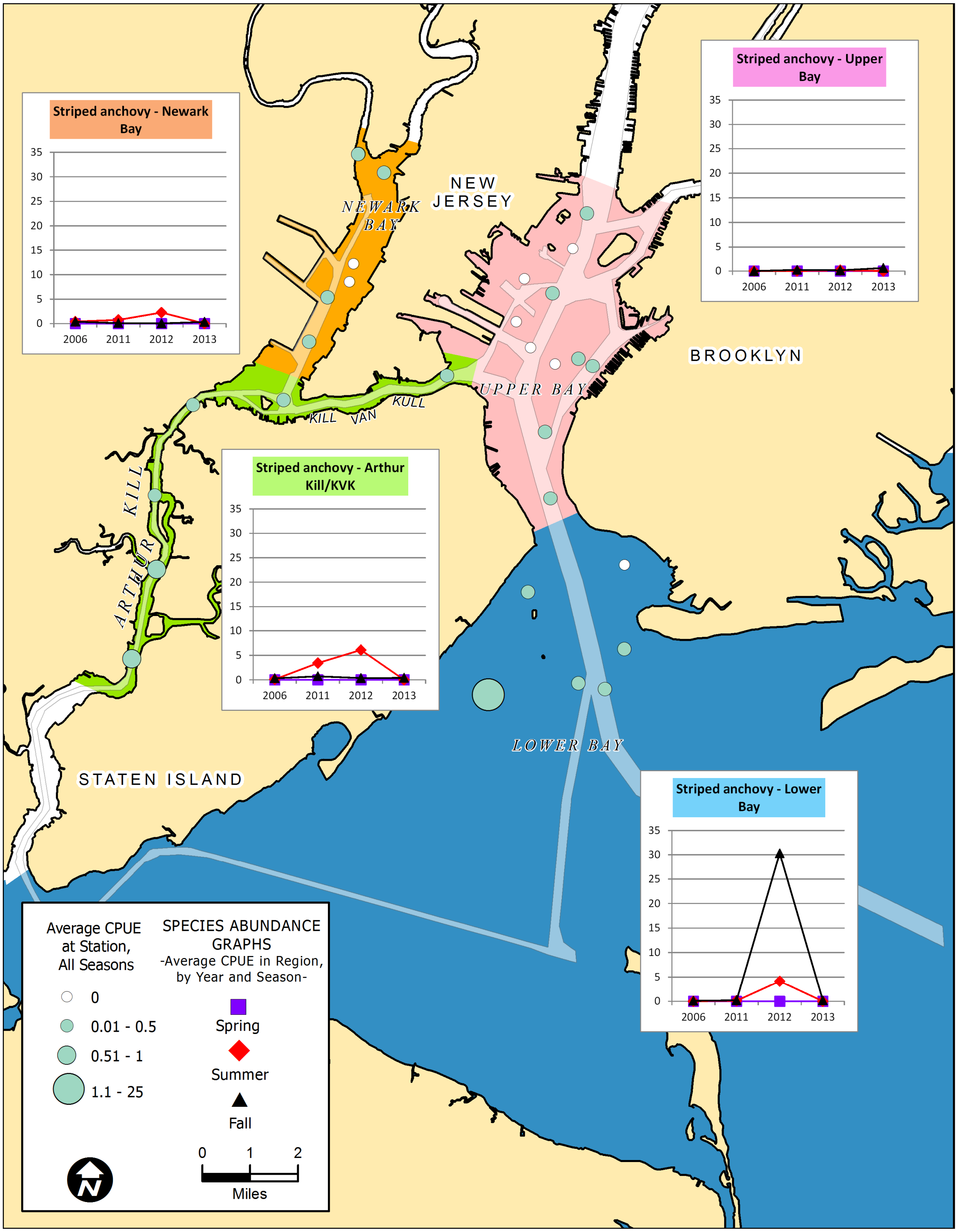

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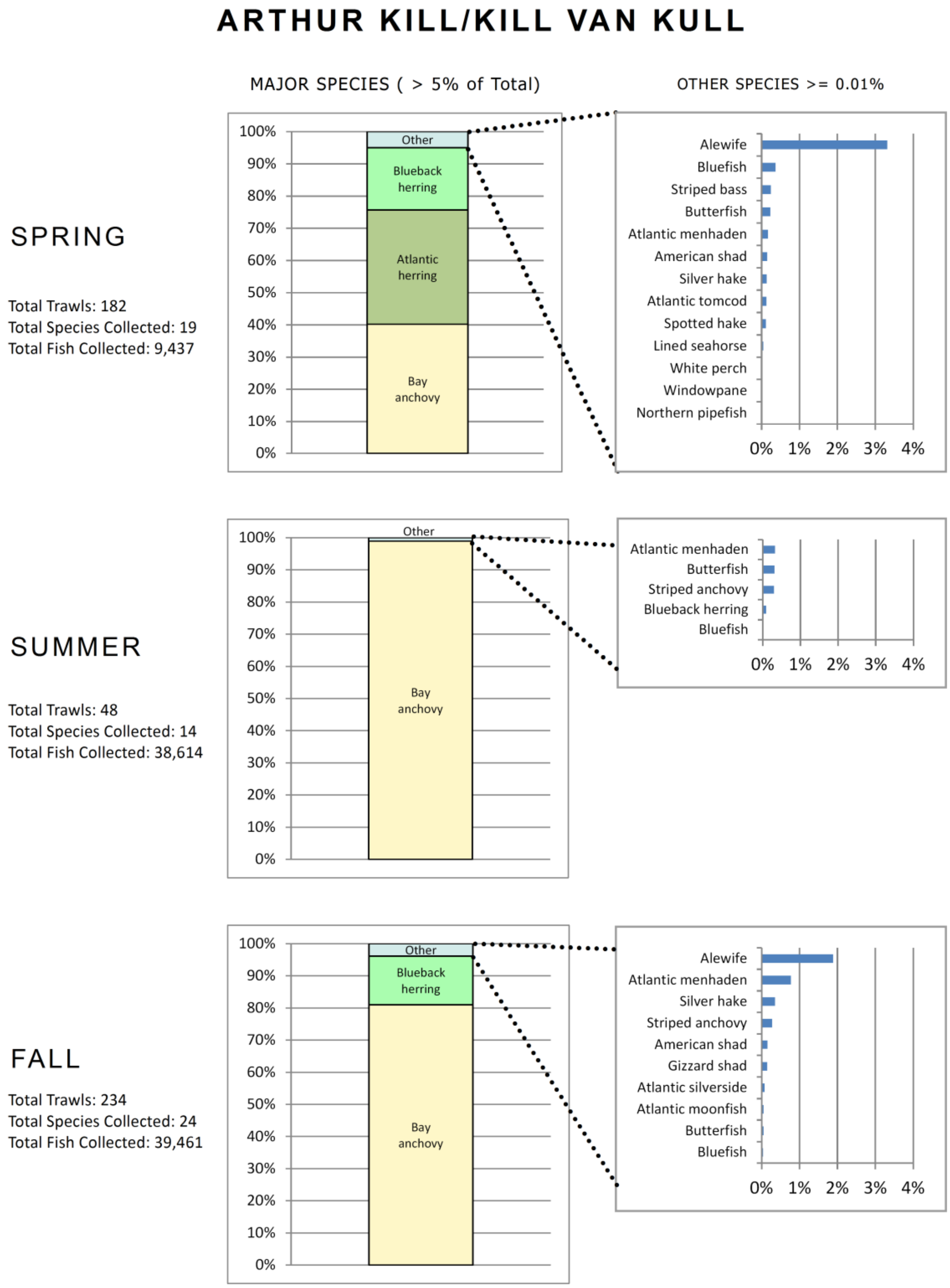

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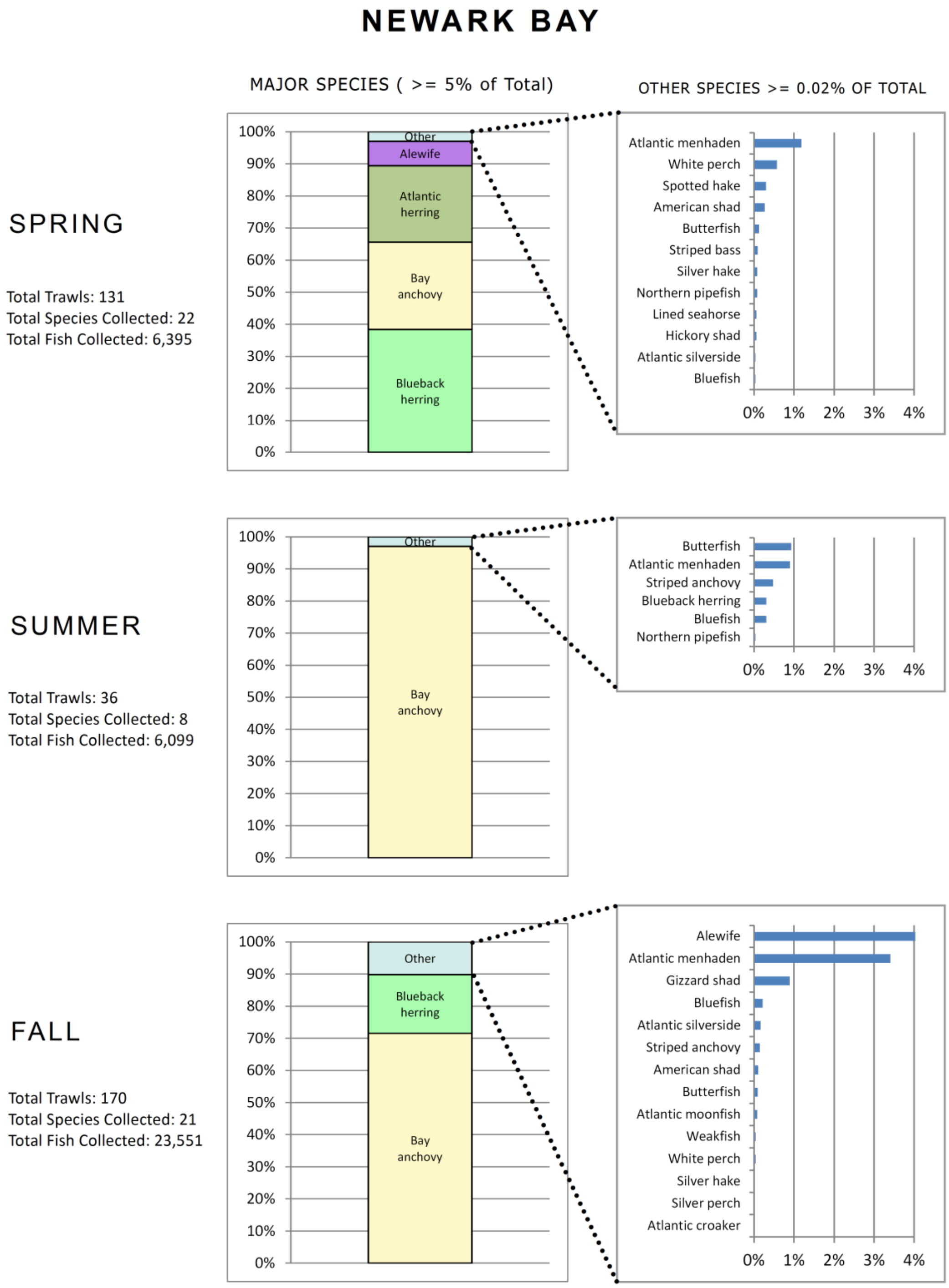

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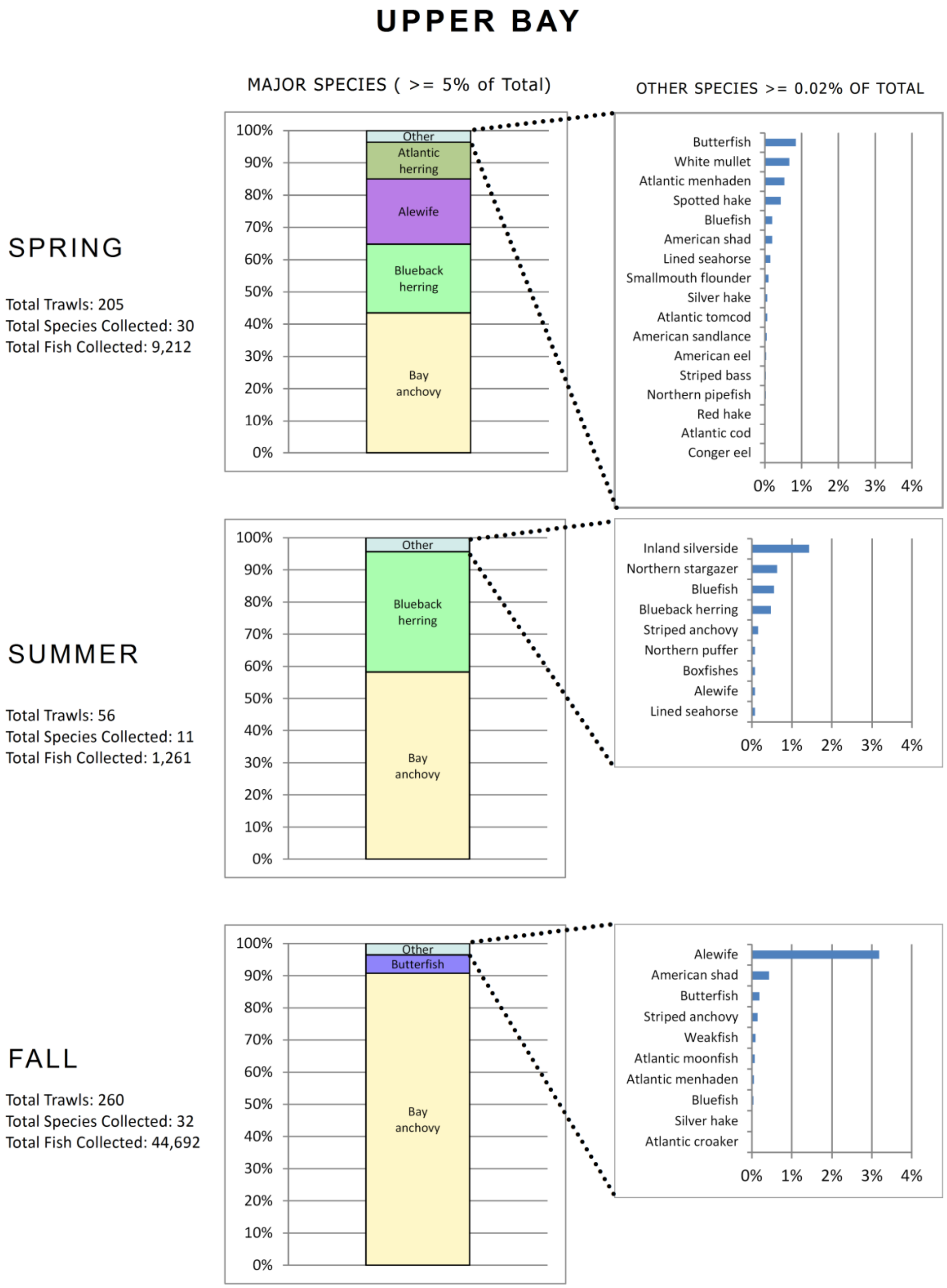

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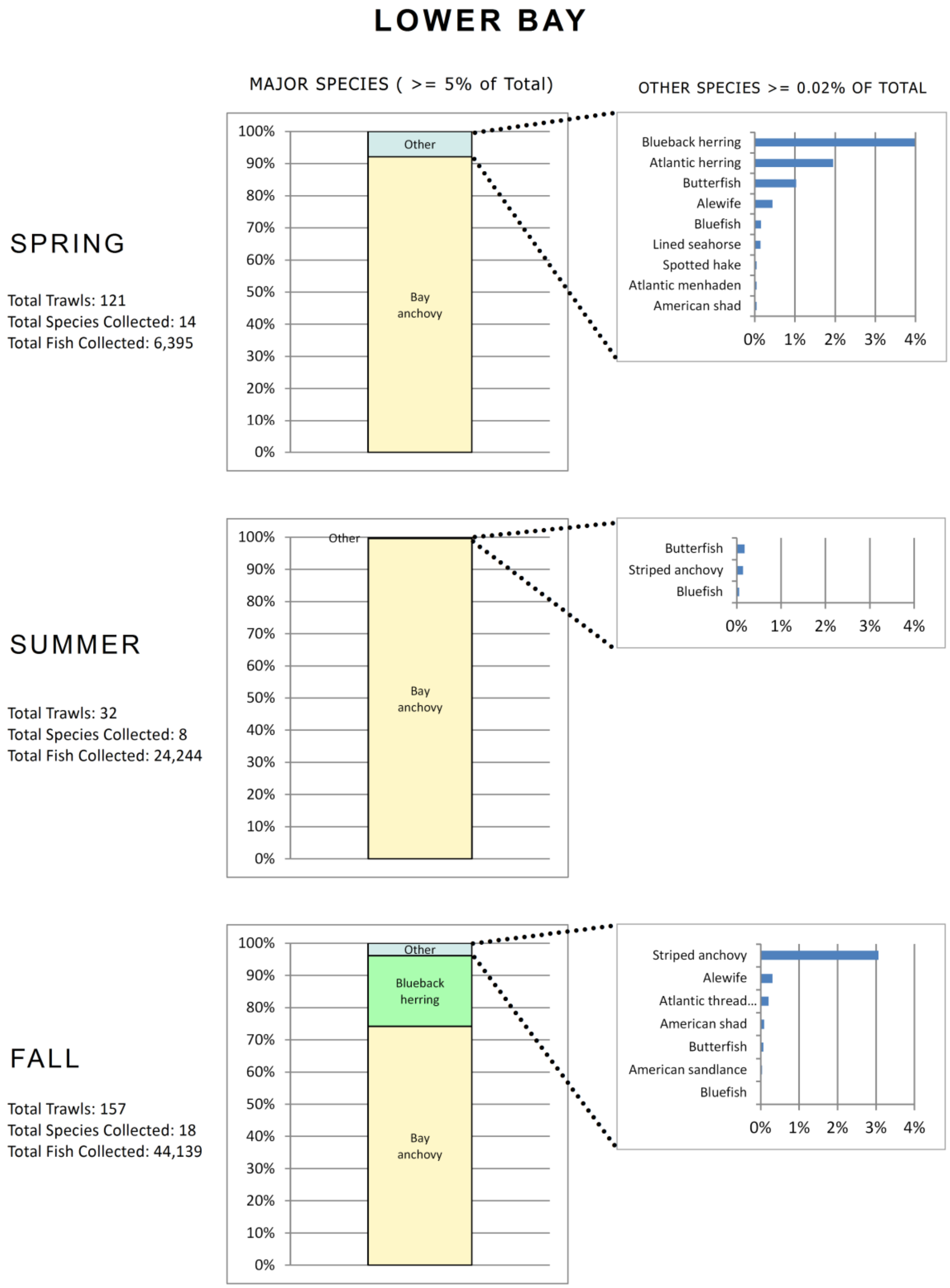

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NEW YORK AND NEW JERSEY HARBOR DEEPENING PROJECT

MIGRATORY FINFISH SURVEY SUMMARY REPORT

Part II: River Herring

December 2015

Prepared for:

U.S. Army Corps of Engineers – New York District

Jacob K. Javits Federal Building
26 Federal Plaza
New York, New York 10278

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1.0 INTRODUCTION

1.1 BACKGROUND

The 2006 and 2011-2013 Migratory Finfish Surveys (MFS) were conducted as part of the New York and New Jersey Harbor Deepening Project (HDP) sponsored by the United States Army Corps of Engineers – New York District (USACE-NYD) and Port Authority of New York and New Jersey (PANYNJ). This project deepened navigation channels to 50 feet to accommodate larger commercial vessels and improve Harbor navigation and safety while minimizing impacts to the overall environment and promoting environmental sustainability. Migratory fish, especially those with high fidelity to spawning sites, are potentially vulnerable to habitat disturbance (factors reducing their ability to migrate), predation, and commercial and recreational fishing along migration corridors because their migratory behavior concentrates them in relatively small areas over short periods of time.

Developing an understanding of where migratory pathways occur and the timing of peak seasonal use will improve effective management of dredging activities within the Harbor while enhancing protection of migratory finfish and habitat. The initial MFS study was conducted during 2006 and follow-up studies were conducted in 2011, 2012 and 2013 to address regional concerns regarding diminishing migratory finfish stocks. In particular, recent evidence suggests that blueback herring and alewife (collectively referred to as river herring) stocks have declined in abundance. Therefore the seasonal movements of alewife and blueback herring in the New York/New Jersey Harbor (Harbor) are examined in this part of the Migratory Finfish Survey Summary Report.

The timing of biannual (spring and fall) migratory movements through the Harbor and locations of migratory pathways have not been well studied. The river herring fishery is one of the oldest in North America, with population declines recorded by the mid-1700s (Hall *et al.* 2012). Over-fishing, habitat degradation, and dam construction that blocked migratory routes have been implicated in early declines of river herring populations throughout their ranges (Hightower *et al.* 1996, Hall *et al.* 2011). Landings have declined sharply in the last several decades (ASMFC 2012) and potential climate change impacts include temporal shifts in migratory behavior (Ellis and Vokoun 2009) and southern range contraction for alewife (Palkovacs *et al.* 2014). River herring are declining in mean length, mean length-at-age, and percent repeat spawners; features characteristic of declining populations (ASMFC 2012). In addition, predation impacts by recovering species, such as striped bass, may be affecting river herring recovery (Heimbuch 2008).

Restoration efforts in the northeastern U.S. involve removing dams and constructing fish ladders so that river herring can access historical spawning grounds in streams and lakes (Walters *et al.* 2009). For example, the American Littoral Society (ALS) conducted a field study in the early 1990s to inventory dams, tide gates and other impediments to anadromous fish migration in NY/NJ Harbor, with emphasis on sites in New Jersey. Over 50 impediments were documented among 40 tributaries. Three New Jersey Rivers in particular were identified as targets for "immediate run restoration" - the Navesink, the Passaic, and the Rahway, based on the presence of multiple large dams along these tributaries (Durkas 1992, 1993). ALS also identified a number of smaller impediments, including wooden wall tide gates, concrete spillways, and culverts along the Shrewsbury, Navesink, Matawan Creek, South River and several other Raritan River tributaries, the Rahway River, Passaic River, the Hackensack River, and tributaries of the Arthur Kill on Staten Island (Pralls Creek and Richmond Creek). In January 2011, NJDEP announced a settlement with the El Paso Corporation to re-establish fish passage to a portion of the Raritan River as compensation to the public for harm to natural resources caused by a refinery and three polymer plants. The settlement required the removal of three dams, providing passage within a nearly 10-mile stretch of the middle and upper Raritan (and 17 miles of tributary waters) within the municipalities of Bridgewater, Bound Brook, Somerville and Manville. Target species include river herring, American shad, American eel, and striped bass.

In New York, NYSDEC has identified over 350 separate impediments to anadromous fish passage on 62 individual tributaries to the Hudson River mainstem (NYSDEC Draft - undated). Most of these are remnants of structures intended to supply water to Colonial Era saw and grist mills, and more recently, for manufacturing facilities and drinking water supplies. While several dams were identified as direct impediments to upstream migration by shad and herring, in most cases the amount of available spawning habitat was limited by additional impediments upstream, or natural barriers/waterfalls. The vast majority of the dams identified among the 62 tributaries are beyond the natural migratory range of herring. Potential opportunities for dam removal have been identified in waterways such as such as Fishkill Creek and Quassaic Creek; however, issues regarding contaminated sediments which may have accumulated behind dams located in these urban waterways may fuel controversy over removal of these structures and will require extensive pre-removal feasibility investigations. Within New York City, the Natural Resources Group (NRG) of the NYC Department of Parks and Recreation conducted investigations on the feasibility of restoring anadromous fish passage in the Bronx River during 2002-2004, including a study of the potential for anadromous fish to spawn and survive in the river; and the development of fish passage design alternatives (Larson and Sugar 2004).

The NRG study concluded that despite the relatively steep reaches between dams that suitable spawning and rearing habitat was available for both blueback herring and alewife. In the Bronx River, they concluded that river herring could survive, reproduce, provide recruitment of a river population, and help increase faunal diversity in the river. Further, Larson and Sugar (2004) determined that the reintroduction of river herring would fit well with the broader conservation and restoration goals for the river. Several steps were recommended including working with the dam owners and other stakeholders to develop acceptable passage alternatives at the dams; implementing a fish stocking program to "jump start" river herring establishment in the river; and continuing to enhance habitat through local and watershed-wide water restoration measures.

Migratory fish are potentially vulnerable to habitat disturbance along migration corridors because their migratory behavior concentrates them in relatively small areas over short periods of time. For example, river herring that use the Hudson River pass through the Harbor to access upstream spawning areas and juveniles must pass through the Harbor as they emigrate to the marine environment. River herring are native to the coastline of the northwest Atlantic Ocean and serve important ecological roles in coastal environments, including nutrient loading (Walters *et al.* 2009, West *et al.* 2010) and as a prey resource for fish (Heimbuch 2008) and piscivorous birds (Jones *et al.* 2010). The transfer of marine derived nutrients to freshwater food webs can take place via excretion, gametes and carcasses and may affect freshwater algal and invertebrate biomass, which in turn, affects growth and survival of organisms at higher trophic levels (Walters *et al.* 2009). Nutrient export to the marine environment occurs when juveniles emigrate from freshwater systems. Timing and duration of passage within the Harbor are influenced by environmental cues including temperature and river discharge, as well as the specific migratory pathway (e.g., spawning run travelled). Spawning runs to the Hudson River and its tributaries as well as the Hackensack and Passaic Rivers and the East River/ western Long Island Sound bays and tributaries are of particular importance because access to these waterbodies requires passage through navigation channels and other areas within the Harbor complex.

Potential dredging-related impacts to successful spawning migrations include the effects of resuspended sediments that may mask pheromones used by fish to identify their spawning grounds (Baker 2003, Newcombe and MacDonald 1991) and noise from dredging activities that may impede migration. The 2015 draft HDP Conservation Recommendation recommends a seasonal dredging restriction from March 1 to June 30 to allow anadromous fish to pass through the Harbor to upstream spawning areas in the Hudson River, Hackensack River, and Passaic River (NMFS 2015). In downstream areas, including Kill Van Kull, Arthur Kill and Newark Bay, the dredging restriction ends on May 31st because it is expected that fish have passed through these areas by this time. At the beginning of 2013, both river herring species were candidates for federal listing. On August 12, 2013, however, based on the best scientific and commercial data available, NMFS determined that listing alewife and blueback herring as endangered or threatened under the Endangered Species Act was not warranted at this time (78 FR 48944-48994, August 12, 2013).

Empirical data collected during two extensive monitoring programs are examined in this report to better document the timing and locations of river herring in New York/New Jersey Harbor. Water temperatures at the time of collections are examined for trends across years of sampling. Other potential physical influences, such as freshwater discharge also are considered. Developing an understanding of where river herring migratory pathways occur and the timing of peak seasonal use (temporal and spatial patterns) can improve effective management of dredging activities within the Harbor while protecting this resource.

1.2 TARGET SPECIES LIFE HISTORY

1.2.1 Alewife

The alewife, an anadromous species, inhabits waters from the Gulf of Saint Lawrence to South Carolina, occurring primarily between the Gulf of Maine and the Chesapeake Bay. Adult alewives enter the NY/NJ Harbor between late-February and mid-March moving upstream to spawn in freshwater tributaries in relatively shallow water with slow currents (Schmidt *et al.* 1988; Everly and Boreman 1999). Alewives typically spawn three to four weeks before blueback herring (Loesch 1987 in ASMFC 2009), when water temperatures rise to approximately 10°C. Alewives enter tributary spawning streams of the Hudson River during early April when water temperatures rise above 10 °C (Kahnle and Hattala 2010). There are at least 18 Hudson River tributaries with recently documented alewife spawning runs, including larger runs in Canterbury Brook, Middlehope Brook, Wappingers Creek, Black Creek, and Rondout Creek in the lower Hudson River and Coxsackie Creek, Vloman Kill, Moordener Kill, and Poesten Kill in the upper Hudson River (Schmidt and Lake 2000).

Alewife larvae and juveniles remain in their freshwater nurseries until late May or June before moving downstream as young-of-the-year into the lower estuary where they remain until moving into the ocean in November (Stone *et al.* 1994, Everly and Boreman 1999). It is generally accepted that juveniles join the adult population at sea within the first year of their lives and follow a north-south seasonal migration along the Atlantic coast, similar to that of American shad (Neves 1981).

Generally, female alewives are larger and heavier, and grow slightly faster than males of the same age (ASMFC 2012). Size and age at sexual maturity vary depending on the latitudinal location of their natal rivers. River herrings with a minimum total length (TL) of 170 millimeters (mm) in the Hudson River watershed are characterized as spawning adults (ASMFC 2012). The River Herring Stock Assessment reported that Hudson River alewives and blueback herring of both sexes have experienced significant decreases in mean length over time and currently range from 240-280 mm TL (ASMFC 2012). Mean TL of river herring sampled during 2004-2010 from the Hudson River were on average about 25-45 mm smaller than those species and sexes sampled prior to 1986 (ASMFC 2012). Age at maturity is often calculated based on the spawning marks left on the fish's scale, which are scar-like rings extending around the scale (like an annuli) that are formed during the spawning migration into fresh water where little or no food is eaten by adult fish (ASMFC 2012). In the Hudson River, alewives that previously spawned ranged in age from four to ten years during 1999-2001, while females ranged in age from five to ten years (ASMFC 2012).

1.2.2 Blueback herring

Blueback herring inhabit coastal and estuarine waters from Nova Scotia to Florida, with concentrations in the Middle and South Atlantic Bight. In general, blueback herring have a more southern distribution than alewife (Mullen *et al.* 1986). Similar to alewife, blueback herring are present in coastal ocean waters prior to entering estuaries on their annual spawning runs during the spring (Schmidt *et al.* 1988). Prior to the spawning run, adult blueback herring stage in estuaries at the mouth of natal rivers in March and early April when water temperatures are approximately 4-9 °C (Loesch and Lund 1977, Able and Fahay 2010).

Adult blueback herring enter the Hudson-Raritan Estuary in early March prior to their migration to spawning areas from May to July (Stone *et al.* 1994). Adult blueback herring swim at mid-water depths and have been documented to feed during their freshwater migration (Monroe 2000). The blueback herring spawning period usually begins about a month later than that of alewife (Loesch 1987) and they prefer deep freshwater habitats with swift currents over hard gravel or sand substrates (Loesch and Lund 1977, Everly and Boreman 1999). After spawning, blueback herring move into the lower estuary and coastal ocean waters, although a few adults may remain in the estuary through winter (Stone *et al.* 1994).

Juvenile blueback herring begin migrating downstream to the estuary at the end of summer, approximately a month after American shad and alewife (Marcy 1976, Monroe 2000 and references therein). By the end of November, juveniles have typically returned to the ocean, though some evidence of juvenile overwintering in estuaries has been reported in New Jersey and the lower Connecticut River (Monroe 2000 and references therein). Aside from a few juveniles overwintering within estuaries during their first year, researchers assume that most juveniles join the adult population at sea within the first year of their lives, and follow a north-south seasonal migration along the Atlantic coast, where changes in temperature likely drive oceanic migration (Neves 1981).

Blueback herring are typically smaller than alewife, but follow the same general pattern of sex-specific growth where females are larger, heavier, and grow slightly faster than males of the same age (ASMFC 2012). As stated above, the River Herring Stock Assessment reported significant decreases in mean length over time for the Hudson River, with adult river herring currently ranging from 240-280 mm TL (ASMFC 2012). In the Hudson River, blueback herring that previously spawned ranged in age from three to nine years based on available data (1989-1990, 1999-2001), while females that had previously spawned ranged in age from three to ten years (ASMFC 2012).

2.0 METHODS

The timing and location of river herring collections in the Harbor were examined using two HDP data sets, the nine-year (2002 - 2010) Aquatic Biological Survey (ABS) conducted by bottom trawl (Figure II-1a) and the four-year (2006, 2011-2013) Migratory Finfish Survey (MFS) conducted by mid-water trawl (Figure II-1b). Sampling methods for bottom trawl (USACE-NYD 2012) and mid-water trawl (Part I of this report) were previously described. ABS sampling using a 30-ft bottom trawl to collect adult and juvenile demersal fish was conducted from December/January to May/June and data from this program were examined to document the timing of winter/spring spawning runs. MFS sampling was generally conducted from March to December (Table II-1). Fall sampling into early December allowed an examination of the timing of juvenile emigration from rivers into the estuary.

Because sub-adults accompany adults on spawning migrations (ASMFC 2012), a size threshold of > 170 mm TL for alewife and blueback herring was appropriate for examining spawning migratory activity, even though blueback herring reach sexual maturity at a larger size. River herring with a minimum TL of 170 mm in the Hudson River watershed were characterized as spawning adults by the Atlantic States Marine Fisheries Commission (ASMFC 2012). Inclusion of these larger sub-adults increased sample sizes and the potential that the timing and locations of migratory activity could be identified. Bottom water temperatures recorded during ABS sampling events in which adult alewife or blueback herring were collected were plotted against the sampling date for each year to allow an examination of potential temperature triggers to migratory activity through the Harbor. Similar plots were generated using MFS temperature and collection data. Using ABS data, adult alewife CPUE in January and February were compared between the Lower Bay, where river herring enter the estuary from the ocean and Newark Bay and Upper Bay, which may represent staging areas for upstream migrations to the

Hackensack/Passaic and Hudson Rivers, respectively. A similar comparison was made for adult blueback herring between Lower Bay and Upper Bay. These comparisons were made using regression analysis on untransformed data, which met the normality and variance assumptions of the test.

3.0 RESULTS

3.1 AQUATIC BIOLOGICAL SURVEY (ABS)

Annual CPUE of alewife and blueback herring sampled during the nine-year adult and juvenile sampling under the ABS program varied considerably, with high winter abundances of both species in 2006 and 2009 and high winter alewife abundances in 2008 (Figure II-2a). Annual CPUEs for both species were lower and less synchronized in the spring (Figure II-2b). The timing of peak blueback herring abundances followed peak alewife abundances by a couple weeks in the winter of some years, (e.g., 2002 and 2006), whereas temporal fluctuations between the species were similar in other years (e.g., 2003, 2005, 2007, and 2009; Figure II-3).

The majority of river herring collected in the Harbor were yearlings, with a stronger bimodal distribution associated with the collection of adults for alewife compared to blueback herring (Figure II-4). Inter-annual variation in the timing of occurrence of adult and juvenile alewife (Figure II-5) and blueback herring (Figure II-6) was evident. However, overall, adult alewives were most commonly collected in the Harbor in January and April, (Figure II-7a). Adult blueback herring abundances were highest in February and April and no adults were collected in the Harbor in June (Figure II-7b). Adult alewife were collected in Upper Bay and Lower Bay in the winter (January to March) at water temperatures less than 7^{o}C (Figure II-8a and b). Winter water temperatures associated with adult alewife in Newark Bay were less than 6 ^{o}C (Figure II-8c) and less than 5 ^{o}C in Arthur Kill (Figure II-8d). Adult alewife were collected in all years of ABS sampling in Upper and Lower Bay and were not collected in 2006 and 2008 in Newark Bay or in 2002 in Arthur Kill. Adult blueback herring were not collected in Upper Bay in 2002 and 2008-2010 (Figure II-9a) and, unlike adult alewife, were not collected in Lower Bay at water temperatures below 4^{o}C (Figure II-9b).

Adult alewife CPUE in January and February in Lower Bay and Upper Bay were positively correlated (r = 0. 86, $p < 0.01$), with highest abundances in both locations in 2007 (Figure II-10). Adult alewives were only collected in January and February in Newark Bay in two years. Adult blueback herring were collected almost exclusively in Lower Bay and Upper Bay and with the exception of 2006 there was little relationship between the winter abundances in these two areas (Figure II-11).

3.2 MIGRATORY FINFISH SURVEY (MFS)

A total of 6,081 alewife were collected during the MFS, yearly totals ranged from a low of 252 in 2013 to a high of 4,276 in 2011, collections totaled 1,061in 2006 and 492 in 2012 (Table I-2). Alewife were primarily collected in the Upper Bay, Newark Bay, and the Arthur Kill/Kill Van Kull during 2011; peak CPUEs (near 30) occurred in the Upper Bay during the spring of 2011with high collections of just over 10 in the Newark Bay and about 5 in the Arthur Kill/Kill Van Kull (Figure I-18). Newark Bay collections peaked during the fall of 2011 at approximately 25 followed by the Arthur Kill/Kill Van Kull with a peak near 10. The Upper Bay fall of 2011 collection was just above 5 and this was below the Upper Bay peak fall collection of about 12 during 2006. Summer CPUEs remained near 0 for all regions during the four years. Lower Bay collections remained near 0 for all years, except the fall CPUE in 2012 was about 2.5. Alewife generally occur with blueback herring, Atlantic herring, and bay anchovy during the spring and with blueback herring and bay anchovy during the fall in all four Harbor regions (Figures I-30 – I-33).

A total of 43,375 blueback herring were collected during the MFS, yearly totals ranged from a low of 1,213 in 2006 to a high of 31,576 in 2012, collections totaled 6,578 in 2011 and 4,008 in 2013 (Table I-2). Blueback herring were primarily collected in the Upper Bay and Lower Bay during the fall of 2012, with CPUEs of 225 and 180 in the Upper Bay and Lower Bay, respectively (Figure I-23), Arthur Kill/Kill Van Kull CPUEs reached a high of about 80 during the fall of 2012 while Newark Bay CPUEs was just below 50 during the fall of 2012 and both spring and fall CPUEs were near 40 during 2013. Spring collections were low for all regions except Newark Bay during 2013 when the CPUE was just under 50. Summer CPUEs remained near 0 for all regions during the four years. Blueback herring generally occur with alewife, Atlantic herring, and bay anchovy during the spring and with alewife and bay anchovy during the fall in all four Harbor regions (Figures I-30 – I-33).

Temporal variation in river herring CPUE in the Harbor was relatively synchronous in the spring, with highest abundances in 2011 for both species (Figure II-12a). Fall CPUEs were dominated by high catches of blueback herring in 2012 (Figure 12b). Seasonal variation in river herring CPUEs was similar among years (Figure II-13). River herring were collected in the spring and fall and were not collected in June and July. The seasonal timing of alewife and blueback herring collections was not consistent among years. In 2006, abundances of both species declined from April to May and fall blueback herring CPUE peaked before alewife CPUE (Figure II-13a). In 2011, river herring CPUEs were similar in October and blueback herring abundances were highest in December (Figure II-13b). In 2012, alewife CPUE peaked several weeks before blueback herring CPUE (Figure II-13c), which is consistent with the reported timing of the respective emigrations of the two species from the estuary (Marcy 1976, Monroe 2000 and references therein). In 2013, spring occurrences of both species coincided in April and blueback herring abundances were high in October (Figure II-13d).

The size distributions of alewife collected in the spring were dominated by juveniles (100 – 120 mm TL), with no obvious change in size across months (Figure II-14). Similarly, alewife collected in the fall (mostly in 2011 and 2012) were predominantly juveniles (Figure II-14). Growth of juvenile blueback herring inhabiting the Harbor in the spring is evident from March to May (Figure II-15a-c). Young-of-the-year blueback herring were collected in August (Figure II-15d) and this cohort was collected in the Harbor at increasingly larger sizes from September through December (Figure II-15 e-h).

Adult alewife were collected by mid-water trawl primarily in April and May in all Harbor areas (Figure II-16 a-c). Adult alewives were not collected by mid-water sampling in March. Water temperatures during spring adult alewife collections ranged from 7 to 14^{o}C. In the fall, adult alewives were collected from September to December at water temperatures that ranged from 7 to 23^{o}C (Figure II-16 a-c). Adult blueback herring were collected only in the spring and primarily in April at water temperatures that ranged from 6 to 16^{o}C (Figure II-17a and b).

3.3 TRENDS IN ADULT SIZE

The mean TL of river herring > 170 mm TL has decreased from the 1970s to 2010 in the Hudson River Estuary (ASMFC 2012). Mean TL of adult alewife (male and female) decreased from 280-315 mm TL in the early 1980s to 240- 270 mm TL from 2005 to 2010 (Figure II-18). A similar decline in adult blueback herring size was observed over the same time period (Figure II-18). Data used to examine temporal trends in adult river herring size were collected using electrofishing, beach seine, and herring seine gears (ASMFC 2012), all of which bias catch composition differently. For comparative purposes, the mean total lengths of river herring > 170 mm TL were plotted for each year of sampling (Figure II-19). Overall, river herring sizes collected during the ABS and MFS studies were smaller (Figure II-19) than the historical record reported in ASMFC (2012). There was no temporal trend in size, however, blueback herring tended to be larger than alewife, which is the opposite of previous reports (ASFMC 2012). However, because fish were not identified by sex, it is possible that differences in sex ratios could account for size differences between the species.

4.0 DISCUSSION

Alewife are an anadromous species that is important as a forage fish, spending most of their lives in coastal waters and returning to freshwater habitat in the spring to spawn. Able (2005) considered alewife to be an obligate estuarine-dependent species. Alewife were common during winter and spring in all Harbor regions at both channel and non-channel stations during the ABS bottom trawl surveys (Figure II-20). Adult alewife were present in the Harbor during winter and early spring, with peak collections in April followed by a rapid decline in May. Adults return to off-shore coastal areas after spawning, again passing through the Harbor on their post spawning migration. Juveniles and sub-adults often follow the adult migrations through the Harbor. Young-of-the-year alewife move down river into the Harbor and coastal estuaries in the fall, with many remaining in the Harbor through the fall and some into winter. Some juveniles and adults move into the Harbor during winter.

Alewife were commonly collected in the ABS bottom trawl surveys, with high abundances in January and February that declined throughout the spring, with only a few alewife collected in May - June (Figure II-5, Figure II-7a). Inter-annual variation in alewife abundance during the ABS was moderate (CV = 101%) (USACE-NYD 2015). Abundances were highest in 2006, 2008 and 2009 (Figure II-3). These years did not coincide with any temperature or river discharge patterns. Relatively high abundances may have been due to some sampling events coinciding with peaks of spawning runs. In winter, alewife were collected in highest concentrations in Lower Bay at channel stations compared to spring when they were relatively more abundant in Arthur Kill non-channel areas (Figure II-20).

During the ABS bottom trawl surveys, adult alewife were collected in the Harbor from January to April; the highest numbers were collected in April, likely corresponding to their spawning migration through the Harbor (Figures II-5 and II-7). Few adults were collected in May indicating that the spawning migration had passed through the Harbor. The MFS collections of adult alewife indicate peak abundances occur in April (Figure II-5), with most collected from the Upper Bay (Figure I-18). Few adult alewife were collected in the Arthur Kill/Kill Van Kull and Newark Bay during April and May, suggesting the Hudson River spawning migration through the Lower Bay and the Upper Bay was much larger than the Passaic River and Hackensack River spawning run via the Arthur Kill/Kill Van Kull and Newark Bay. However, if the Passaic River and Hackensack River spawning runs occurred earlier, then this might account for fewer adults during April. The Hudson River run via the Lower Bay and Upper Bay appears to begin when alewife entered the Lower Bay in early winter and moved to the Upper Bay where they apparently staged and then entered the Hudson River (Figure II-10). Data suggested that a small proportion of alewife branch out from the Lower Bay and Upper Bay using the Arthur Kill / Kill Van Kull (Figures II-8d and II-16d) and Newark Bay (Figures II-8c and II 16c) to access the Hackensack River and Passaic River.

Blueback herring are anadromous, entering estuaries in the spring, migrating into freshwater habitat to spawn. Similar to alewife, peak abundance years occurred in 2006 and 2009 (Figure II-3). Able (2005) considered blueback herring to be an obligate estuarine-dependent species. Blueback herring were common during winter and spring in all Harbor regions at both channel and non-channel stations (except in Lower Bay during winter when the majority of blueback herring were collected at channel stations). The highest mean CPUEs were collected in the Lower Bay during winter (Figure II-21). In the Harbor, the timing of spring migrations through the estuary was similar to that of alewife, with peak abundances in February and few blueback herring present in June (Figure II-3). Blueback herring move through the Harbor in March – April on their spawning migrations and adults return to off-shore coastal areas again passing through the Harbor on their post spawning migration. Juveniles and sub-adults may often follow the adult migrations through the Harbor. Young-of-the-year blueback herring move down river into the Harbor and coastal estuaries in the fall.

Blueback herring also were commonly collected in the ABS bottom trawl surveys, with a peak average CPUE of over 17 in the Lower Bay during winter followed by the Upper Bay (>8); CPUEs ranged from 2 to 5 in other seasons and Harbor areas (Figure II-21). For the MFS mid-water trawl surveys, the peak spring CPUE was near 50 in Newark Bay during 2013 and CPUEs remained near 0 in the Lower Bay.

During the ABS, adult blueback herring were present in the Harbor from January to April; the highest numbers were collected in February and April (Figure II-5). Abundance data suggests a prolonged migration period through the Harbor potentially including staging during winter followed by spawning migration through the Harbor during April. The MFS collections of adult blueback herring suggests a peak from mid April through early May in the Harbor (Figure II-13), with most collected from the Upper Bay as they migrated upriver (Figure I-23). Few adult blueback herring were collected in the Arthur Kill/Kill Van Kull and none from Newark Bay during April and May, suggesting an earlier start of spawning runs in these rivers, but more likely that the Hudson River spawning migration through the Lower Bay and the Upper Bay was much larger than the Passaic River and Hackensack River spawning run via the Arthur Kill/Kill Van Kull and Newark Bay. The Hudson River run via the Lower Bay and Upper Bay appeared to begin when blueback herring entered the Lower Bay in early winter, primarily February, and the majority had moved to the Upper Bay where they apparently staged and then entered the Hudson River. A few blueback herring moved through the Kill Van Kull and Arthur Kill (Figure II-17c) into Newark Bay prior to joining the smaller spawning runs in the Hackensack River and Passaic River.

The draft 2015 Conservation Recommendation includes a seasonal dredging restriction from March 1 to June 30 in the Hudson River, Hackensack River and Passaic River to allow anadromous fish to pass through the Harbor to upstream spawning areas (NMFS 2015). In downstream areas, including Kill Van Kull, Arthur Kill and Newark Bay, the dredging restriction ends on May 31st because it is expected fish have passed through these areas by this time. Most adult river herring appear to be out by the end of April / early May using ABS 2002 to 2010 early winter to late spring bottom trawl data; however the MFS data indicates slightly later, out by the end of May / early June at the latest which potentially could be due to changes in depth of the water column used due to temperature, salinity, and/or diurnal factors) resulting in higher use of mid-waters during May and June, especially for alewife.

Analysis of total river herring abundance across the four study years of the MFS indicate that the migratory pathway through the Upper Bay to the mainstem of the Hudson River (and ultimately the individual tributary spawning areas used by river herring) is much stronger than the migration corridor through the Arthur Kill/Kill Van Kull complex leading to spawning areas within the upper (i.e., non-tidal freshwater) Hackensack and Passaic Rivers, which does not support the NMFS 2015 draft conservation recommendations for the Arthur Kill/Kill Van Kull complex. Moreover, unless bucket dredging were to be conducted in a very confined waterway, it is unlikely that either suspended sediment plumes or radiated sounds would represent a migratory barrier to adult river herring, especially in a waterway as wide as the mainstem of the Hudson River. Based on the timing and occurrence of river herring migrations, USACE-NYD has requested modification to the migratory finfish window to no longer include May in the Kill Van Kull, Arthur Kill and Newark Bay regions of the Harbor. Coordination with NMFS is ongoing with regards to the draft 2015 Conservation Recommendations.

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6.0 TABLES (PART II)

Table II-1. Summary of two data sources used to examine river herring activity patterns in the New York / New Jersey Harbor.

	Aquatic Biological Survey	**Migratory Finfish Sampling**
Time period of sampling	2002-2010	2006, 2011-2013
Gear type	Bottom trawl	Mid-water trawl
Seasons of sampling	Dec/January to May/June	March to December*
Total # alewife collected	11,669	6,081
Total # blueback herring collected	7,072	43,375
Alewife size range (mm TL)	11-435	28-307
Blueback herring size range (mm TL)	29-335	32-295

* MFS sampling was not conducted in March, July or December of 2006 and March and June of 2011.

7.0 FIGURES (PART II)

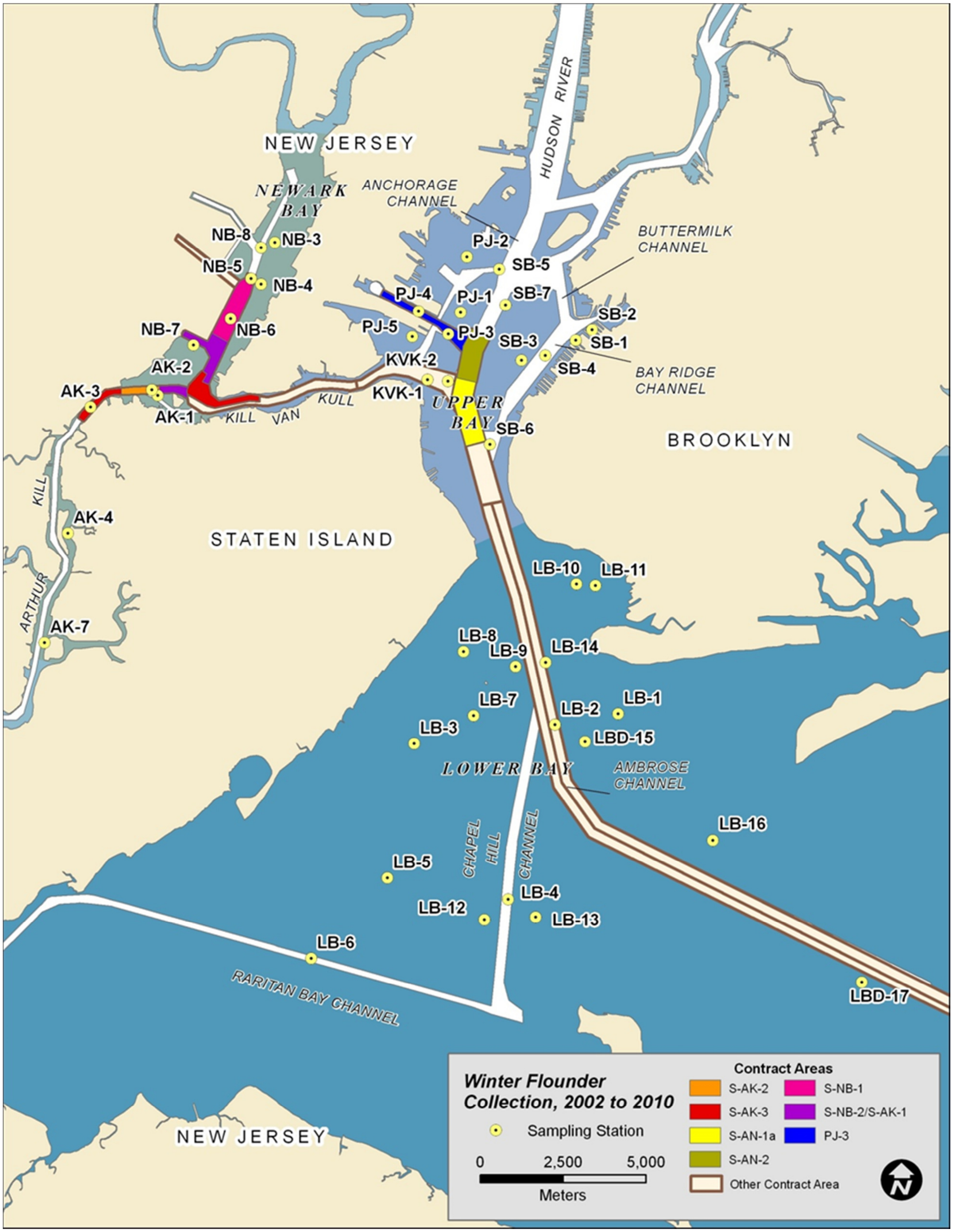


Figure II-1a. Aquatic Biological Survey (ABS) sampling locations from 2002-2010 with HDP contract areas.

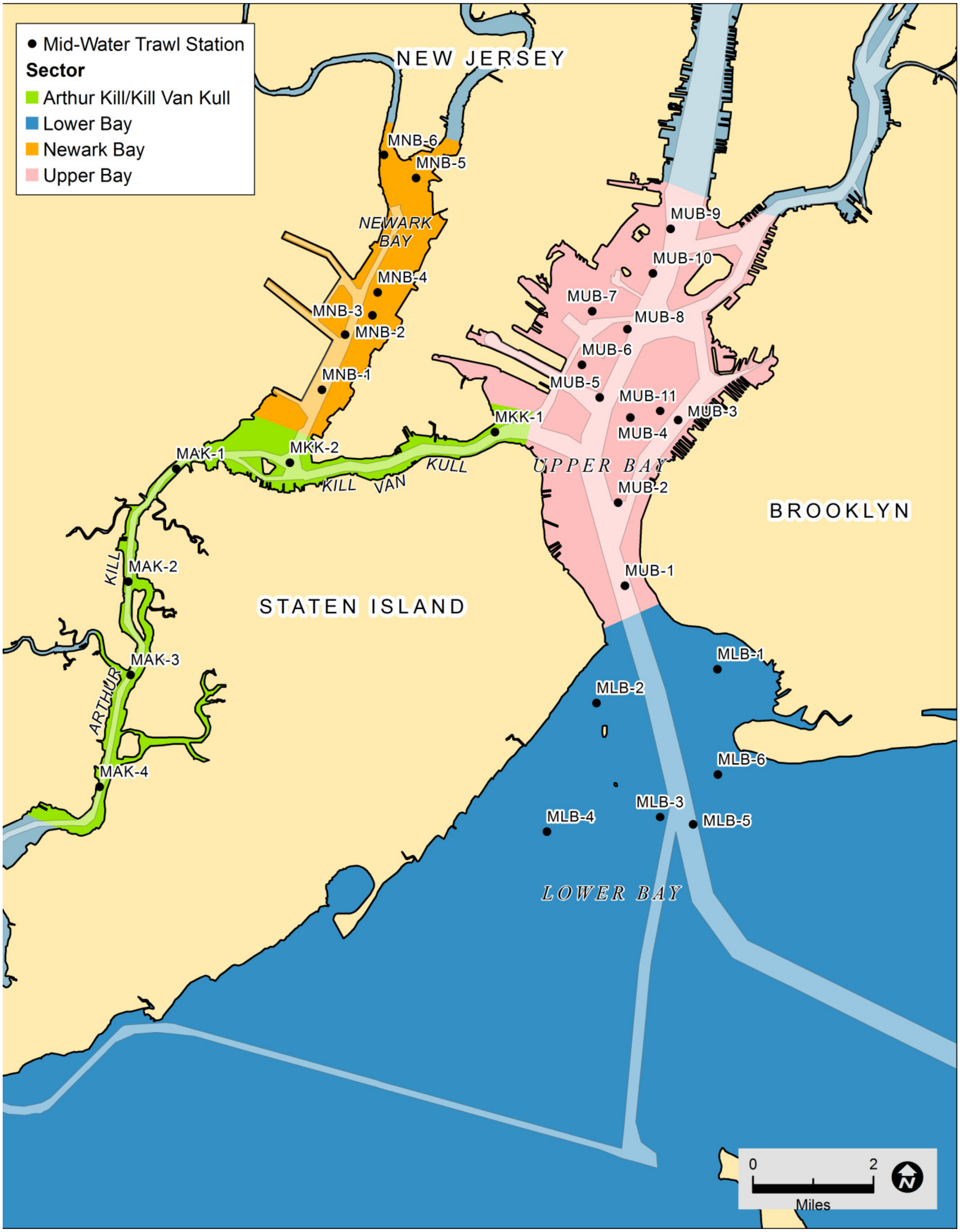


Figure II-1b. Migratory Finfish Sampling Program (2006 and 2011-2013) mid-water trawl locations.

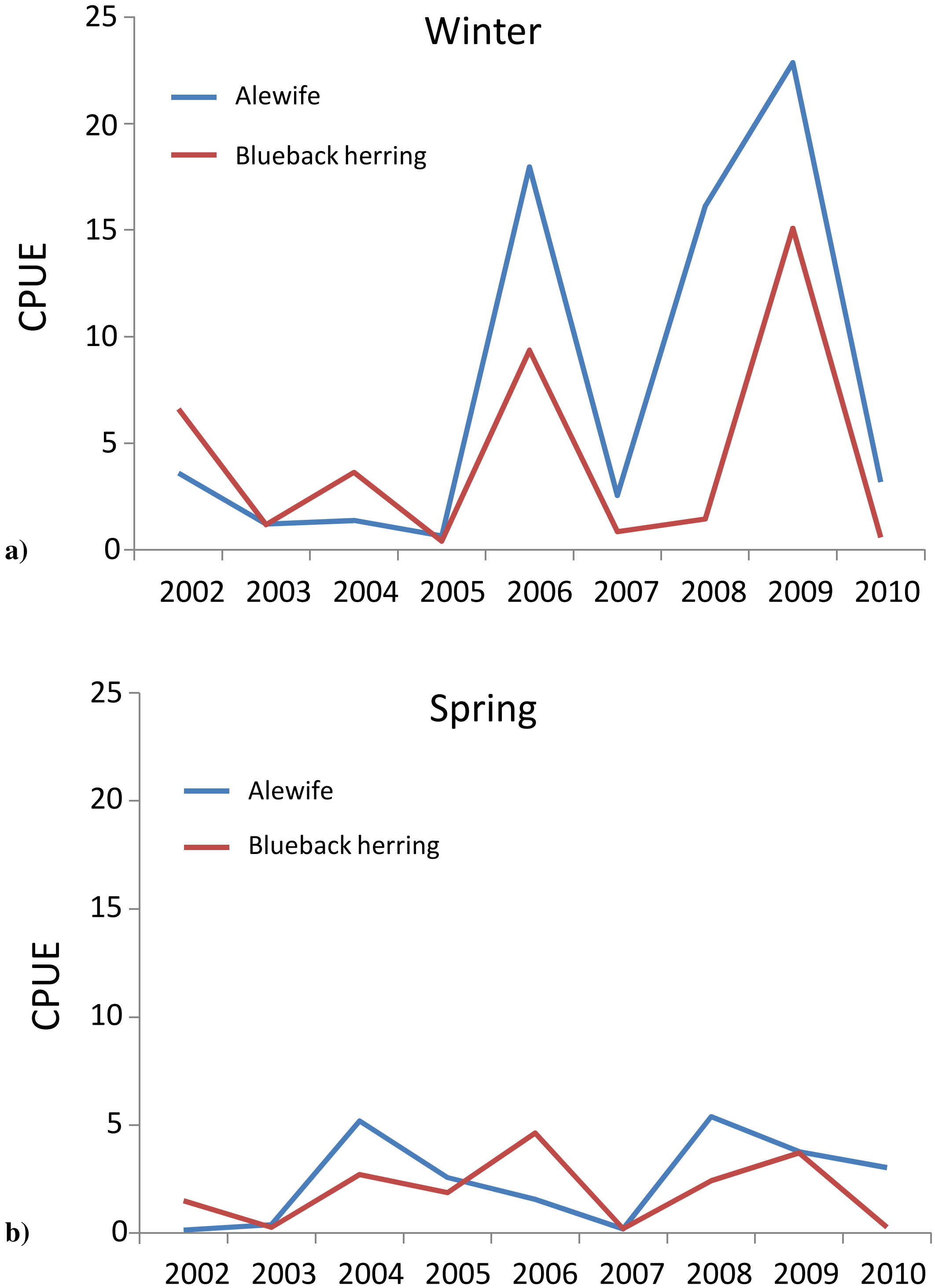


Figure II-2. Mean annual alewife and blueback herring CPUE in the winter (a) and spring (b) for each year of Aquatic Biological Survey sampling.

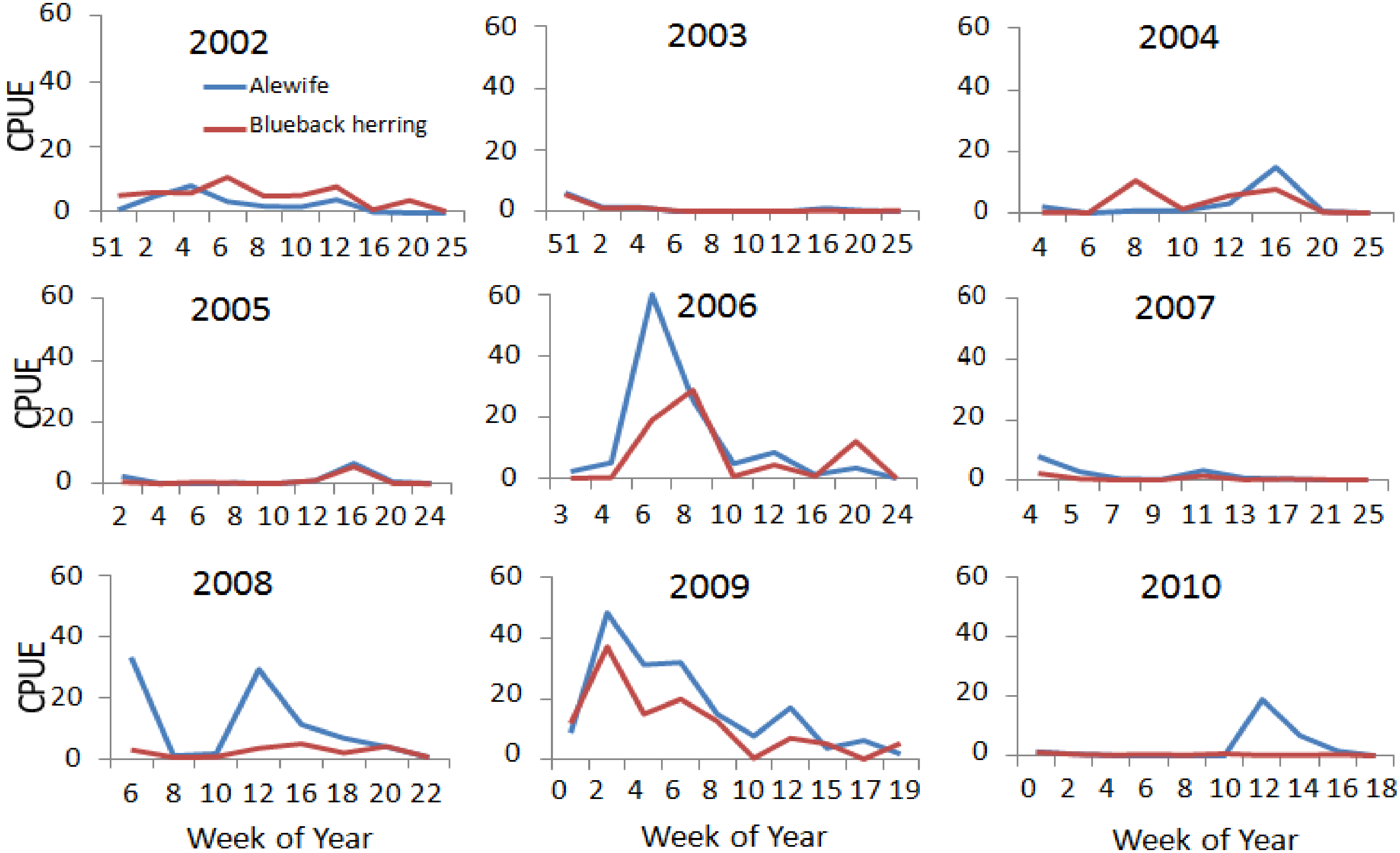
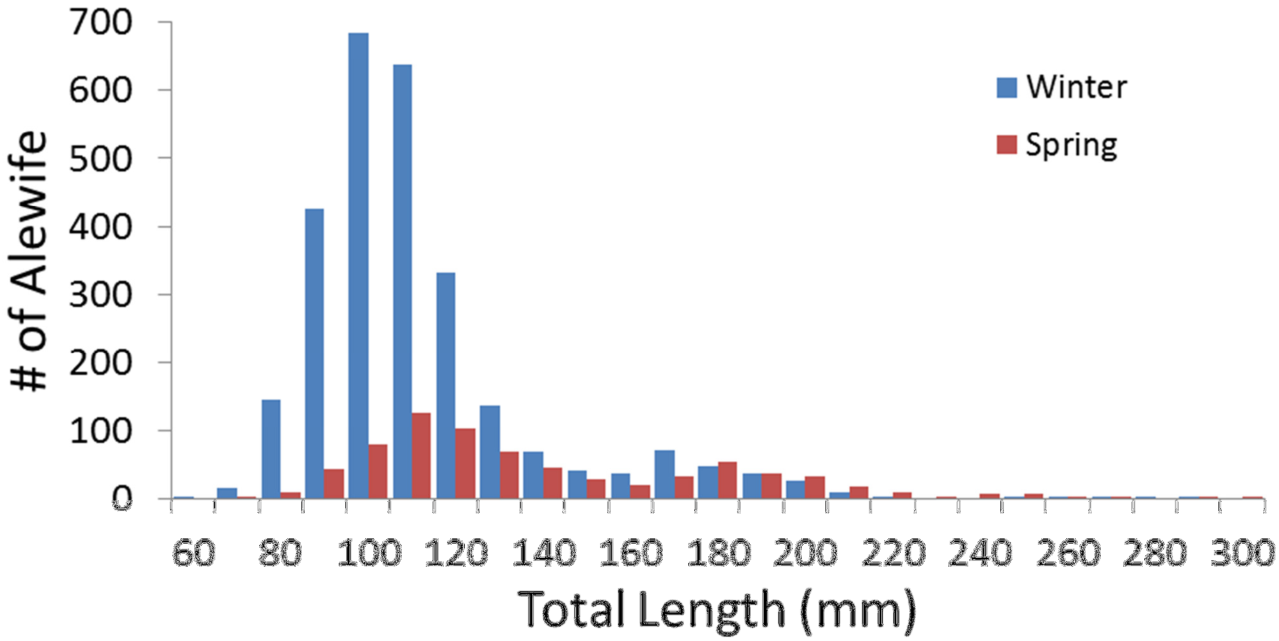
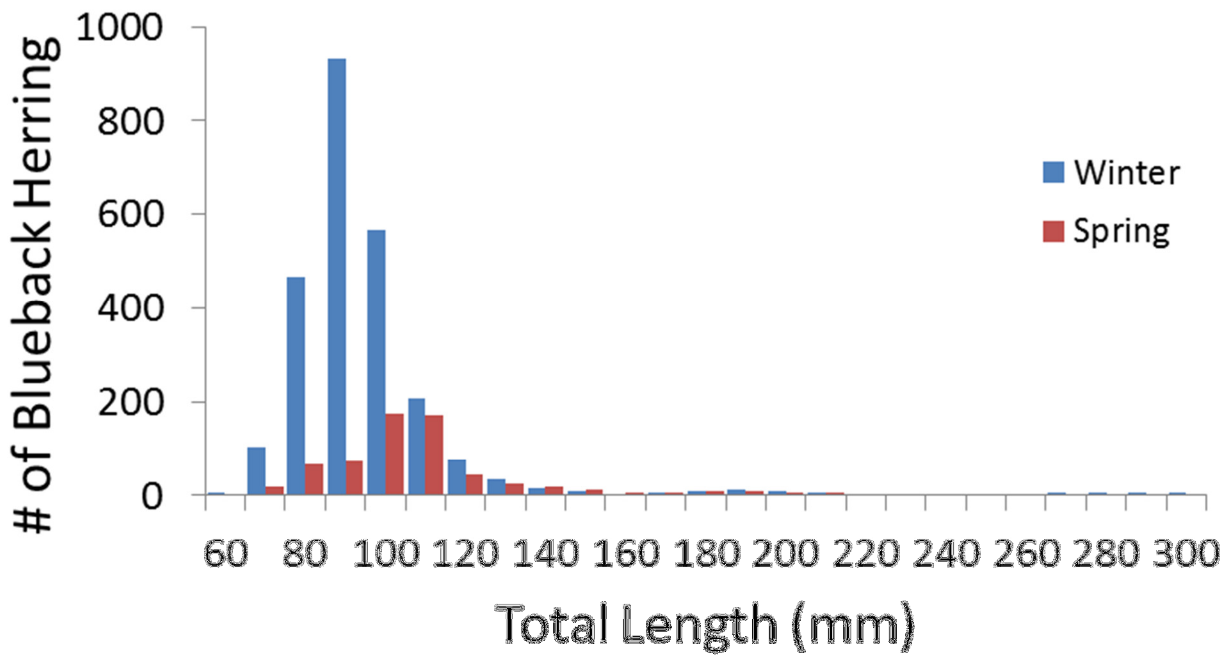


Figure II-3. Mean CPUE of alewife (blue line) and blueback herring (red line) for each of Aquatic Biological Survey sampling period by year. Sampling times varied among years, but overall extended from December to June.

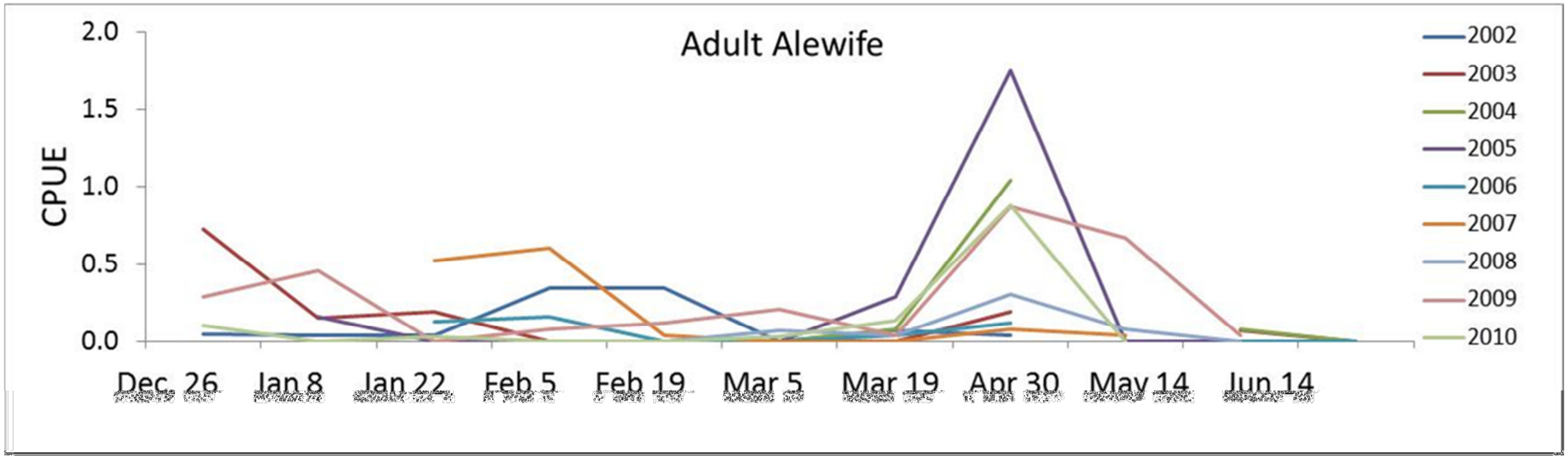


a)

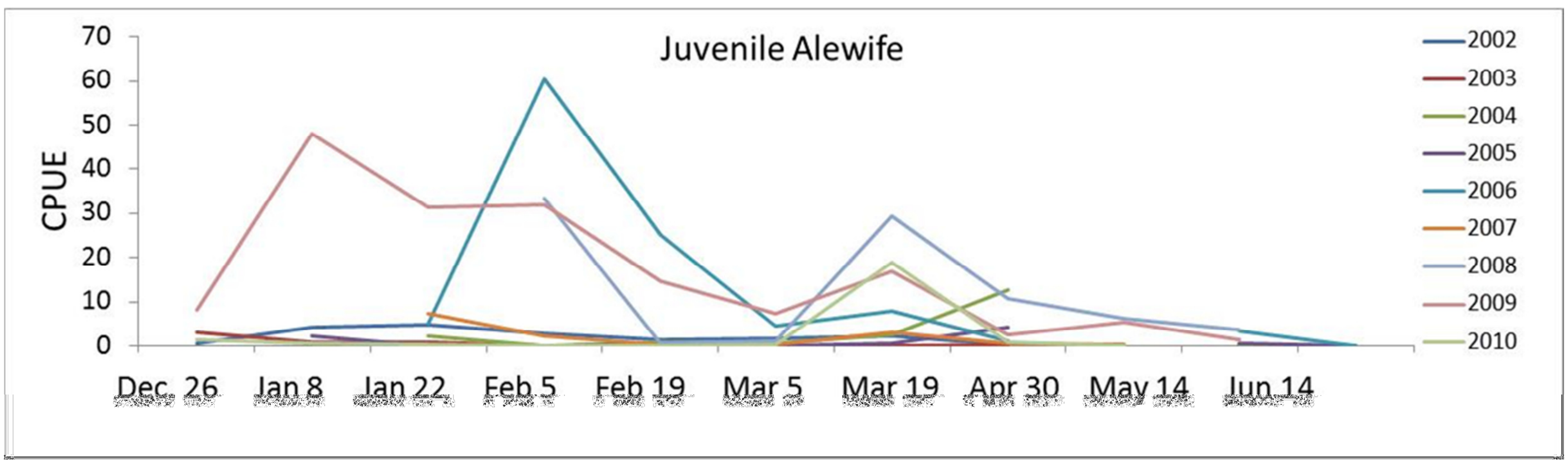


b)

Figure II-4. Size frequency distributions of alewife (a) and blueback herring (b) collected during winter and spring Aquatic Biological Survey (2002-2010) bottom trawl sampling.

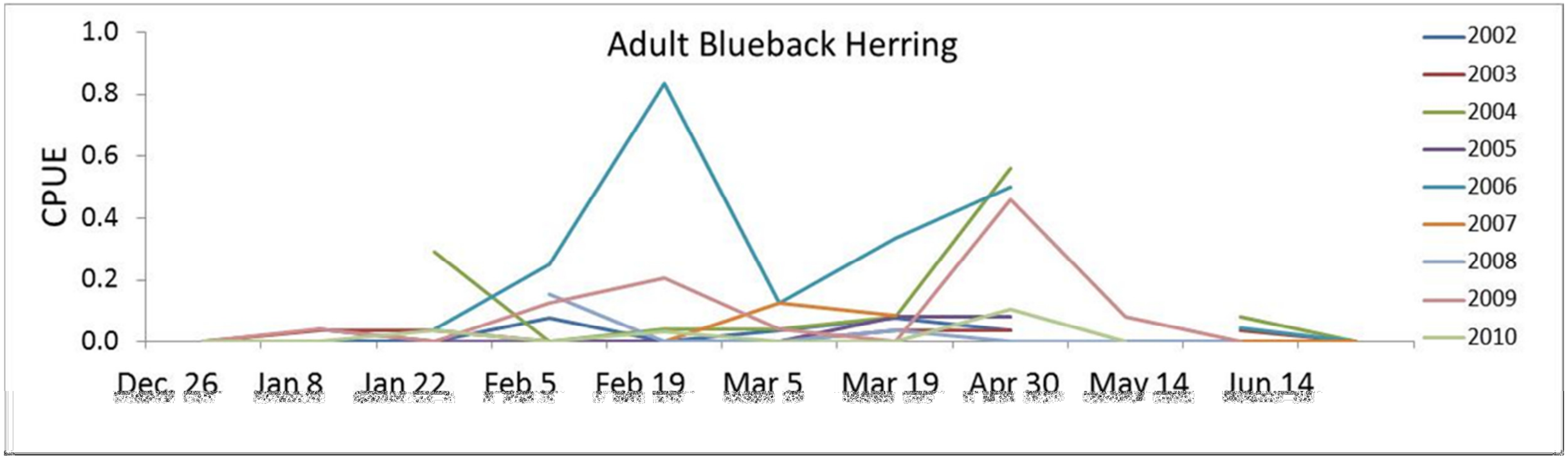


a)

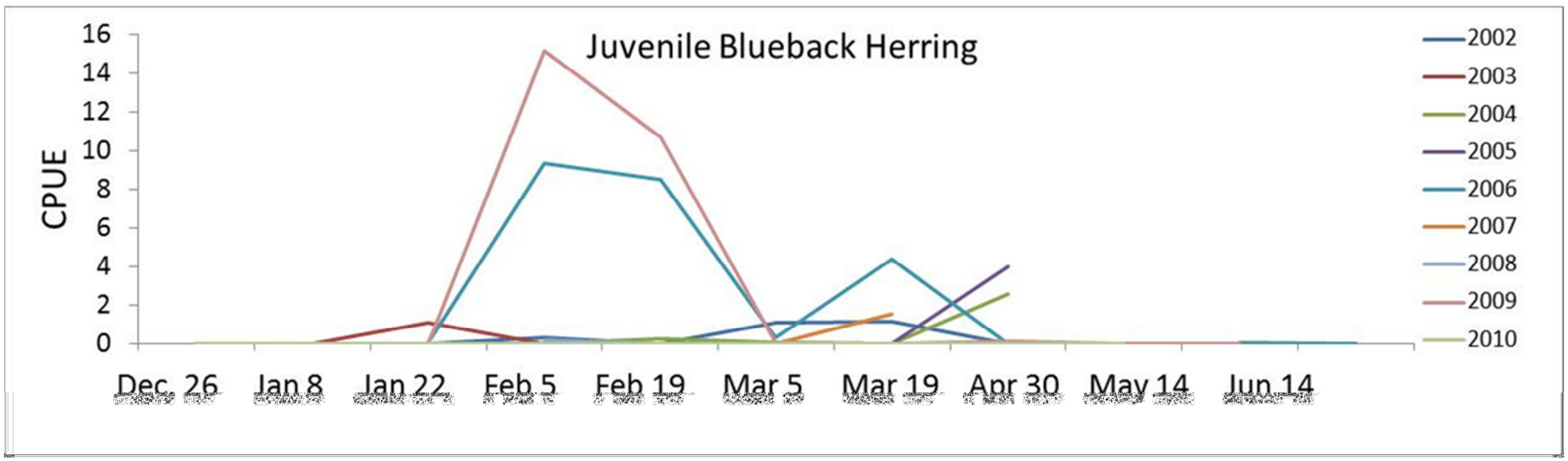


b)

Figure II-5. Mean adult (a) and juvenile (b) alewife CPUE for each sampling period by year of Aquatic Biological Survey sampling.

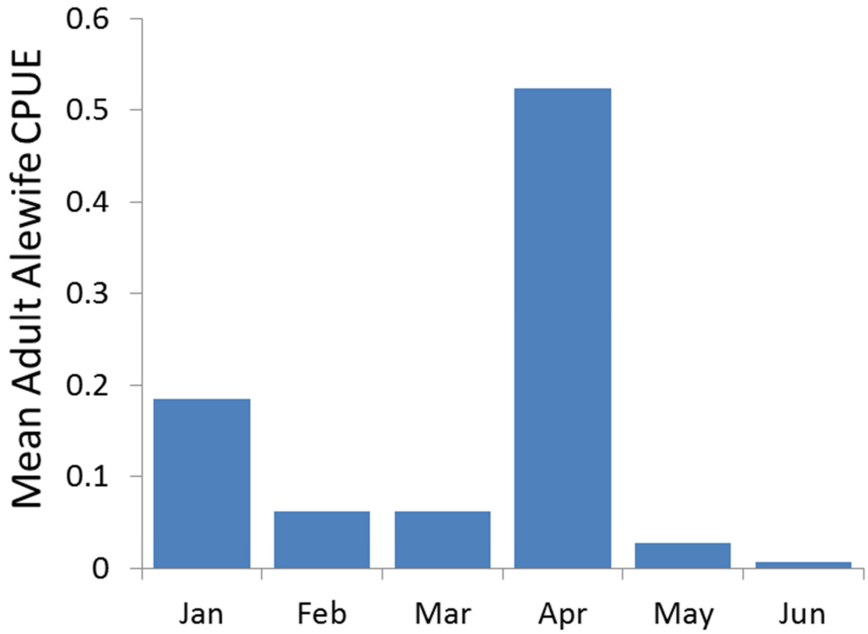


a)

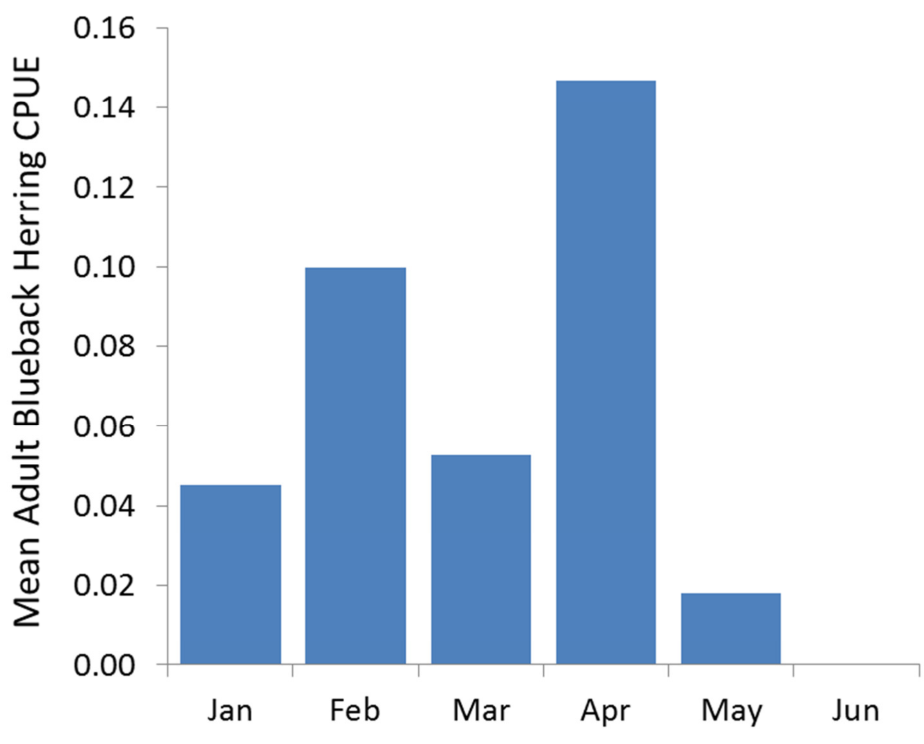


b)

Figure II-6. Mean adult (a) and juvenile (b) blueback herring CPUE for each sampling period by year of Aquatic Biological Survey sampling.



a)



b)

Figure II-7. Mean monthly CPUE for adult alewife (a) and blueback herring (b) in Aquatic Biological Survey samples from 2002 to 2010.

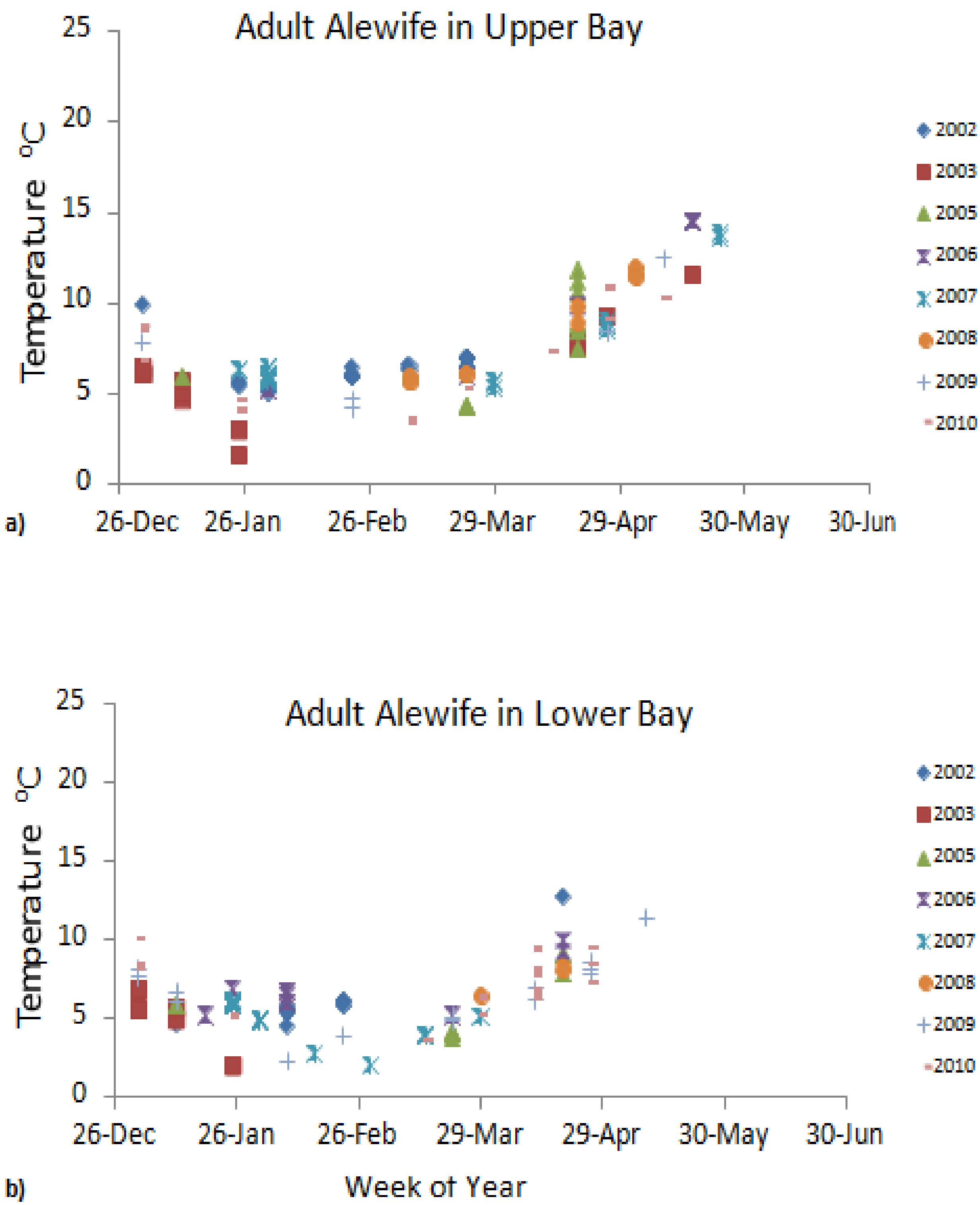
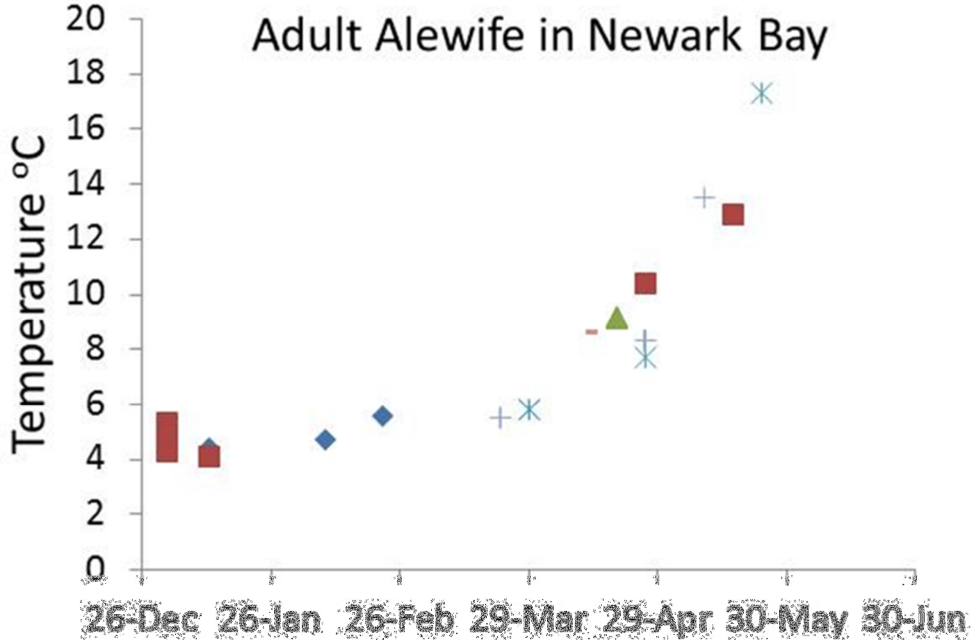
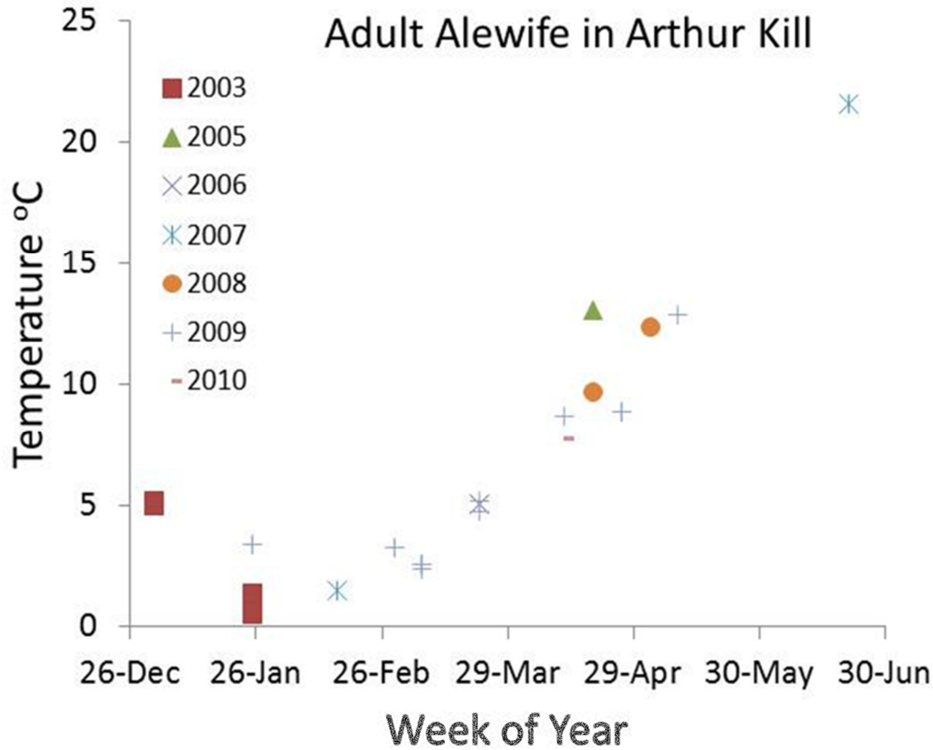


Figure II-8. Water temperatures recorded at the time that adult alewife were collected in Upper Bay (a) and Lower Bay (b) during Aquatic Biological Survey bottom trawl sampling. Each symbol represents a sample that contained one or more adult alewives.

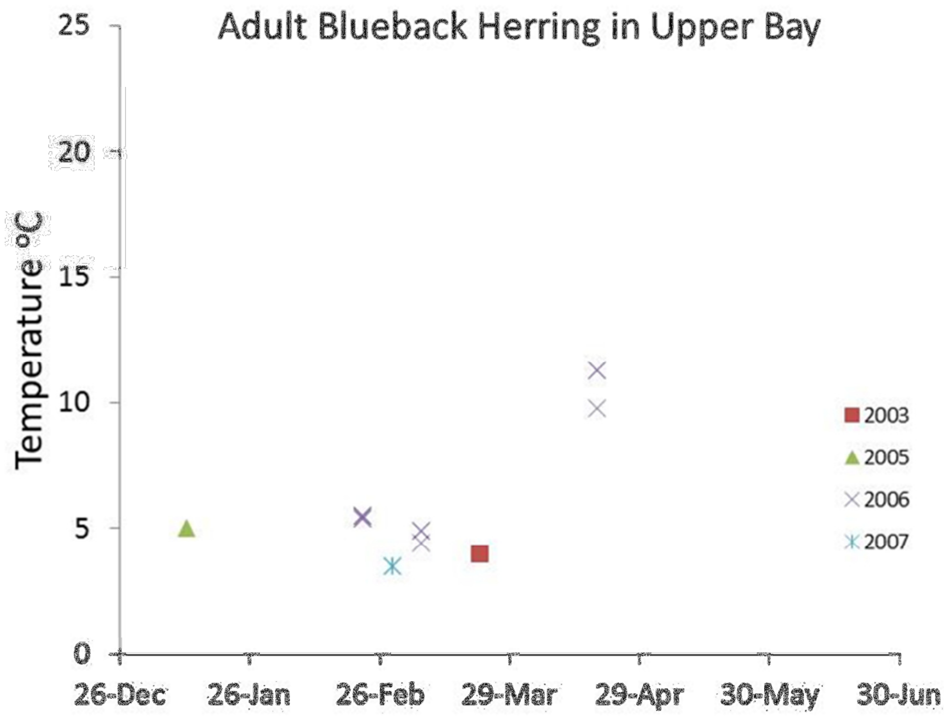


c)

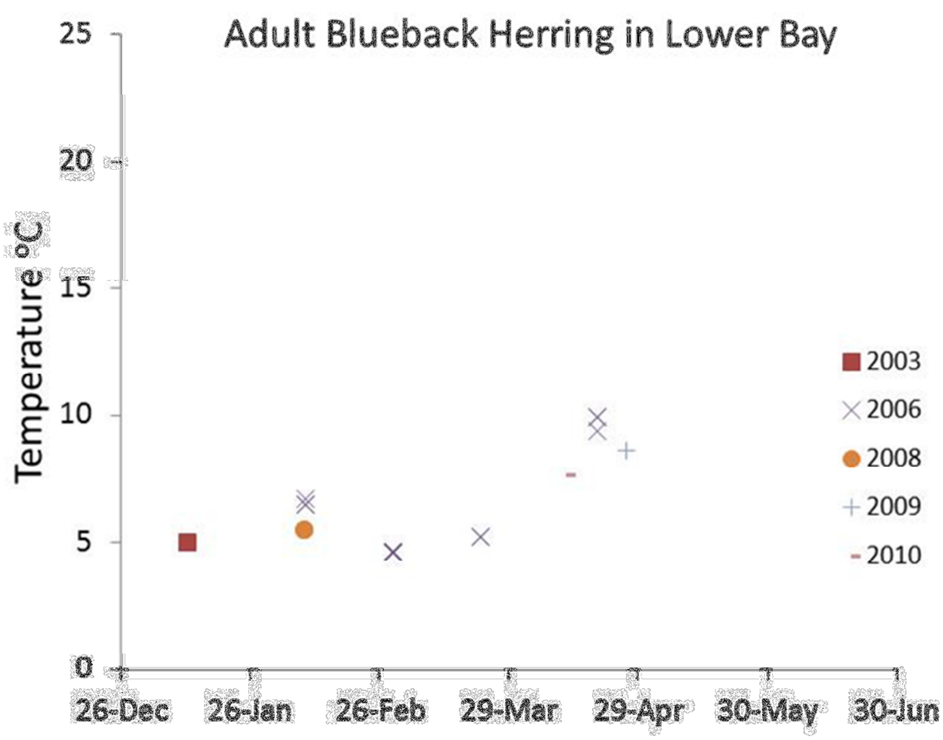


d)

Figure II-8 (continued). Water temperatures recorded at the time that adult alewife were collected in Newark Bay (c) and Arthur Kill (d) during Aquatic Biological Survey bottom trawl sampling. Each symbol represents a sample that contained one or more adult alewives.



a)



b)

Figure II-9. Water temperatures recorded at the time that adult blueback herring were collected in Upper Bay (a) and Lower Bay (b) during Aquatic Biological Survey bottom trawl sampling. Each symbol represents a sample that contained one or more adult blueback herring.

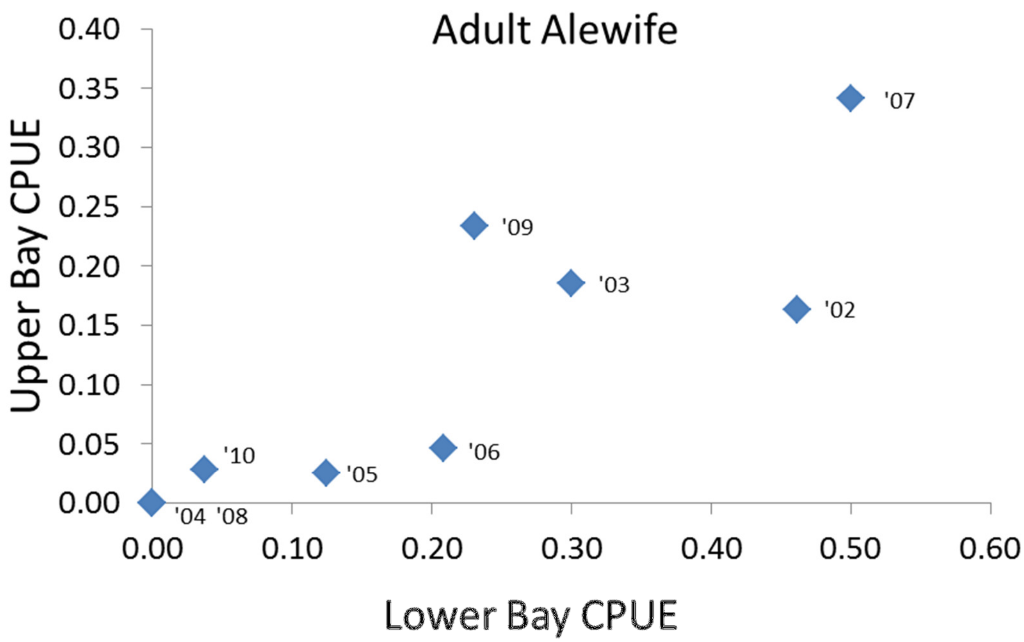


Figure II-10. Relationship between adult alewife CPUE in January and February in Lower Bay and Upper Bay for each year of Aquatic Biological Survey bottom trawl sampling. Data points are labeled by year of sampling.

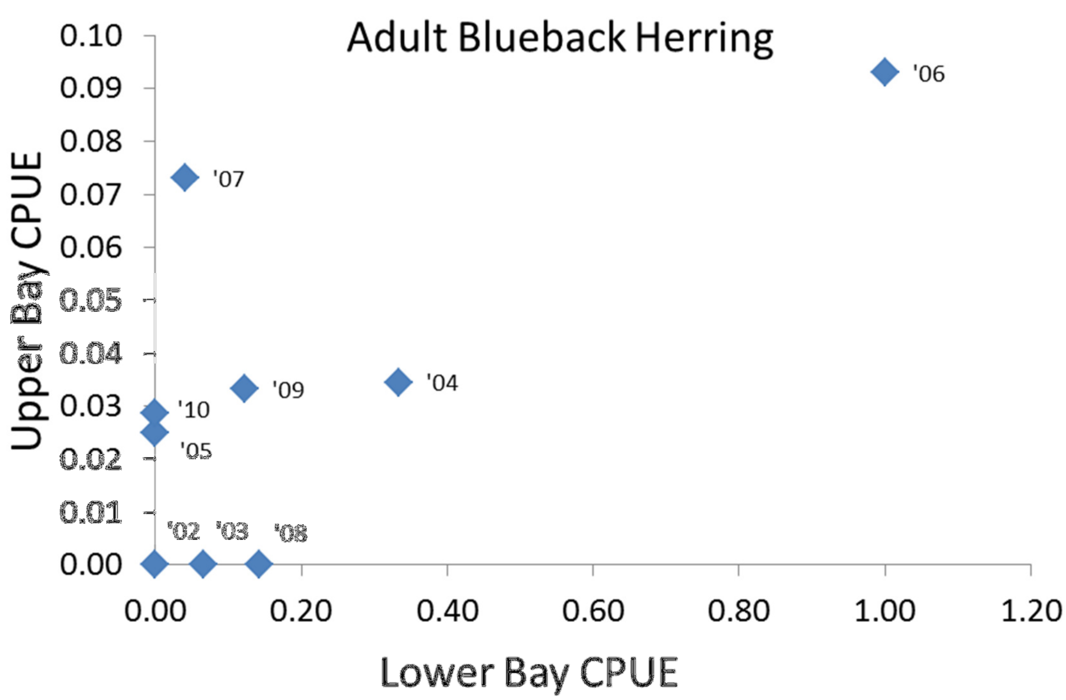


Figure II-11. Relationship between the numbers of adult blueback herring collected from January through March in Lower Bay and Upper Bay for each year of Aquatic Biological Survey bottom trawl sampling. Data points are labeled by year of sampling.

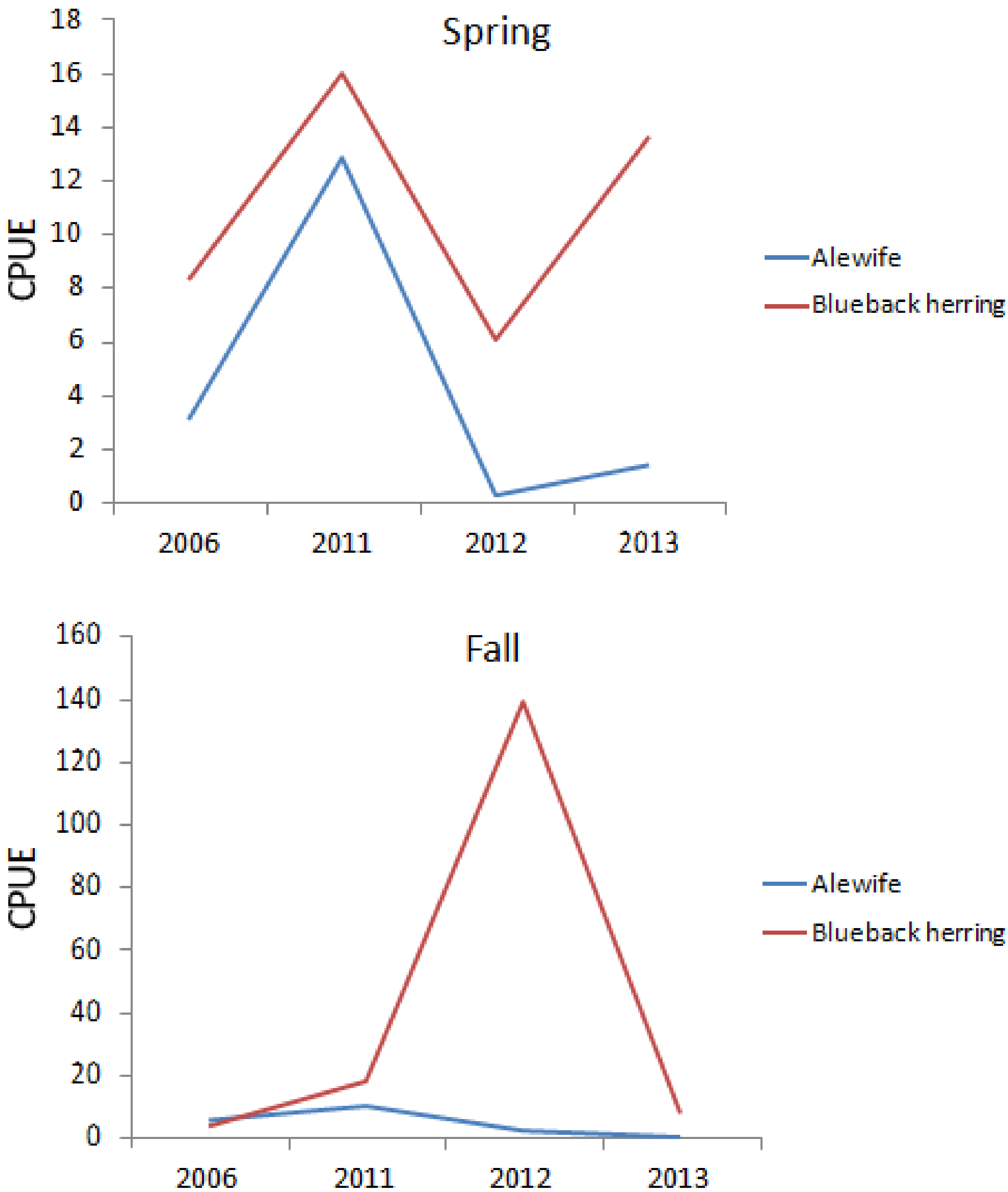


Figure II-12. Mean annual alewife and blueback herring CPUE in the spring (a) and fall (b) for each year of mid-water trawl sampling in the Migratory Finfish Survey.

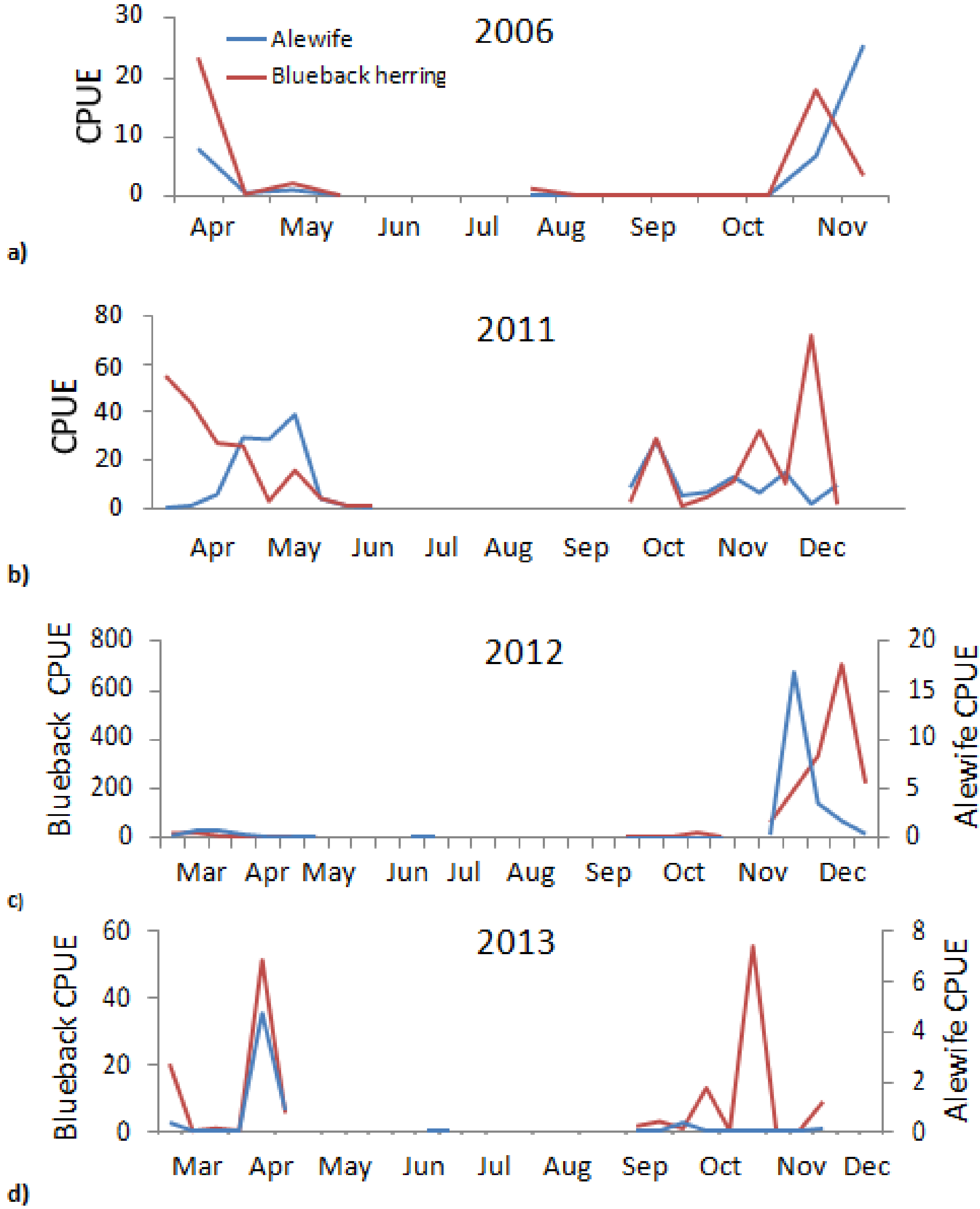


Figure II-13. Mean alewife and blueback herring CPUE for each MFS sampling event in 2006 (a), 2011 (b), 2012 (c) and 2013 (d).

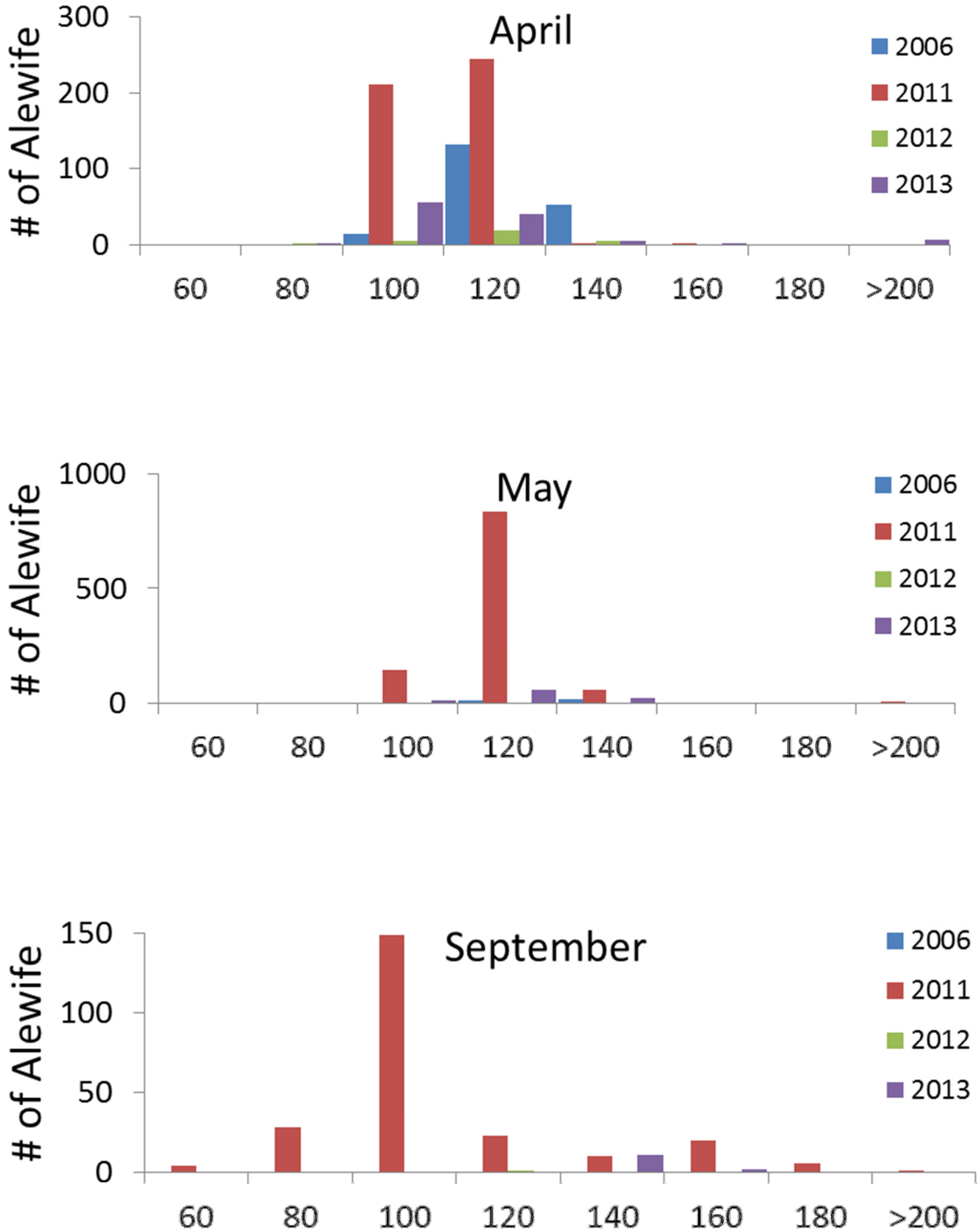
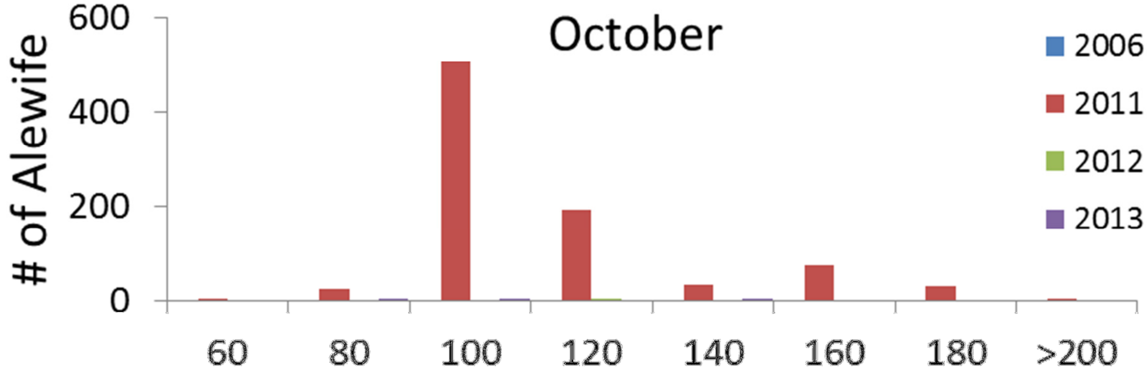
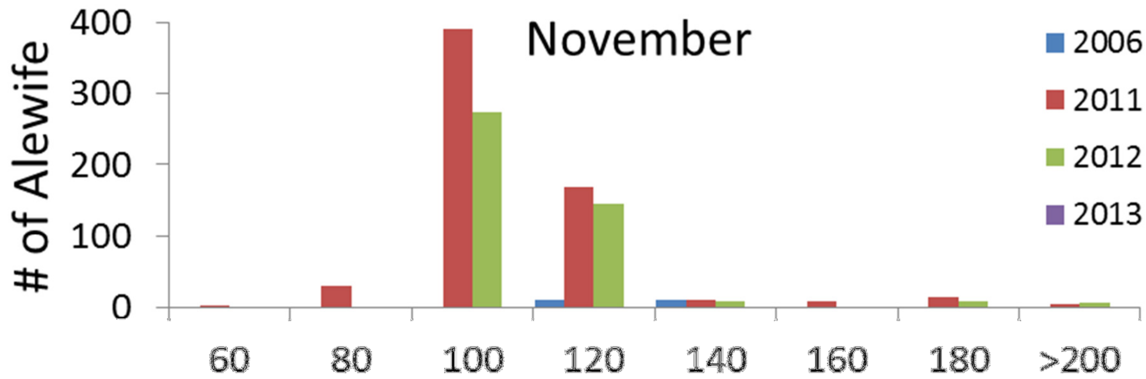


Figure II-14. Monthly size frequency distributions for alewife collected during the Migratory Finfish Survey.





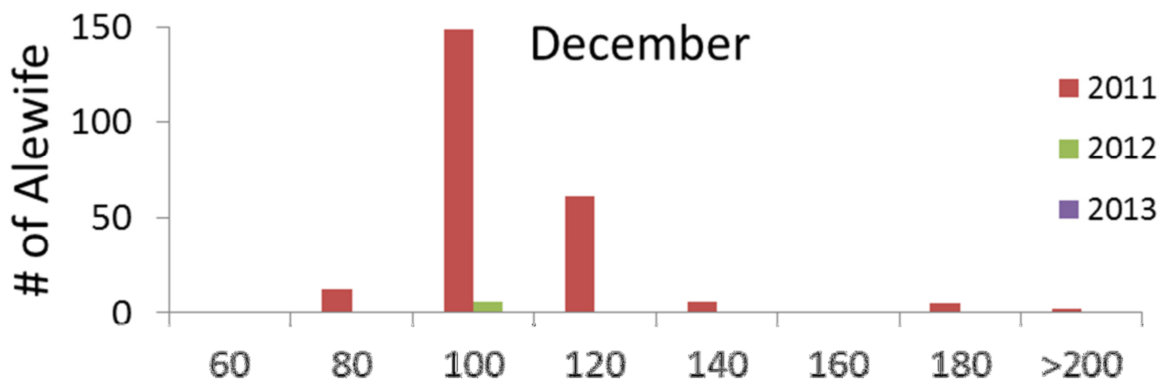


Figure II-14 (continued). Monthly size frequency distributions for alewife collected during the Migratory Finfish Survey.

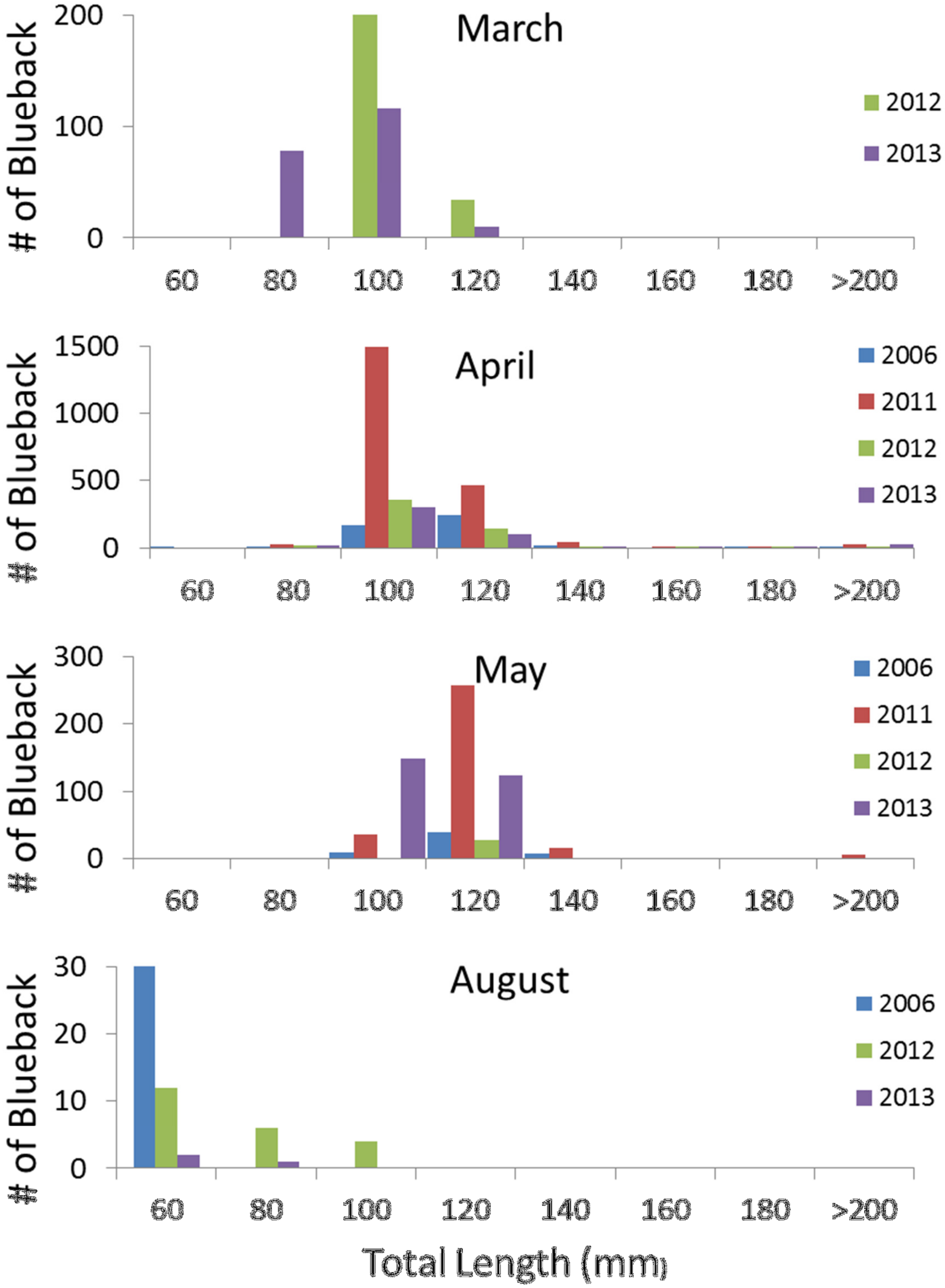


Figure II-15. Monthly size frequency distributions for blueback herring collected during the Migratory Finfish Survey.

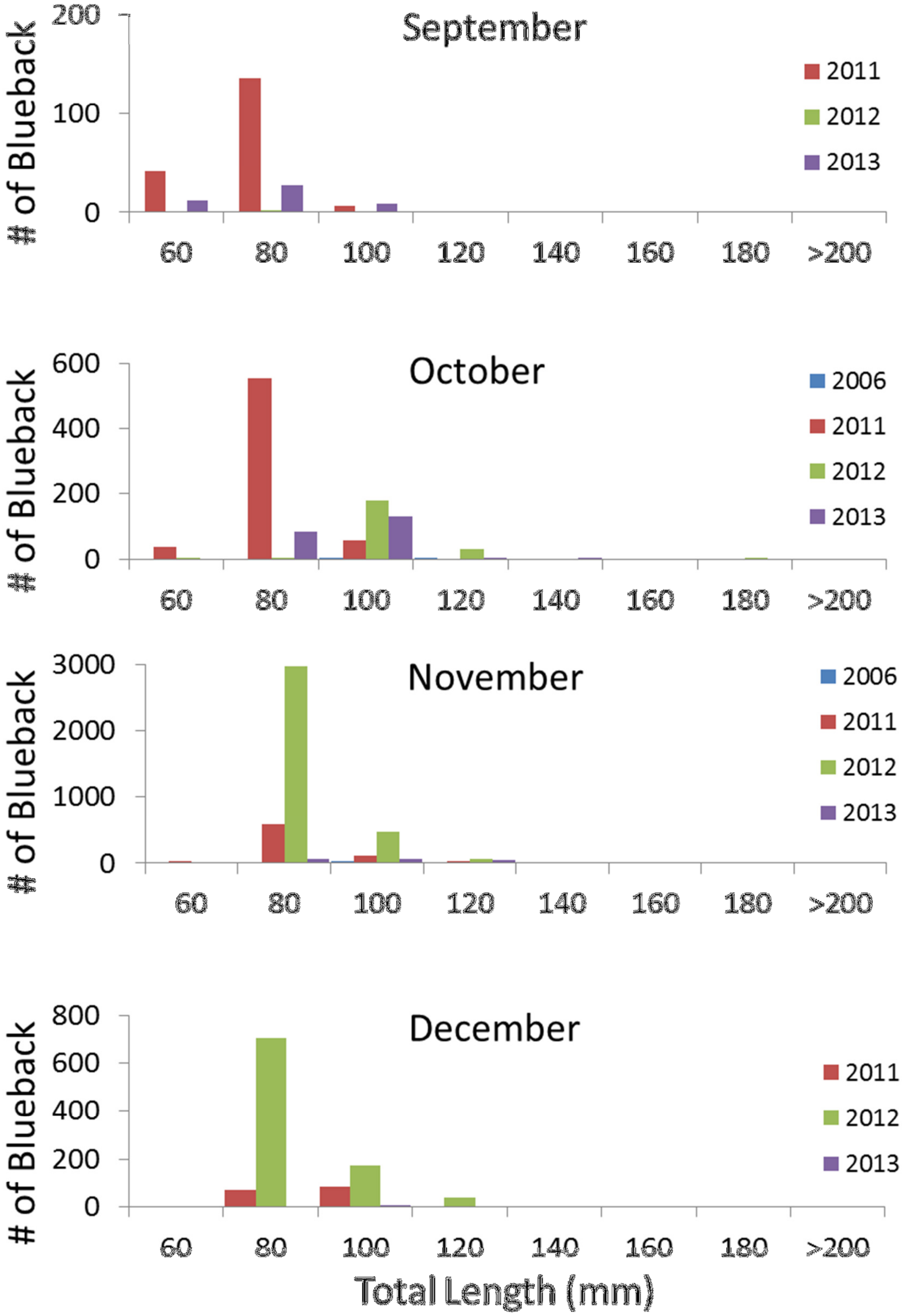
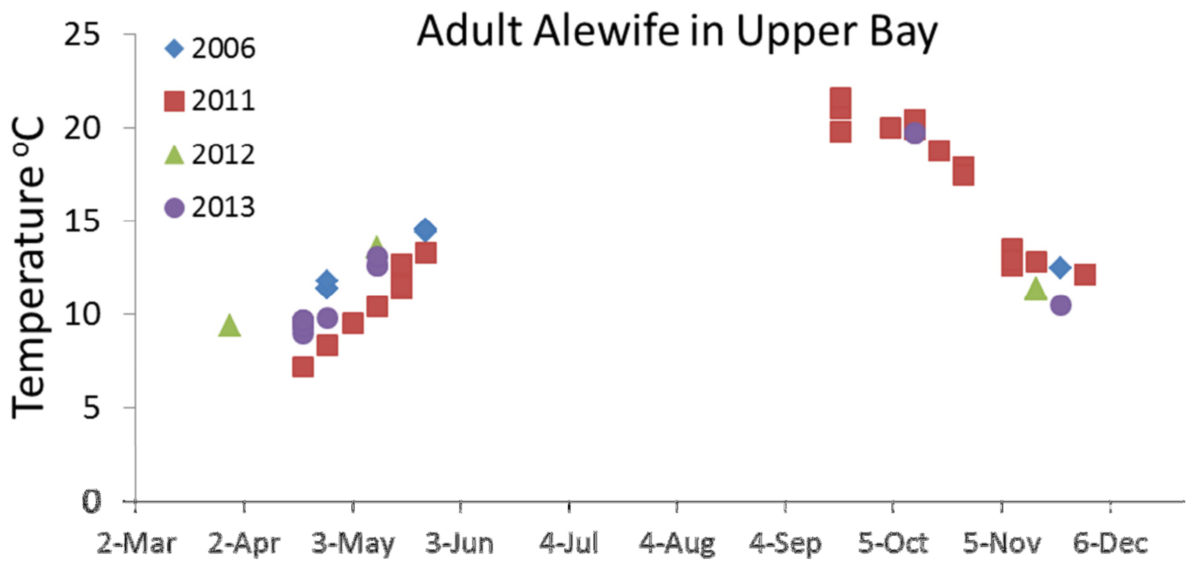
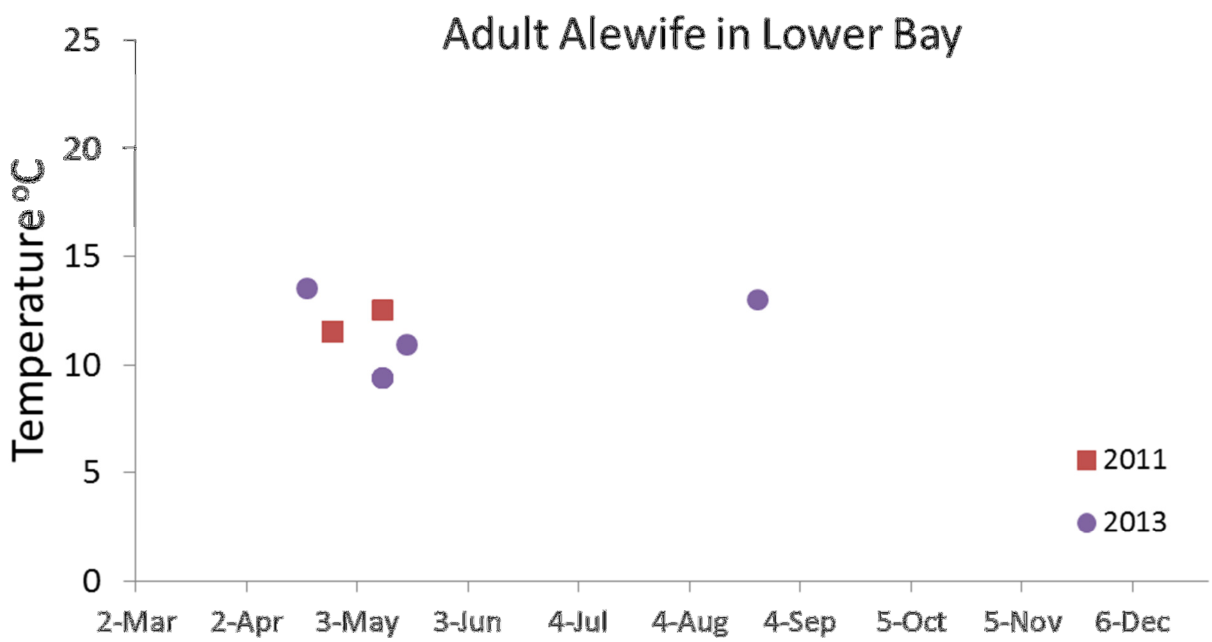


Figure II-15 (continued). Monthly size frequency distributions for blueback herring collected during the Migratory Finfish Survey.

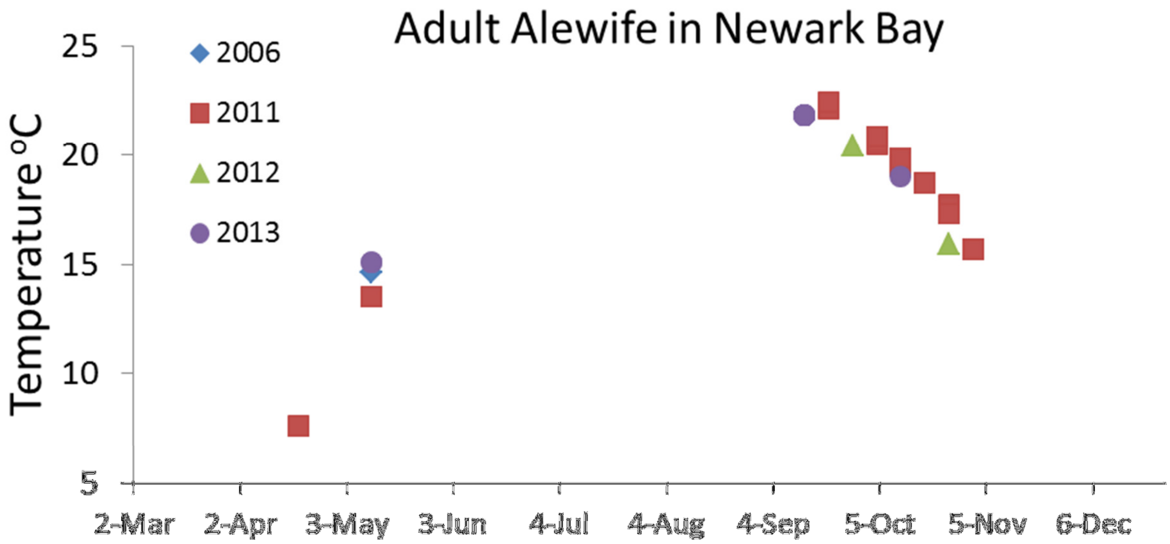


a)

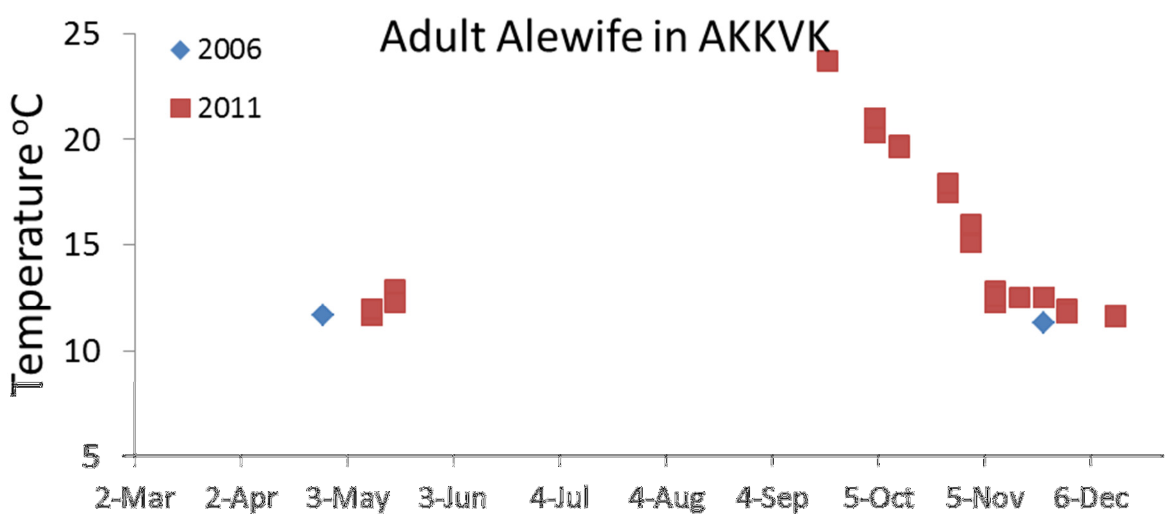


b)

Figure II-16. Water temperatures recorded at the time that adult alewife were collected in Upper Bay (a) and Lower Bay (b) during the mid-water trawl Migratory Finfish Survey. Each symbol represents a sample that contained one or more adult alewives.

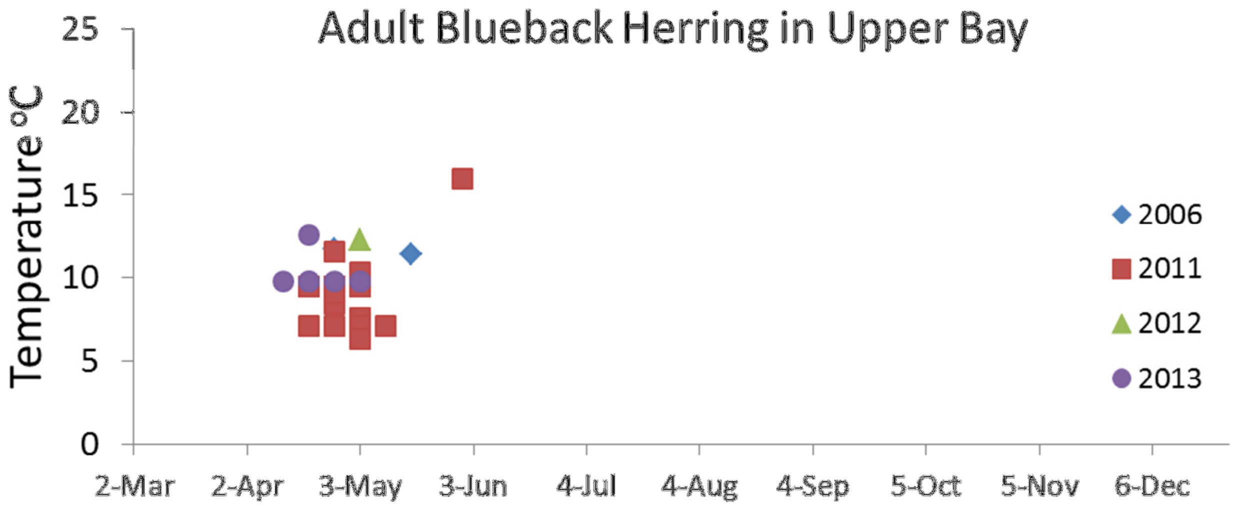


c)

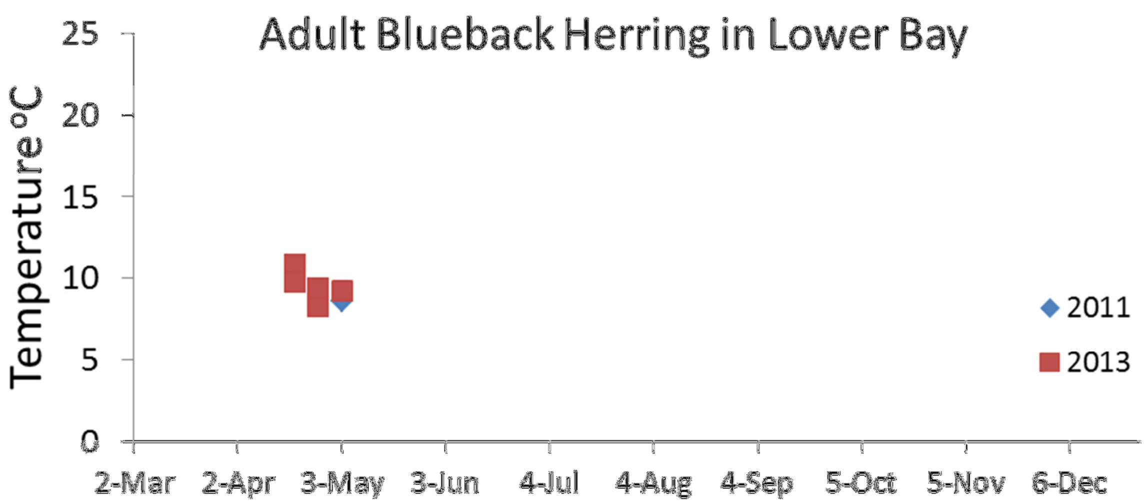


d)

Figure II-16 (continued). Water temperatures recorded at the time that adult alewife were collected in Newark Bay (c) and Arthur Kill/Kill Van Kull (d) during the mid-water trawl Migratory Finfish Survey. Each symbol represents a sample that contained one or more adult alewives.



a)



b)

Figure II-17. Water temperatures recorded at the time that adult blueback herring were collected in Upper Bay (a) and Lower Bay (b) during Migratory Finfish Survey mid-water trawl sampling. Each symbol represents a sample that contained one or more adult alewives.

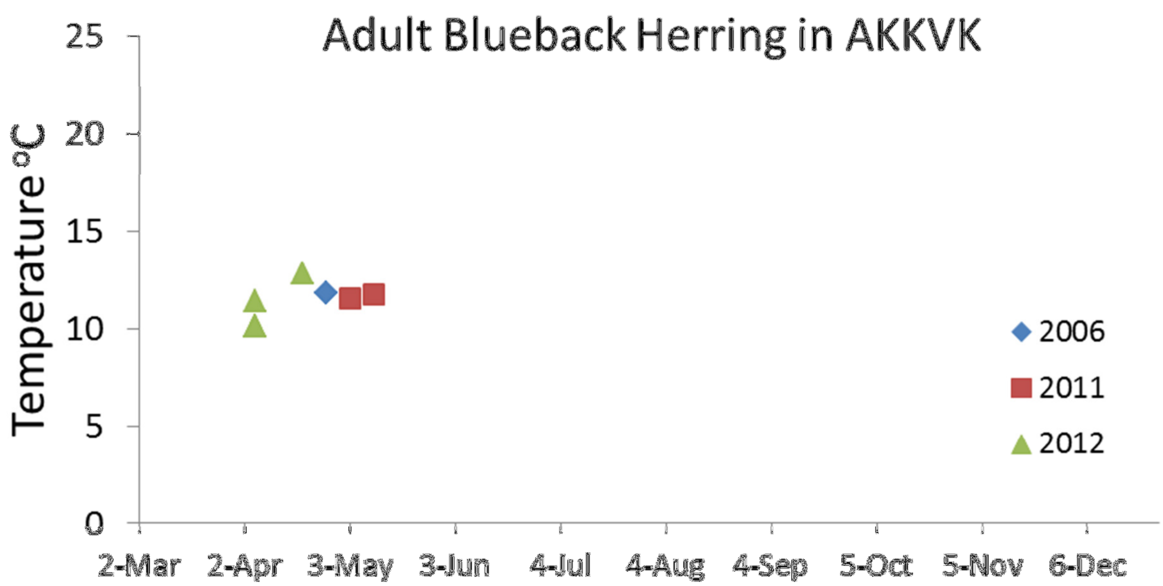


Figure II-17 (continued). Water temperatures recorded at the time that adult blueback herring were collected in Arthur Kill/Kill Van Kull (c) during Migratory Finfish Survey mid-water trawl sampling. Each symbol represents a sample that contained one or more adult alewives.

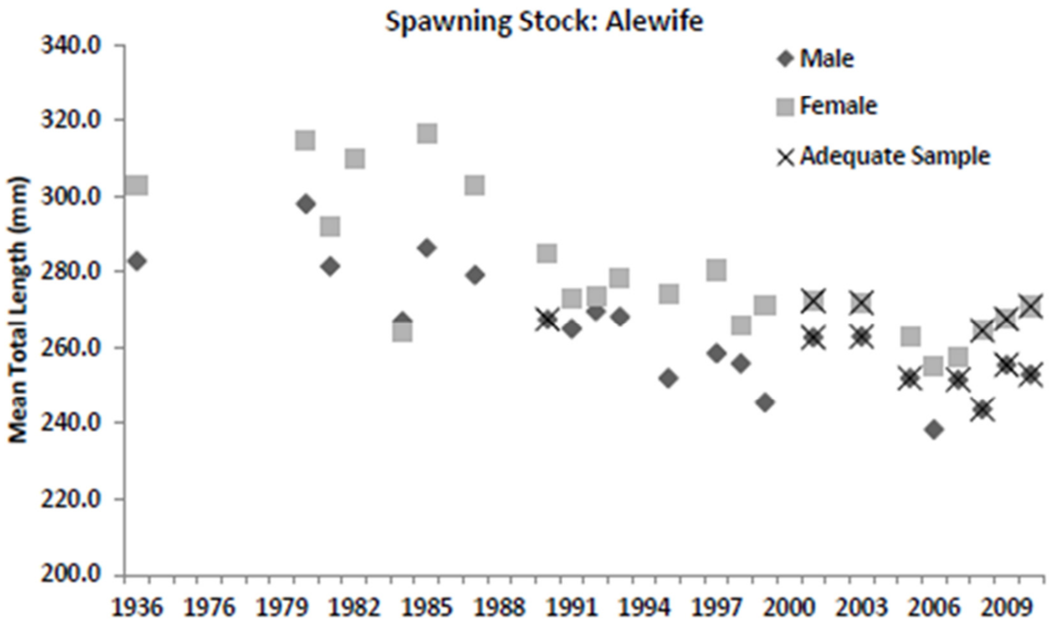


Figure 10.12 Mean total length of adult (>170mm) alewife collected in electrofishing, beach seine, and herring seine gears in the Hudson River Estuary.

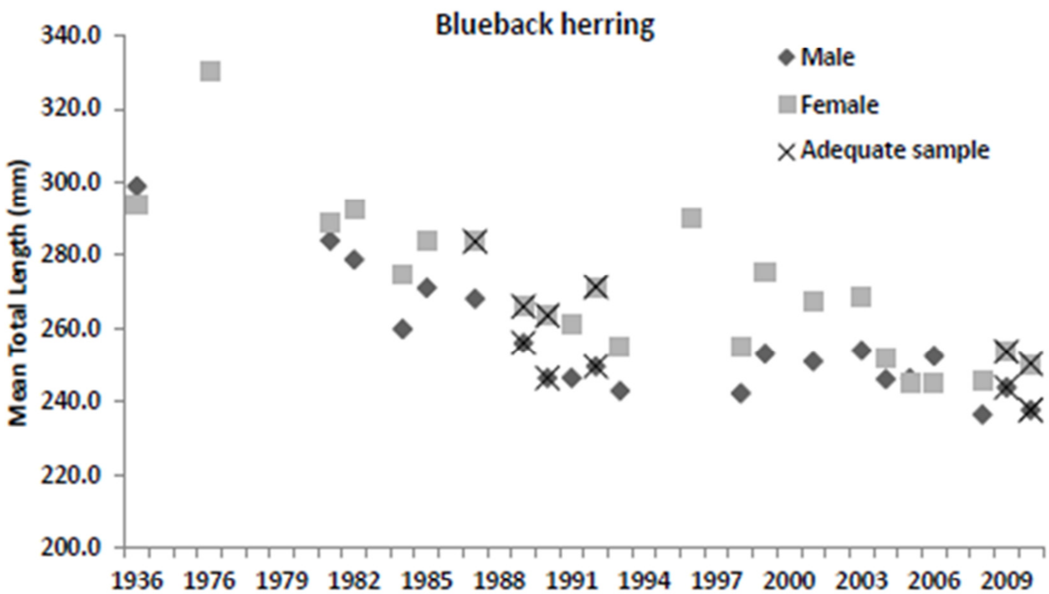


Figure 10.13 Mean total length of adult (>170mm) blueback herring collected in electrofishing, beach seine, and herring seine gears in the Hudson River Estuary.

Figure II-18. Temporal trends in declining adult alewife and blueback herring body size reported in ASMFC, 2012 (p. 351) for the Hudson River Estuary.

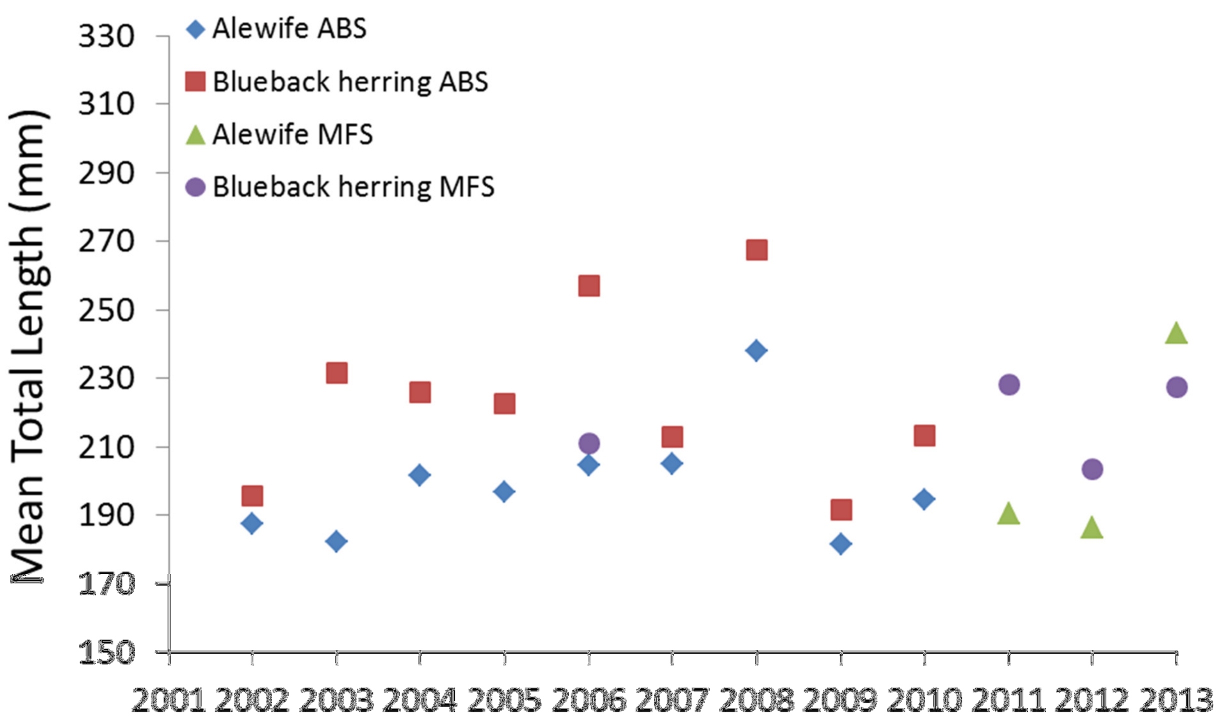


Figure II-19. Mean total length (mm) of alewife and blueback herring > 170 mm TL collected during the Aquatic Biological Survey and Migratory Finfish Survey. The sexes of river herring were not identified during either study.

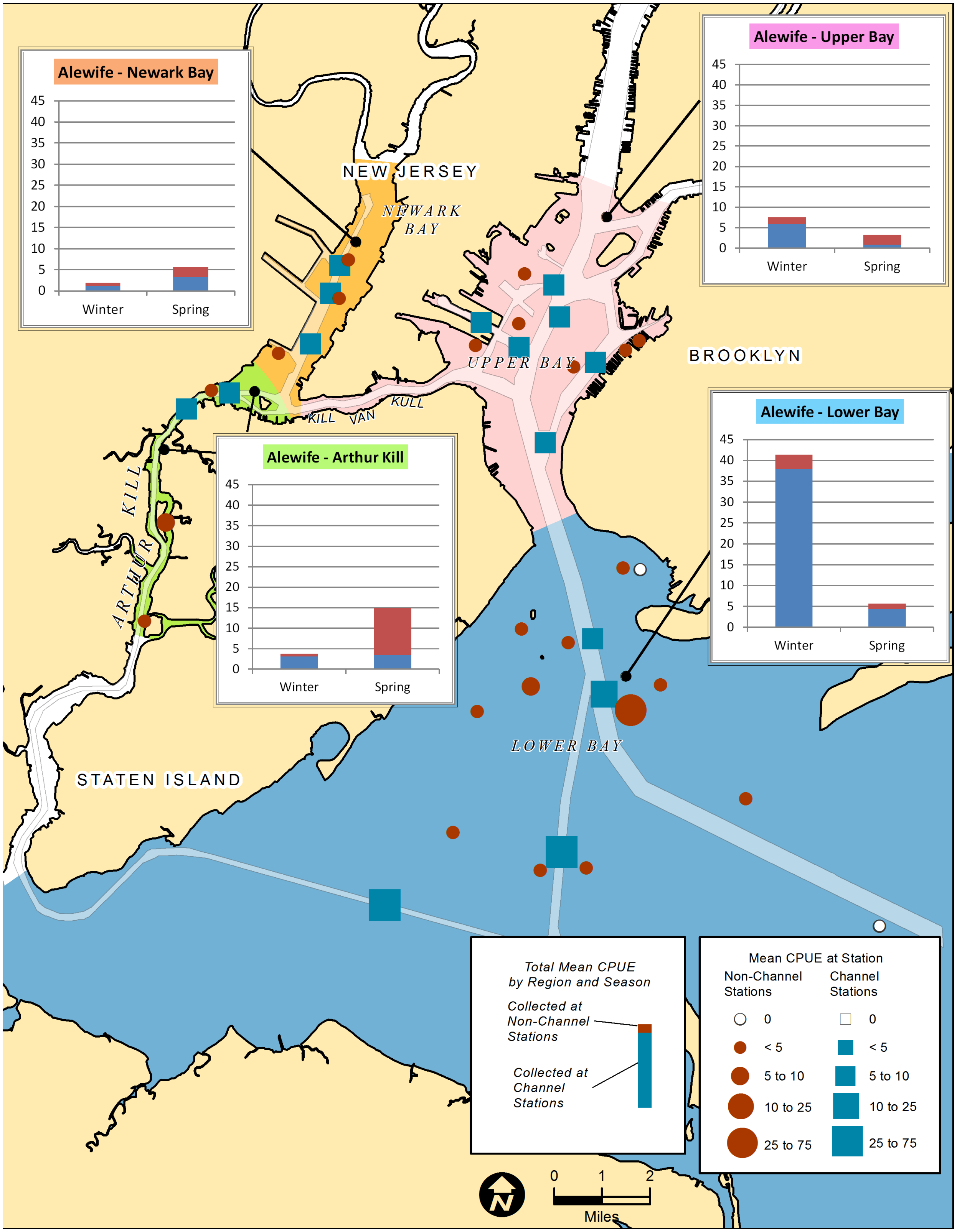


Figure II-20. Alewife bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

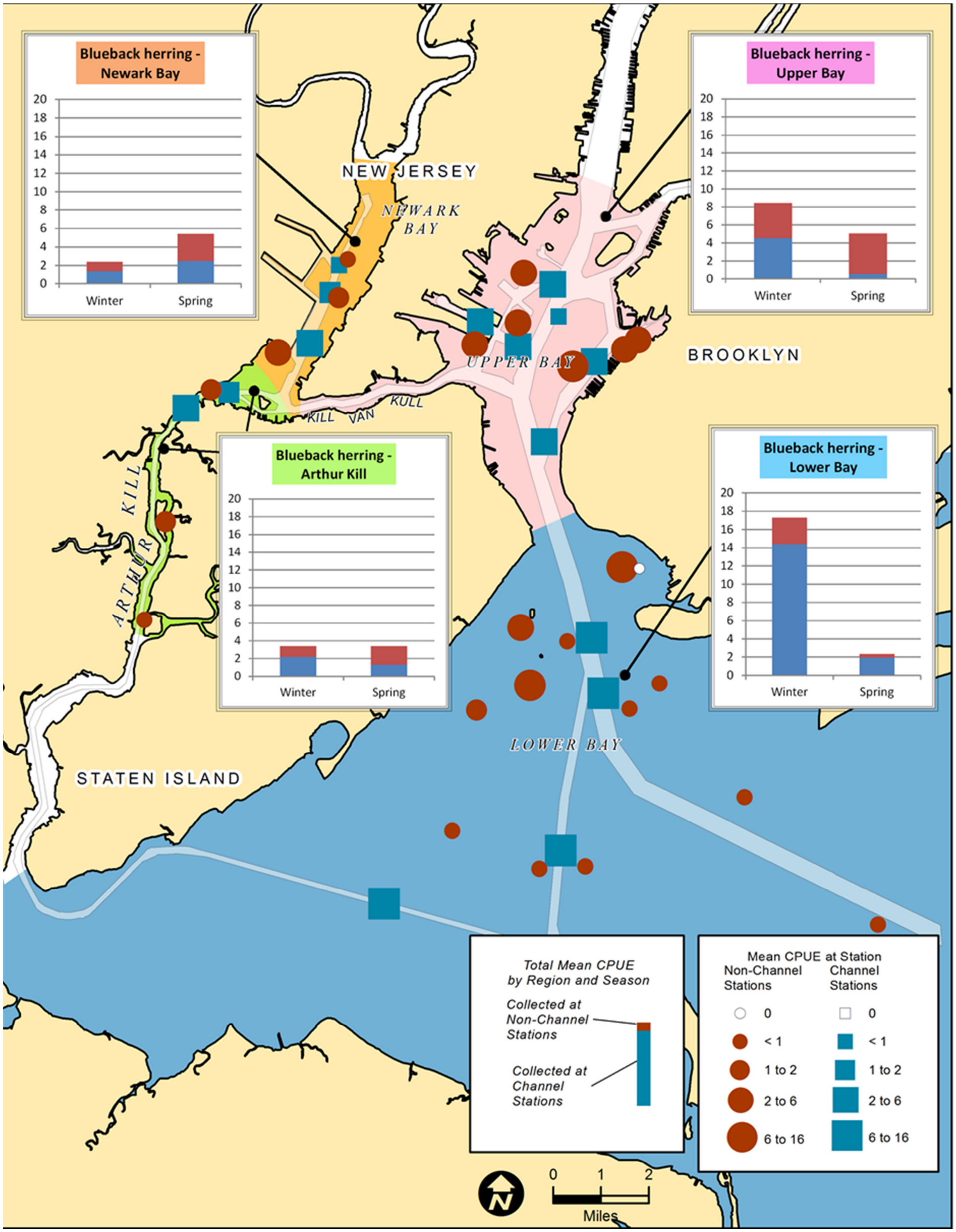


Figure II-21. Blueback herring bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.