US Army Corps of Engineers®
New York District

NEW YORK AND NEW JERSEY
HARBOR DEEPENING PROJECT

Demersal Fish Assemblages of New York/New Jersey Harbor and Near-Shore Fish Communities of New York Bight

October 2015

NEW YORK AND NEW JERSEY HARBOR DEEPENING PROJECT

DEMERSAL FISH ASSEMBLAGES

OF NEW YORK / NEW JERSEY HARBOR

AND NEAR-SHORE FISH COMMUNITIES OF NEW YORK BIGHT

Part A: Adult/Juvenile Assemblages

Part B: Ichthyoplankton Distribution

Part C: Evaluation of State-Managed and Forage Species Habitat Use in NY/NJ Harbor and Near-shore Communities

October 2015

U.S. Army Corps of Engineers

New York District

26 Federal Plaza

New York, New York 10278

Executive Summary

Determinations of seasonal dredging restrictions throughout the United States are frequently based on outdated information or perceptions of the dredging process and in only a few instances on conclusive scientific evidence (National Research Council 2001). During the past decade, the U.S. Army Corps of Engineers – New York District (USACE-NYD) conducted an extensive Aquatic Biological Survey (ABS) of New York and New Jersey Harbor (the Harbor). The program was developed in coordination with National Marine Fisheries Service (NMFS) and the state environmental regulatory agencies in New York and New Jersey, as well as the project sponsor, the Port Authority of New York and New Jersey (PANYNJ) to assess the seasonal distribution and abundance of aquatic resources including essential fish habitat (EFH) species and habitat information as a basis for informed dredging management practices and to promote the protection of fish assemblages utilizing existing habitats of the Harbor and near shore habitats of the New York Bight.

The ABS was a long-term, diverse and spatially robust sampling program that included bottom trawl surveys of demersal or near bottom occurring finfish (2002 – 2010 dataset), ichthyoplankton tows using a benthic sled equipped with a plankton net to collect fish eggs and larvae near the bottom (2002 – 2011 dataset), and benthic grab samples (2005 - 2012) to identify sediment types and benthic invertebrates as well as underwater video surveys to map benthic habitat. For purposes of this report, species collected during the ABS program were divided into three broad groups: 1) EFH managed species (species which the NMFS has designated habitat in the Harbor as essential for certain species and life stages), 2) important non-EFH managed species (listed or proposed Threatened and Endangered species (TES) as well as 3) species which the state/federal resource agencies have considered important commercially, recreational, or important prey/forage species), and other common species.

Demersal (living and feeding on or near the bottom of the water body) fish assemblages in the Harbor were numerically dominated by schooling species, many of which move through the estuary as they migrate to and from either freshwater (white perch) or marine habitats (bay anchovy, spotted hake, Atlantic herring, winter flounder, Atlantic silversides, and Atlantic

menhaden) and others that migrate between marine and freshwater (alewife, blueback herring, and striped bass). Because of these migratory species, overall fish abundances in the winter (December through March) in the Newark Bay and Arthur Kill were nearly twice as high as Lower Bay fish densities and nearly four times higher than Upper Bay fish densities. Juvenile winter flounder and red hake were also among the most abundant fish collected in the Newark Bay and Arthur Kill in winter. Fish diversity in Upper Bay and Lower Bay in the winter was greater than that of Arthur Kill and Newark Bay, even though densities were lower. In the spring, bay anchovies were numerically dominant in both Upper Bay and Lower Bay and spotted hake and Atlantic herring were dominant in Arthur Kill and Newark Bay, respectively.

Multivariate statistical analyses were used to examine whether fish were distributed relatively homogeneously across the Harbor or whether distinct assemblages were associated with different Harbor areas and habitats and whether water temperature and salinity/freshwater discharge may influence the areas and habitats used by species. Overall, fish abundances were greater in channels in winters with relatively moderate temperatures (2002, 2006-2010). This spatial pattern included higher abundances in channels of white perch and striped bass in Arthur Kill and Newark Bay, alewife and spotted hake in Lower Bay and Upper Bay and American sandlance and Atlantic silversides in Lower Bay. During the years with more severe cold temperatures (2003-2005), fish distributions between channel and non-channel locations were more homogeneous, thus it does not appear that channels provide a thermal refuge from extreme cold temperatures.

The major findings in this report include the following:

Part A: Adult/Juvenile Assemblages

- Nine years (2002-2010) of bottom trawl sampling in the Harbor from the winter (December or January) to early summer (May or June) revealed several fish assemblages utilizing habitats in the Harbor.
- Over the nine years of ABS bottom trawl sampling, 142,036 fish from 81 taxa, most identified at the species level, were collected. Fifty-eight percent of the fish (based on

CPUE) were collected from channel stations. Fifteen species accounted for 95% of the total overall abundance in bottom trawl catches and five species; bay anchovy, white perch, spotted hake, alewife, and striped bass accounted for two-thirds of all fish collected.

- The most common finfish species were predominately juveniles with the following exceptions: bay anchovy in spring and white perch during spring and winter were primarily adults. The adult/ juvenile ratio was mixed for alewife during spring, Atlantic silversides during winter and windowpane during both seasons; with the following exception for windowpane in the Arthur Kill/Newark Bay during winter which were primarily juveniles.
- Mean CPUEs were generally higher at channel stations during winter and except for the Arthur Kill region, higher at non-channel stations during spring.
- Mean CPUEs were generally higher at channel than non-channel stations during mild winters than during colder winters when densities were more evenly distributed between channel and non-channel stations for most species.
- The overall abundances of fish of all species in the winter in Arthur Kill/Newark Bay are nearly twice as high as that collected in Lower Bay and nearly four times as high as winter fish abundances in Upper Bay. Total winter fish CPUE over the nine years of sampling averaged 96 fish/10 minute trawl in Arthur Kill/Newark Bay, 58 fish/10 minute trawl in Lower Bay and 28 fish/10 minute trawl in Upper Bay.
- Although the Upper Bay demersal fish densities were lower than that of Arthur Kill and Newark Bay, the community was more diverse, with 13 species comprising 95% of the fish collected. Striped bass, blueback herring, alewife, and spotted hake accounted for more that 50% of the Upper Bay winter fish community.
- The Lower Bay winter fish community also was relatively diverse, with 12 species comprising 95% of fish collected. Alewife, American sandlance and blueback herring accounted for more than 50% of these fish.
- Winter Fish assemblages were primarily composed of white perch, striped bass, alewife, blueback herring, spotted hake, winter flounder, Atlantic silversides and red hake. Alewife, blueback herring, spotted hake, winter flounder, and red hake co-occur in all

Harbor areas during the winter. The majority of these (six species) are obligate estuarine-dependent species and three including Atlantic silversides, spotted hake, and red hake are facultative.

- Winter species assemblages were similar in the Arthur Kill and Newark Bay regions due to high collections of white perch and striped bass, species that were much less common in finfish collections in the Upper Bay and Lower Bay regions (except for striped bass in the Upper Bay). Generally, alewife, blueback herring, spotted hake, winter flounder, and red hake co-occur in all Harbor areas during the winter.
- Spring Fish Assemblages were primarily composed of bay anchovy, spotted hake, Atlantic herring, alewife, blueback herring, and winter flounder. Bay anchovy, spotted hake, Atlantic herring, alewife, blueback herring, and winter flounder co-occur in all Harbor areas during the winter. Alewife, blueback herring, and winter flounder are obligate estuarine-dependent species and bay anchovy, spotted hake, and Atlantic herring are facultative.
- Overall demersal fish CPUE and diversity were higher throughout the Harbor in the spring (April through June). Fish densities were highest in Upper Bay, mean total of 115 fish/10 minute trawl compared to 92 fish/10 minute trawl in Arthur Kill/Newark Bay and 64 fish/10 minute trawl in Lower Bay.
- In all Harbor areas except Arthur Kill, bay anchovy was the numerically dominant species in the spring. In both Arthur Kill and Newark Bay, 10 species comprised 95% of the total number of individuals collected, with spotted hake accounting for more than half the fish in Arthur Kill and bay anchovy and Atlantic herring comprising more than half the fish in Newark Bay.
- Mean CPUEs of juveniles and adults for 8 species (white perch, striped bass, alewife, blueback herring, spotted hake, American sandlance, Atlantic silversides and winter flounder), peaked during winter while densities of three species (bay anchovy, spotted hake, and Atlantic herring) peaked during spring.

Part B: Ichthyoplankton Distribution

- Ten years of ABS ichthyoplankton / benthic sled sampling in the Harbor (2002 – 2011) from January to June documented demersal egg and larval densities for winter and spring spawning fish species in various Harbor areas.
- The numerically dominant egg species collected included bay anchovy, wrasses, Atlantic menhaden, and windowpane and their densities increased through the spring into June.
- A few species (e.g., winter flounder and Amercian sandlance) spawned in the Harbor in the winter, but egg densities of these species were relatively low compared to egg densities of spring spawning species.
- The abundance and distribution of Atlantic menhaden, bay anchovy, windowpane, and wrasse eggs suggest spawning throughout the Harbor; while the abundance and distribution of fourbeard rockling, hogchoker, and weakfish eggs seem to suggest they may spawn primarily in the Upper Bay and Newark Bay.
- Infrequent winter collections of fourbeard rockling, grubby, sand flounders and spotted hake eggs and yolk-sac larvae of rock gunnel, Atlantic tomcod, sea raven and longhorn sculpin indicate winter spawning occurs near the Harbor and these early life history stages may be advected into the estuary.
- Larvae were more evenly distributed among Harbor areas than eggs, probably because mixing and transport from spawning sites occurs on tidal currents.
- Bay anchovy, goby, and northern pipefish larvae were relatively more abundant in Arthur Kill/Newark Bay than in Lower Bay and Upper Bay channel locations, whereas winter flounder, windowpane, and grubby larvae were not as abundant in Arthur Kill/Newark Bay.

Part C: State-Managed and Forage Species Evaluation

- Annual fluctuations in total abundances include species with highly variable annual abundances include American sandlance (CV = 208%), red hake (CV = 170%), Atlantic silversides (CV = 145%), and Atlantic tomcod (CV = 131%).

- Whereas annual abundances of winter flounder (CV = 35%) and striped bass (CV = 55%) were relatively consistent.
- There was no indication of long-term trends (either increasing or decreasing) in abundance for any species.
- The majority of the demersal finfish species collected in the Harbor during the nine years of ABS sampling were also collected in either near-shore areas off the south shore of Long Island (USACE 2008a and 2008b) or in the surf zone of northern New Jersey (Wilber *et al.* 2003).
- There were sufficient numbers of both juvenile and adult white perch collected in Arthur Kill/Newark Bay, Atlantic silversides in Lower Bay, and alewife and bay anchovies throughout the Harbor to test whether use of channel locations differed by age classes. For these species and areas, the abundances of adults and juveniles did not differ between channel and non-channel locations.

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Part A: Adult/Juvenile Assemblages

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Introduction

The United States Army Corps of Engineers – New York District's (USACE-NYD's) congressionally authorized Harbor Deepening Project (HDP) is aimed at improving Harbor navigation and safety while minimizing impacts to the overall environment, as well as promoting environmental sustainability and improvements. The project is currently under construction and nearing completion. Prior to construction, a comprehensive review of the literature in the mid-1990s 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 species, shellfish and benthic macro-invertebrate species (USACE-NYD 1998).

Since determinations of seasonal dredging restrictions throughout the United States were frequently found to be based on outdated information or perceptions of the dredging process and in only a few instances on conclusive scientific evidence (National Research Council 2001), additional biological data for assessing current dredging restrictions in the NY/NJ Harbor area was warranted. In an effort to collect Harbor area specific data for evaluating management decisions including essential fish habitat (EFH)[1] designations, the Aquatic Biological Survey (ABS) was developed in coordination with National Marine Fisheries Service (NMFS) and the state environmental regulatory agencies in New York and New Jersey, as well as the project sponsor, the Port Authority of New York and New Jersey (PANYNJ) to assess the seasonal distribution and abundance of these biotic resources.

The ABS was a long-term, diverse and spatially robust sampling program that included bottom trawl surveys of demersal or near bottom occurring finfish, ichthyoplankton tows using a benthic sled equipped with a plankton net to collect fish eggs and larvae near the bottom, and benthic grab samples to identify sediment types and benthic invertebrates as well as underwater video

[1] EFH is defined under section 305(b)(2) of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCA) as amended by the Sustainable Fisheries Act of 1996 (Public Law 104-267) as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity."

surveys to map benthic habitat. For purposes of this report, species collected during the ABS program were divided into three broad groups: 1) EFH managed species (species which the NMFS has designated habitat in the Harbor as essential for certain species and life stages), 2) important non-EFH managed species (listed or proposed TES species as well as species which the state/federal resource agencies have considered important commercially, recreational, or 3) important prey/forage species), and other common species.

PREVIOUS WINTER FLOUNDER AND ABS REPORTING

Because of its commercial and recreational value, and because it is a species known to spawn in shallow water areas of estuaries, winter flounder is often targeted by resource agencies as a species of concern for in-water construction work in NY/NJ Harbor. In 2001, NMFS issued a conservation recommendation (CR) letter (NMFS 2001) regarding potential impacts of the HDP on federally managed EFH species. The potential project impacts identified in the letter included the re-deposition of sediment suspended during dredging, physical removal of bottom habitat, entrainment of eggs and larvae in dredging equipment, and loss of EFH function. Specifically, the 2001 CR letter identified winter flounder as a species "that will be most affected by the deepening, or are representative of other federally managed species."

Consequently, ABS sampling as well as previous reporting has focused on both winter flounder early life history eggs and larvae (USACE 2010, Wilber *et al.* 2013a) and adult/juvenile collections (USACE 2012, Wilber *et al.* 2013b). Since its inception in 1998, the ABS underwent a number of modifications and enhancements, but data used in the previous summary reports and peer-reviewed publications have focused on habitat usage during spawning and the sampling conducted from December/January to May/June from 2002-2010 for bottom trawls and 2002-2011 for ichthyoplankton collections.

The ABS program provides broad spatial and temporal data on the occurrence of early life stage winter flounder within the Harbor. The spatial data show the relative utilization of both channel and non-channel areas in each of the harbor regions by winter flounder and potential EFH function of habitat usage. The temporal data were used to demonstrate that recent available information can be used to further reevaluate and refine the conservation recommendation through the timing of winter flounder egg and larvae occurrence in the Harbor and establish a relationship between winter flounder life stage data and EFH function of habitat usage including environmental factors that may result in yearly variability of the data.

Application of Winter Flounder Early Life History Data (USACE-NYD 2010)

Over the nine year study period (2002-2010), USACE-NYD 2010 showed that winter flounder eggs were distributed throughout the Harbor, with significantly lower egg densities in the Arthur Kill/Newark Bay area. Eggs collected in the Arthur Kill/Newark Bay area accounted for less than 5% (based on density) of the total egg collection within the Harbor area. Winter flounder larval densities were highest in the Lower Bay and lowest in the Arthur Kill/Newark Bay area where yolk-sac and post-yolk-sac larval collections averaged 10% and 14%, respectively, of the overall larval collections from 2002 to 2010.

Of the 2,643 eggs collected from 2002 to 2010, only six (<1%) were collected in the Arthur Kill and these collections were confined to two of the five stations sampled in the Arthur Kill area Egg collections at Newark Bay stations totaled 52 (2%) and 83% of these eggs were collected at a single station (NB-7) a shallow non-channel station located on Elizabeth Flats. *These data strongly suggest that the winter flounder generally do not utilize the Arthur Kill area as spawning habitat, and therefore, dredging restrictions in February that are designed to protect winter flounder eggs may not be necessary for this area as well as the Newark Bay area.*

Within the Upper and Lower Bays, shallow benthic habitat (typically less than 6 meters) was used as winter flounder spawning habitat. In some years, eggs were concentrated in either the Lower Bay (2002, 2003 and 2004) or Upper Bay (2005, 2006, and 2008). Eggs occurred in relatively even densities in the Lower and Upper Bay areas in other years (2007, 2009, and 2010). Yolk-sac and post-yolk-sac larval densities were highest in the Lower Bay. There were no statistical associations found between egg and larval distributions among the Harbor areas and several environmental variables (river discharge, salinity, dissolved oxygen and temperature).

Since winter flounder egg and larval distributions are most highly concentrated in the Upper and Lower Bays, seasonal dredging restrictions in these areas could be carefully refined to encompass demonstrated periods of egg and larval occurrences.

Winter flounder eggs occurred in the Harbor from early February to early April, with 90% of the annual egg collections obtained after 18 February in eight of nine years of the ABS program. Overall, 90% of yolk-sac larvae were collected during April and 90% of post-yolk sac larvae were collected by 16 May. Study results indicate that the two years in which the 90% collection of post-yolk-sac larvae occurred later in May (2003 and 2005) were years with the most extreme low water temperatures in March of less than 2°C. *Since extreme cold temperatures have been found to delay egg and larval development, adaptive management decisions on dredging restrictions in May could be revised on a yearly basis by reviewing March water temperatures to determine if it is likely that larvae would still be present in the Harbor during mid to late May.*

The ABS study provides strong scientific evidence and is consistent with existing literature in showing channels are not high value spawning habitat. Among the non-channel stations sampled for the ABS, egg collections were highest at the shallowest stations. Stations with the highest catches of eggs were at approximately three meters (10 feet) depth, whereas non-channel stations with low egg abundances were at depths of eight and nine meters (26 and 30 feet). In addition, nearly all (98%) newly spawned eggs (stages 1 and 2, less than 48 hours old) were collected at non-channel stations and samples that contained multiple egg stages (presumably from multiple spawning events, which is indicative of spawning sites or sinks) were collected almost exclusively at non-channel stations. *These results strongly suggest that the Federal channels are not used as spawning habitat by winter flounder in the Harbor and the proposed re-designation of winter flounder early life stage EFH to 20 meters (66 feet) was not warranted and was the rational used by NMFS and the New England Fishery Management Council to not enact this proposed re-designation.*

Application of Winter Flounder Adult and Juvenile Data (USACE-NYD 2012)

USACE-NYD (2012) indicated that over the nine year ABS bottom trawl program from 2002 to 2010, winter to early summer habitat use within the Harbor varied by size/age class showing that Year-1 juvenile winter flounder densities were significantly higher in the Arthur Kill/Newark Bay area and adult densities were significantly lower in this area compared to the Lower Bay and Upper Bay areas. The relatively high densities of Year-1 juveniles and low densities of adults in the Arthur Kill suggests this area is used for early grow out but is not of high value as spawning habitat, especially when taken in conjunction with findings from additional studies (USACE 2010) that showed very few eggs and larvae collected in the Arthur Kill/Newark Bay area.

However, the combined juvenile and adult winter flounder densities did not differ significantly by Harbor area and both juvenile and adult winter flounder densities were higher at channel than non-channel stations. Adult densities peaked in April at Lower Bay and Upper Bay stations after the spawning season ended, which coincided with the time that adults typically forage inshore before emigrating from estuaries. Year-1 juvenile densities peaked in all three Harbor areas during January with secondary peaks in March, peak densities by Harbor area occurred in the Upper Bay during January and the Arthur Kill/Newark Bay area during March.

There was no indication, in the ABS data, that revision of the current dredging restrictions that are currently in place to protect winter flounder egg and larval stages would provide more protection to juvenile and adult winter flounder, based on their distribution patterns within the Harbor. *This report's results confirm that the existing conservation recommendations and environmental window restrictions discussed in 2010 Early Life Stage Application Report should not apply to the more mobile juvenile and adult life stages of winter flounder, which can avoid potential impacts associated with dredging (i.e. physical disturbances and re-suspended sediments).*

Report Objectives

Placed in the context of the previous two winter flounder summary reports (USACE-NYD 2010 and USACE-NYD 2012), the objective of this third summary report of the available ABS data is to provide an overview of the demersal fish data for other species besides the heavily studied Winter Flounder, and to use the results as a basis for informed dredging management practices and to promote the protection of federal EFH managed species, state managed species, state and/or federally threatened and endangered species (TES), important forage and migratory fish species [including early life stages (egg and larval) through juvenile and adult life stages]. This report examines the spatial (if these species have shallow non-channel or channel habitat preferences) and temporal/seasonal usage of the Harbor (i.e. more likely to use the Harbor during winter or spring). No ABS bottom trawl sampling was conducted during the summer and fall seasons.

Occurrence of species assemblages and habitat utilization within the Harbor are primarily based on data collected as part of the ABS bottom trawl program (2002 – 2010) and ichthyoplankton benthic sled program (2002 – 2011). ABS data may provide a basis for informed dredging management practices and to promote the protection of fish assemblages utilizing existing habitats of the NY/NJ Harbor and near shore habitats of the NY Bight including utilization by eggs, larvae, juveniles and adults (including sub-adults and spawning adults). The following Chapter 3 summary report focuses on the Fish Assemblages of NY/NJ Harbor and the Nearshore Communities of the NY Bight (Part A); Ichthyoplankton Distribution (Part B) and the Evaluation of NY/NJ Harbor & Near-Shore Habitat Use by State Managed Species (Part C).

Part A of this report documents juvenile and adult fish assemblages (i.e., groups of species that frequently co-occur) in the Harbor and in near-shore coastal areas. The focus is on demersal fish species using the ABS bottom trawl data as the primary data set used in the analysis with references when relevant to existing sediment, benthic, TSS/Water Quality and underwater video data.

Fish species were assessed based on their degree of estuarine dependence (Able 2005) and use of Harbor and near-shore coastal areas. Groups of species that commonly co-occur in different areas of the Harbor (Arthur Kill, Newark Bay, Upper Bay, Lower Bay) are identified and these fish assemblages provide spatial and temporal resolution on the fish species that may potentially be affected by future projects in particular Harbor areas. Figures prepared using geographic information system (GIS) data are provided that depict fish assemblage distributions in channel and non-channel habitat in each of the Harbor areas during winter and spring. These figures also include the species and their relative abundance in each species assemblage.

The following questions were considered in Part A:

a. Spatial Distributions

- Do juvenile and adult fish assemblages differ between channel and non-channel areas?
- Are channel fish assemblages comprised primarily of obligate estuarine-dependent species or species that are facultative (i.e., also occur in near-shore coastal habitat)?
- Are environmental variables (e.g., temperature, freshwater input) associated with spatial differences in fish distributions?

b. Temporal Distributions

- Are there seasonal differences in fish assemblages among Harbor areas?
- Are there predictable environmental (e.g., temperature) triggers that are associated with the occurrence of fish assemblages?

Methods

BOTTOM TRAWL FIELD COLLECTION

During the ABS Program, bottom trawl sampling for adult and juvenile finfish was conducted using a Wilcox 30 foot flat otter trawl with 1.0-inch square mesh netting and a 0.75-inch square mesh cod end with a 0.25-inch cod end liner. The trawl was towed over the bottom at approximately five feet per second. Sampling was scheduled to bracket the period when adult winter flounder are historically present in the Harbor to spawn, including the post-spawn period when eggs and larvae are also present. Bottom trawl surveys were conducted from 2002 to 2010[2] beginning in December or January and ending in May or June at approximately 24 to 29 fixed location stations, which varied by year of sampling.

Overall, the sampling effort ranged from 194 to 286 bottom trawls per year from 2002 to 2010 (Table A1), with the concentration of effort shifting increasingly toward Lower Bay non-channel stations in latter years as it became increasingly clear from the ichthyoplankton surveys that winter flounder do not commonly use the Arthur Kill/Newark Bay area as spawning habitat and shallow, non-channel areas (more common in the Lower Bay) was found to be important spawning habitat. Although this spatial and temporal design targeted winter flounder, it also overlapped the seasonal occurrence of several other species (bay anchovy, white perch, spotted hake, alewife, Atlantic herring, blueback herring, American sandlance, red hake, Atlantic silverside, Atlantic tomcod, American shad, silver hake, and other less common species).

Since 2002, when ABS sampling began in the Lower Bay, the study objectives, survey areas and sampling gear remained relatively consistent among sampling years to allow for inter-annual comparisons. Throughout the survey, a set of approximately 24 to 29 sampling locations were used, but some adjustments were made from year to year to accommodate HDP construction, changes in station bathymetry and program data requirements. Sample locations were divided

[2] Bottom trawls were conducted during the night from the 1999 through 2004 sampling programs. In 2005, sampling was changed to daylight hours due to safety considerations.

into channel and non-channel areas. Consistency embedded in the ABS sampling design allows the cumulative 2002 through 2010 dataset to serve as a foundation for analyses in this report.

ENVIRONMENTAL DATA SOURCES

Water temperature data were obtained from records for the NOAA gauge (station ID 8518750) located at the southern tip of Manhattan Island (the Battery, at 40°42.0′N, 74°0.8′W). Hudson River discharge data was obtained from records for the United States Geological Survey (USGS) station 01358000 at Green Island.

DATA ANALYSIS

Spatial Distributions

Because temperature is a major determinant of fish distributions that affects both their regional distributions by latitude (Murawski 1993) and the onset of migratory behaviors through an estuary (e.g., Bigelow and Welsh 1925, Loesch and Lund 1977), the spatial distributions of the Harbor demersal fish community is described separately by season. Multivariate statistical methods were used to examine whether fish assemblages differed among Harbor areas or by station type (channel and non-channel) and significant results were depicted using non-metric multidimensional scaling (nMDS) plots. These analyses were conducted separately by season, i.e., winter (January, February and March) and spring (April, May, and June).

Analysis of Similarities (ANOSIM) was used (PRIMER version 6.1, Clark and Warwick, 2001) to test for these potential differences using ranked similarity matrices based on Bray-Curtis similarity measures of square-root transformed data. Similarity percentages (SIMPER) were used to identify fish taxa contributing to any differences that were detected. Multivariate results were examined using Pearson correlation analyses to determine whether environmental factors such as severity of winter temperatures and freshwater discharge were associated with fish distribution patterns.

Results

Winter flounder have been among the ten most common species collected each year over the ABS bottom trawl sampling program from 2002-2010 and results for the adults/juveniles of this species have been described previously (USACE-NYD 2012). Other common species (collectively within the top 95% composition of species collected during the nine year bottom trawl sampling program) included four other EFH managed species (Atlantic herring, red hake, silver hake also known as whiting, and windowpane); four important state managed species (alewife, American shad, blueback herring, and striped bass); and six other common species including American sandlance, Atlantic silverside, Atlantic tomcod, bay anchovy, spotted hake, and white perch. Overall, 15 species collectively made up approximately 95% of the bottom trawl catch over the nine year program. The six other common species (n = 84,393) made up 59.3% of the total catch of these 15 species, while the five EFH managed species (n = 20,552) and four important non-EFH managed species (n = 29,694) made up 14.5% and 20.9% of these 15 species, respectively (Table A1).

ENVIRONMENTAL FACTORS

Seasonal water temperatures ranged from winter lows of -1.3 to 6^{o}C to summer highs of 23^{o}C to 26^{o}C (Figure A1). Annual differences in water temperatures were most apparent in the severity of cold winter extremes. For instance, extreme low temperatures (less than 2^{o}C) occurred in 2003, 2004 and 2005.

Freshwater discharge to the Harbor, as represented by Hudson River flows, peaked in March and April of most years (Figure A2), except 2006, when river discharge in the spring was lower than flows measured in January and June. Seasonal fluctuations in salinity reflect the general trends in freshwater inflows, with highest overall monthly salinities in February when flows are lowest and lower salinities in the spring when river discharges peak (Figure A3). Overall salinity trends are complicated by the time of sampling relative to the direction of tidal currents, which strongly influence Harbor physical processes (Waldman 1999). Salinities were lowest in the Arthur Kill/Newark Bay region, with monthly averages ranging from 17 to 21 practical salinity units (psu), intermediate in Upper Bay (21 to 24 psu) and highest in Lower Bay (24 to 28 psu; Figure A3). Dissolved oxygen concentrations were always above hypoxic conditions and averages for sampling events ranged from 5 to 11 milligrams per liter (mg/L).

DEMERSAL FISH COMMUNITIES

Over the nine years of ABS bottom trawl sampling, 142,201 fish from 81 taxa, most identified at the species level, were collected. Fifteen species accounted for 95% of the total overall abundance in bottom trawl catches and five species; bay anchovy, white perch, spotted hake, alewife, and striped bass accounted for two-thirds of all fish collected (Tables A1 and A2). With the exception of a few species in which mostly adults were collected (white perch, Atlantic silversides, bay anchovy in spring, and windowpane and alewife in certain regions and seasons), the majority of fish collected were juveniles (Table A3).

Of the 142,201 fish collected, 22,466 (15.8%) were collected in the Arthur Kill (18,249 during winter and 4,217 during spring); 31,562 (22.2%) were collected in the Newark Bay (18,303 during winter and 13,259 during spring); 44,594 (31.4%) were collected in the Upper Bay (14,403 during winter and 30,191 during spring); 43,414 (30.6%) were collected in the Lower Bay (23,896 during winter and 19,518 during spring). Although sampling effort varied by region, season and station type, it is relatively clear that winter collections were generally higher at channel stations and spring collections were higher at non-channel stations (Figures A4 to A13).

SPATIAL DISTRIBUTIONS

<u>Winter</u>

Many of the numerically dominant fish species collected during the winter (Table A4), such as white perch, striped bass, and winter flounder, were concentrated in Arthur Kill/Newark Bay (Figure A4). Therefore, the overall abundances of fish of all species in the winter in Arthur Kill/Newark Bay are nearly twice as high as that collected in Lower Bay and nearly four times as high as winter fish abundances in Upper Bay. Total winter fish CPUE over the nine years of sampling averaged 96 fish/10 minute trawl in Arthur Kill/Newark Bay, 58 fish/10 minute trawl in Lower Bay and 28 fish/10 minute trawl in Upper Bay.

The numerically dominant fish species (collectively comprising 95% of all fish collected in winter) in Arthur Kill (Figures A6 and A7) and Newark Bay (Figures A8 and A9) were similar. White perch, striped bass, winter flounder, and red hake were the most abundant fish in both areas in the winter. Although the Upper Bay demersal fish densities were lower than that of Arthur Kill and Newark Bay, the community was more diverse, with 13 species comprising 95% of the fish collected in winter (Figure A4). Striped bass, blueback herring, alewife, and spotted hake accounted for more that 50% of the Upper Bay winter fish community (Figure A10). The Lower Bay winter fish community also was relatively diverse, with 12 species comprising 95% of fish collected (Figure A12). Alewife, American sandlance and blueback herring accounted for more than 50% of these fish.

Spring

Overall demersal fish CPUE and diversity were higher throughout the Harbor in the spring (April through June; Figure A5). Fish densities were highest in Upper Bay, averaging 115 fish/10 minute trawl compared to 92 fish/10 minute trawl in Arthur Kill/Newark Bay and 64 fish/10 minute trawl in Lower Bay. In all Harbor areas except Arthur Kill, bay anchovy was the numerically dominant species in the spring (Figure A5). In both Arthur Kill and Newark Bay, 10 species comprised 95% of the total number of individuals collected, with spotted hake accounting for more than half the fish in Arthur Kill (Figure A7) and bay anchovy and Atlantic herring comprising more than half the fish in Newark Bay (Figure A9). The spring demersal fish communities in Upper Bay (Figure A11) and Lower Bay (Figure A13) were dominated by bay anchovies, followed by spotted hake and Atlantic herring.

Fish in Channel vs. Non-channel Areas

The species composition of fish assemblages differed between channel and non-channel locations in the winters of most years (Table A5). There was a significant positive correlation ($r = 0.69$, $p < 0.05$; Figure A14) between the degree to which winter fish assemblages differed spatially (ANOSIM R statistic) and the severity of winter temperatures (cumulative degree days January through March). In other words, when winter temperatures were relatively moderate (cumulative degree days large), winter fish assemblages differed among Harbor areas and channel and non-channel locations (Figure A15). In years with colder winters (2003, 2004 and 2005), fish distributions differed by Harbor area, but not between channel and non-channel locations (Table A5; Figure A16).

In winters with moderate temperatures (2002, 2006-2010), differences in fish assemblage distributions were largely attributable to more white perch and striped bass at channel stations in Arthur Kill/Newark Bay, alewife and spotted hake in channels in Lower Bay and Upper Bay, and American sandlance and Atlantic silversides in Lower Bay (Table A6). Other fish species that tended to be more abundant at channel stations in all Harbor areas included; blueback herring, winter flounder, and red hake. For those years when fish assemblage composition was similar between channel and non-channel stations, white perch and striped bass were consistently more abundant in Arthur Kill/Newark Bay (Table A7). Because sampling occurred at night from 2002-2004, daily activity patterns may have affected the channel/non-channel locations of fish for these years. For instance, white perch, striped bass, and winter flounder are active and feed at night; therefore their abundances in non-channel habitat during 2002-2004 sampling may reflect foraging activity that is not apparent in later years when sampling was conducted during the day. Night sampling occurred in years with both severe and relatively moderate winter temperatures.

Fish assemblage composition in the spring was very similar throughout the Harbor for all years (Table A5), except 2010 (Table A8, Figure A17), when spotted hake and red hake were concentrated in channel locations, primarily in Arthur Kill/Newark Bay and Upper Bay.

Discussion

The demersal fish community of New York / New Jersey Harbor is dynamic, differing in species composition among Harbor areas primarily in the winter. Winter fish assemblages in Arthur Kill and Newark Bay have lower diversity and higher abundances compared to Lower Bay and Upper Bay (Figure A4). Spring fish assemblages are diverse in all Harbor areas and overall abundances are highest in Upper Bay (Figure A5). 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 prey for other fish species. Many of the numerically dominant species are common in the navigation channels and have strong ecological dependence on freshwater habitats (Table A2). For example, alewife, striped bass, blueback herring and white perch spawn in freshwater and migrate either to the estuary (white perch) or all the way through the estuary to nearshore oceanic habitat as juveniles, spending adult years at sea (alewife, blueback herring, and striped bass) before returning through the estuary on spawning migrations.

Fish assemblages in this study can be compared among Harbor areas and over time because the sampling gear and protocol remained constant throughout the course of the study. However, comparisons to other studies with different sampling methods, e.g. beach seine (Hurst *et al.* 2004) or benthic traps (Duffy-Anderson *et al.* 2003) should be made with caution. For instance, silver perch and naked gobies were highly abundant in benthic traps in Arthur Kill in 1995 (Duffy-Anderson *et al.* 2003). Similar species were the most abundant in a beach seine sampling program (1980-2000) in the Hudson River and included Atlantic silversides, striped bass, white perch, American shad, and blueback herring (Hurst *et al.* 2004).

WINTER FISH ASSEMBLAGES

Based on the 2002-2010 ABS bottom trawl data, winter fish assemblages were primarily composed of white perch, striped bass, alewife, blueback herring, spotted hake, winter flounder, Atlantic silversides and red hake (Table A4). Alewife, blueback herring, spotted hake, winter flounder, and red hake co-occur in all Harbor areas during the winter. The majority of these (six species) are obligate estuarine-dependent species and three including Atlantic silversides, spotted hake, and red hake are facultative (Able 2005). Overall CPUEs suggest white perch, striped bass, winter flounder and red hake also co-occur by habitat (i.e., at channel and non-channel stations) in the Arthur Kill/Newark Bay region during winter. Arthur Kill/Newark Bay winter fish assemblages differed from other Harbor regions due to the abundance of white perch and to a lesser extent striped bass. Winter flounder and striped bass are present in lower densities in other Harbor regions; white perch are uncommon in the Upper Bay and are rarely collected in the more saline waters of the Lower Bay. Both winter flounder and striped bass CPUEs were highest in the Arthur Kill/Newark Bay followed by the Upper Bay and were slightly lower for winter flounder in the Lower Bay, while striped bass CPUEs were much lower in the Lower Bay. Red hake CPUEs were lower than these species but were similar in the three Harbor areas.

Overall % composition of Arthur Kill winter fish assemblages suggest white perch and striped bass co-occur by area and habitat in the Arthur Kill during winter (Figure A6). Winter flounder and red hake also co-occur with these species at channel stations and spotted hake co-occur at non-channel stations. Overall % composition of Newark Bay winter fish assemblages suggest white perch and striped bass co-occur by area and habitat in Newark Bay during winter (Figure A8). Winter flounder and red hake also co-occur with these species at channel stations and Atlantic silverside, blueback herring, and winter flounder co-occur at non-channel stations; bay anchovy and alewife were also present at non-channel stations during winter.

Overall % composition of Upper Bay winter fish assemblages suggest striped bass, blueback herring, alewife, spotted hake, winter flounder and red hake co-occur in Upper Bay channels during winter (Figure A10). Striped bass, blueback herring, and alewife along with winter flounder, Atlantic silverside and American shad co-occur at Upper Bay non-channel habitats.

Overall % composition of Lower Bay winter fish assemblages suggest finfish assemblages in the Lower Bay channels are primarily composed of alewife and blueback herring, along with American sandlance, Atlantic silverside and spotted hake (Figure A12). Other marine species including silver hake, winter flounder, and Atlantic menhaden were less common. Winter fish assemblages in the Lower Bay non-channel habitats were composed primarily of American sandlance and Atlantic silverside; alewife, blueback herring, smallmouth flounder, winter flounder, and spotted hake were also present.

SPRING FISH ASSEMBLAGES

Based on the 2002-2010 ABS bottom trawl data, spring Fish Assemblages were primarily composed of bay anchovy, spotted hake, Atlantic herring, alewife, blueback herring, and winter flounder (Table A4). Bay anchovy, spotted hake, Atlantic herring, alewife, blueback herring, and winter flounder co-occur in all Harbor areas during the spring (Figure A5). Alewife, blueback herring, and winter flounder are obligate estuarine-dependent species and bay anchovy, spotted hake, and Atlantic herring are facultative (Able 2005).

Bay anchovy, spotted hake, and Atlantic herring are the primary species that co-occur in the Arthur Kill/Newark Bay during spring. Alewife, striped bass, winter flounder, blueback herring, red hake, and white perch, although less common, also co-occur in this region during spring. Overall % composition of Arthur Kill spring fish assemblages suggest spotted hake, bay anchovy, red hake, winter flounder, striped bass, white perch, alewife and blueback herring co-occur at channel stations and alewife, striped bass, spotted hake, bay anchovy, white perch and blueback herring co-occur at non-channel stations in this region during spring (Figure A7).

Overall % composition of Newark Bay spring fish assemblages suggest spotted hake, red hake, Atlantic herring, bay anchovy and Atlantic tomcod co-occur at channel stations and Atlantic herring and bay anchovy co-occur at non-channel stations in the Newark Bay during spring (Figure A9). Winter flounder, striped bass, alewife and blueback herring also co-occur with species at channel and non-channel stations.

Overall % composition of Upper Bay spring fish assemblages suggest bay anchovy, spotted hake, and Atlantic herring are the primary species co-occurring in the Upper Bay along with Atlantic tomcod, winter flounder, striped bass, red hake, and blueback herring during spring (Figure A11). Bay anchovy and Atlantic herring were the primary species co-occurring at non-channel stations along with windowpane, striped bass, blueback herring, Atlantic herring, spotted hake and American sandlance. Spotted hake and red hake were the primary species co-occurring at channel stations along with winter flounder, windowpane, bay anchovy, and Atlantic tomcod.

Overall % composition of Lower Bay spring fish assemblages suggest bay anchovy and spotted hake are the primary species co-occurring in the Lower Bay during spring (Figure A13). Other less common co-occurring species include Atlantic herring, alewife, winter flounder and scup at channel stations and American sandlance at non-channel stations.

DISTRIBUTION OF COMMOM ESTUARINE DEPENDENT FINFISH SPECIES

Of the more common obligate estuarine-dependent species, white perch were primarily collected in the Arthur Kill/Newark Bay region during winter (mean CPUE of 80.15) and striped bass were primarily collected from the Arthur Kill/Newark Bay region during winter and spring (mean CPUE of 19.48 and 4.26, respectively) (Table A4). Few white perch were collected in the Arthur Kill/Newark Bay region during spring and striped bass were collected in the Upper Bay during winter and spring (Table A4). Very few white perch or striped bass were collected in other Harbor regions. Most white perch and striped bass were collected from channel stations (see also Figures C17 and C19).

Few bay anchovy, a facultative estuarine-dependent species, were collected in the Harbor during winter, however collections increased substantially during spring in all Harbor regions with the highest mean CPUE in the Upper Bay (79.66), followed by the Lower Bay (43.63) and the Arthur Kill/Newark Bay region (28.93) (Table A4). They were collected primarily from non-channel stations in all regions (see also Figure C11).

Alewife and blueback herring (obligate estuarine-dependent species) were common during winter and spring in all Harbor regions at both channel and non-channel stations (except in the Lower Bay during winter when the majority of alewife and blueback herring were collected at channel stations) (see also Figures C3 and C12). The mean CPUEs were also highest in the

Lower Bay region (16.17 and 7.17 for alewife and blueback herring, respectively) during winter (Table A4).

Spotted hake were present in all Harbor regions during winter and spring. They were less common during winter than in the spring when mean CPUEs of 23.46, 17.50 and 6.78 occurred at Arthur Kill/Newark Bay, Upper Bay and Lower Bay, respectively (Table A4). Spotted hake, a facultative estuarine-dependent species, were collected primarily at channel stations during spring, but some were collected primarily from channel stations in the Upper Bay and Lower Bay during winter (see also Figure C16).

American sandlance, a facultative estuarine-dependent species, were primarily collected in the Lower Bay at non-channel stations during winter and spring, mean CPUEs of 10.97 at Lower Bay stations during winter and 0.06 during spring (Table A4). They were also collected at Upper Bay non-channel stations during spring (see also Figure C5).

Atlantic herring, a facultative estuarine-dependent species, were primarily collected in the Arthur Kill/Newark Bay and Upper Bay regions during spring with mean CPUEs of 23.07 and 14.09, respectively (Table A4).

Please see also Part C of this report for additional discussion of state-managed and forage species habitat use in the Harbor and linkages to near-shore habitat for juvenile and adult fish assemblages (i.e., groups of species that frequently co-occur) in the Harbor.

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Tables (Part A)

Table A1. Annual number of juvenile and adult finfish collected in winter and spring ABS bottom trawl samples that collectively account for 95% of all individuals collected from 2002-2010. The number of trawls each year is given in parentheses.

Common Name	Scientific Name	2002 (255)	2003 (266)	2004 (194)	2005 (208)	2006 (213)	2007 (212)	2008 (203)	2009 (240)	2010 (286)	Total
Bay anchovy	*Anchoa mitchilli*	471	1,637	1,775	2,289	12,356	1,363	9,024	3,148	820	32,883
White perch	*Morone americana*	1,425	2,212	1,775	212	1,724	2,361	3,202	3,508	9,862	26,281
Spotted hake	*Urophycis regia*	4,397	2,475	255	109	1,735	527	2,002	239	2,987	14,726
Alewife**	*Alosa pseudoharengus*	494	170	524	250	2,648	371	2,210	4,108	894	11,669
Striped bass**	*Morone saxatilis*	1,294	1,237	1,871	83	861	522	1,420	684	1,995	9,967
Atlantic herring*	*Clupea harengus*	45	648	506	624	538	53	2,667	3,761	333	9,175
Blueback herring**	*Alosa aestivalis*	1,139	230	613	163	1,496	130	391	2,772	138	7,072
American sandlance	*Ammodytes americanus*	0	64	0	0	20	0	1,052	270	4,283	5,689
Winter flounder*	*Pseudopleuronectes americanus*	830	529	612	449	263	428	808	430	910	5,259
Red hake*	*Urophycis chuss*	138	135	47	55	819	186	35	41	2,361	3,817
Atlantic silverside	*Menidia menidia*	35	46	36	62	58	200	714	318	2,108	3,577
Windowpane*	*Scophthalmus aquosus*	487	295	60	54	59	66	116	54	153	1,344
Atlantic tomcod**	*Microgadus tomcod*	40	279	543	60	12	218	55	10	20	1,237
American shad**	*Alosa sapidissima*	109	27	131	44	408	48	65	47	107	986
Silver hake*	*Merluccius bilinearis*	34	53	31	69	121	65	19	59	506	957
Other fish		2,240	695	222	337	756	800	835	264	1,413	7,562
Total number of all fish collected:		**13,178**	**10,732**	**9,001**	**4,860**	**23,874**	**7,338**	**24,615**	**19,713**	**28,890**	**142,201**

* Federally managed (EFH) species
** State managed species of concern

Table A2. Summary of bottom trawl catches over nine years (2002-2010). Guild assignments are diadromous (D), estuarine (E), and marine (M) and are based on Hurst *et al*. 2004 and Able 2005.

Common Name	Scientific Name	Guild	# Years	Total	Cum. %
Bay anchovy	*Anchoa mitchilli*	M	9	32,883	23.1
White perch	*Morone americana*	E	9	26,281	41.6
Spotted hake	*Urophycis regia*	M	9	14,726	52.0
Alewife**	*Alosa pseudoharengus*	D	9	11,669	60.2
Striped bass**	*Morone saxatilis*	D	9	9,967	67.2
Atlantic herring*	*Clupea harengus*	M	9	9,175	73.6
Blueback herring**	*Alosa aestivalis*	D	9	7,072	78.6
American sandlance	*Ammodytes americanus*	M	5	5,689	82.6
Winter flounder*	*Pseudopleuronectes americanus*	M	9	5,259	86.3
Red hake*	*Urophycis chuss*	M	9	3,817	89.0
Atlantic silverside	*Menidia menidia*	M	9	3,577	91.5
Windowpane*	*Scophthalmus aquosus*	M	9	1,344	92.4
Atlantic tomcod**	*Microgadus tomcod*	D	9	1,237	93.3
American shad**	*Alosa sapidissima*	D	9	986	94.0
Silver hake*	*Merluccius bilinearis*	M	9	957	95.4
Atlantic menhaden**	*Brevoortia tyrannus*	M	9	912	96.0
Smallmouth flounder	*Etropus microstomus*	M	8	885	96.6
Scup*	*Stenotomus chrysops*	M	8	617	97.1
Little skate*	*Raja erinacea*	M	9	519	97.4
Summer flounder*	*Paralichthys dentatus*	M	9	414	97.7
Grubby	*Myoxocephalus aenaeus*	M	9	311	97.9
Clearnose skate*	*Raja eglanteria*	M	7	307	98.2
Atlantic croaker**	*Micropogonias undulatus*	E	7	290	98.4
Atlantic butterfish*	*Peprilus triacanthus*	M	9	256	98.5
Northern pipefish	*Syngnathus fuscus*	M	9	248	98.7
Striped searobin	*Prionotus evolans*	M	8	233	98.9
Gizzard shad	*Dorosoma cepedianum*	F	9	194	99.0
Cunner	*Tautogolabrus adspersus*	M	9	177	>99.0
Weakfish	*Cynoscion regalis*	M	9	165	>99.0
Tautog	*Tautoga onitis*	M	9	150	>99.0
Spot	*Leiostomus xanthurus*	M	2	126	>99.0
Northern searobin	*Prionotus carolinus*	M	7	106	>99.0
Silver perch	*Diapterus rhombeus*	M	3	84	>99.0
Fourspot flounder	*Hippoglossina oblonga*	M	6	47	>99.0
Winter skate*	*Raja ocellata*	M	6	45	>99.0
Striped cuskeel	*Ophidion marginatum*	M	4	37	>99.0
American eel	*Anguilla rostrata*	D	8	34	>99.0
Black sea bass*	*Centropristis striata*	M	7	33	>99.0
Rock gunnel	*Pholis gunnellus*	M	7	30	>99.0

Table A2 (continued).

Common Name	Scientific Name	Guild	# Years	Total	Cum. %
Naked goby	*Gobiosoma bosci*	M	5	29	>99.0
Spiny dogfish	*Squalus acanthias*	M	3	29	>99.0
Bluefish	*Pomatomus saltatrix*	M	6	28	>99.0
Conger eel	*Conger oceanicus*	M	1	27	>99.0
Pollock	*Pollachius virens*	M	6	27	>99.0
Striped mullet	*Mugil cephalus*	M	6	22	>99.0
Smooth dogfish	*Mustelus canis*	M	3	16	>99.0
American lobster	*Homarus americanus*	M	3	14	>99.0
Northern puffer	*Sphoeroides maculatus*	M	3	13	>99.0
Seaboard goby	*Gobiosoma ginsburgi*	M	4	12	>99.0
Lined seahorse	*Hippocampus erectus*	M	4	11	>99.0
Hogchocker	*Trinectes maculatus*	E	5	10	>99.0
Striped killifish	*Fundulus majalis*	E	4	9	>99.0
Threespine stickleback	*Gasterosteus aculeatus*	E	3	9	>99.0
Atlantic cod	*Gadus morhua*	M	2	8	>99.0
Oyster toadfish	*Opsanus tau*	M	5	7	>99.0
Shortnose sturgeon	*Acipenser brevirostrum*	D	4	6	>99.0
Longhorn sculpin	*Myoxocephalus octodecemspinosus*	M	2	5	>99.0
Four beard rockling	*Enchelyopus cimbrius*	M	2	4	>99.0
Sheepshead	*Archosargus probatocephalus*	M	2	4	>99.0
White mullet	*Mugil curema*	M	2	3	>99.0
Atlantic sturgeon	*Acipenser oxyrinchus oxyrinchus*	D	2	2	>99.0
Feather blenny	*Hypsoblennius hentzi*	E	2	2	>99.0
Mummichog	*Fundulus heteroclitus*	E	2	2	>99.0
Rainbow smelt	*Osmerus mordax mordax*	D	2	2	>99.0
Atlantic moonfish	*Selene setapinnis*	M	1	1	>99.0
Black drum	*Pogonias cromis*	M	1	1	>99.0
Crevalle jack	*Caranx hippos*	M	1	1	>99.0
Fourspine stickleback	*Apeltes quadracus*	M	1	1	>99.0
Hickory shad	*Alosa mediocris*	E	1	1	>99.0
Northern kingfish	*Menticirrhus saxatilis*	M	1	1	>99.0
Northern stargazer	*Astroscopus guttatus*	M	1	1	>99.0
Striped anchovy	*Anchoa hepsetus*	M	1	1	>99.0
Striped burrfish	*Chilomycterus schoepfii*	M	1	1	>99.0
Yellowtail flounder	*Pleuronectes ferrugineus*	M	1	1	>99.0

* Federally managed (EFH) species
** State managed species of concern

Table A3. Percentage of numerically dominant fish that were juveniles in the winters and summers of 2002- 2010 listed by Harbor area and season. Estimated size at maturity (mmTL) is given in parentheses for each species.

Winter				Spring			
Species	**AKNB**	**LB**	**UB**	**Species**	**AKNB**	**LB**	**UB**
White perch (100 mm)	16	0	12	Bay anchovy	37	29	27
Alewife** (170 mm)	85	87	89	Spotted hake	>99	>99	>99
Striped bass** (600 mm)	99	90	99	Atlantic herring** (220 mm)	99	97	99
Blueback herring** (250 mm)	99	97	98	Alewife**	71	38	64
American sandlance (85 mm)	-	94	80	Winter flounder**	97	70	77
Spotted hake (225 mm)	>99	>99	>99	Striped bass**	99	91	99
Winter flounder* (250 mm)	98	88	92	Atlantic tomcod** (170 mm)	86	-	97
Atlantic silverside (90 mm)	47	51	50	Blueback herring**	100	96	99
Red hake** (200 mm)	94	97	89	Red hake**	89	87	80
Silver hake* (220 mm)	100	100	100	White perch	34	-	1
American shad** (380 mm)	100	100	100	Windowpane**	67	44	45
Windowpane** (200 mm)	96	76	63	Scup** (150 mm)	-	88	94
Atlantic menhaden** (230 mm)	82	>99	90				
Bay anchovy (70mm)	94	82	86				

*Federally managed (EFH) species
**State managed species (listed on http://www.asmfc.org/fisheries-management/program-overview)

Table A4. Overall mean CPUE for species that collectively comprised 95% of all fish collected in a subarea in the winter and spring (2002- 2010).

Winter				Spring			
Species	**AKNB**	**LB**	**UB**	**Species**	**AKNB**	**LB**	**UB**
White perch	80.15	0.01	0.80	Bay anchovy	28.93	43.63	79.66
Alewife**	1.51	16.17	3.73	Spotted hake	23.46	6.78	17.50
Striped bass**	19.48	0.11	5.07	Atlantic herring*	23.07	2.67	14.09
Blueback herring**	1.45	7.17	4.23	Alewife**	3.84	2.55	1.68
American sandlance	0.01	10.97	0.08	Winter flounder*	2.52	1.97	3.10
Spotted hake	1.48	5.24	3.57	Striped bass**	4.26	0.13	2.84
Winter flounder*	4.12	1.55	2.98	Atlantic tomcod**	1.07	0.02	5.50
Atlantic silverside	0.71	6.52	0.64	Blueback herring**	2.26	0.88	2.65
Red hake*	2.11	1.23	2.91	Red hake*	2.12	0.47	2.75
Silver hake*	0.11	1.56	0.24	White perch	2.31	0.00	0.28
American shad**	0.25	0.47	1.15	Windowpane*	0.56	0.56	1.37
Windowpane*	0.26	0.50	1.00	Scup*	0.01	1.22	1.20
Atlantic menhaden**	0.05	1.47	0.17	Atlantic butterfish*		0.85	
Bay anchovy	0.42	0.79	0.51	Striped searobin		0.65	
Smallmouth flounder	0.05	1.17	0.34	American sandlance		0.06	1.51
Grubby			0.21				
Atlantic croaker			0.60				
Atlantic herring*		0.76	0.44				
Spot			0.51				

*Federally managed (EFH) species
**State managed species (listed on http://www.asmfc.org/fisheries-management/program-overview)

Table A5. Analysis of Similarities (ANOSIM) results indicating how fish assemblages differed among Harbor areas and/or station type (channel vs. non-channel) in the winter and spring of each year. Winter temperatures (cumulative degree days January 1 – March 31), Hudson River discharge (mean March/April cfs), and time of sampling are given.

	Winter (R)	Spring (R)	Factor	Temperature Cum dd Winter	Mean March/ April Flow (cfs)	Time of Sampling
2002	0.64	0.20	Area x Type	532	21,820	Night
2003	0.48	0.06	Area	227	29,695	Night
2004	0.44	0.12	Area	270	23,445	Night
2005	0.20	0.08	-	280	26,375	Day
2006	0.11	0.04	-	298	18,635	Day
2007	0.59	0.31	Area x Type	408	37,035	Day
2008	0.53	0.39	Area x Type	461	38,435	Day
2009	0.44	0.14	Area x Type	489	25,890	Day
2010	0.68	0.58	Area x Type	522	27,625	Day

Table A6. Average winter CPUE of species contributing at least 5% to between group (Harbor area and channel vs. non-channel) dissimilarities.

	Winter - 2002					
	AKNBCH	AKNBNC	UBCH	UBNC	LBCH	LBNC
White perch	37.6	12.2	0.0	0.0	0	0
Striped bass**	24.1	15.8	0.7	4.4	0.1	0
Blueback herring**	6.6	2.1	17.7	5.1	3.7	0.1
Winter flounder*	3.8	0.9	5.5	1.8	5.8	0.3
Spotted hake	4.5	3.2	14.4	1.7	34.5	1.3
Alewife**	1.5	1.4	4.4	7.5	3.8	0.2
Windowpane*	1.5	0.3	4.4	0.8	1.9	1.0
Smallmouth flounder	0.2	0.1	0.6	1.4	16.5	5.7
Red hake*	0.1	0.0	1.0	0.3	3.1	0.1
Clearnose skate*	0.0	0.1	1.9	0.6	5.9	1.1
American shad	0.3	1.0	0.7	2.2	0.1	0.0
	Winter - 2007					
White perch	98.9	0.1	0.3	0.0	0.0	0.0
Striped bass**	10.4	0.1	2.9	0.4	0.9	0.0
Winter flounder*	2.6	0.1	5.0	1.4	2.4	0.3
Alewife**	0.5	0.0	1.9	0.1	15.9	0.0
Blueback herring**	0.1	0.6	1.1	0.1	3.8	0.4
Atlantic silverside	0.1	2.8	0.3	5.4	2.4	2.6
	Winter - 2008					
White perch	378.1	0.0	9.0	0.1	0.0	0.0
Striped bass**	72.8	0.0	26.8	12.5	0.0	<0.1
Winter flounder*	40.3	0.0	5.4	0.9	1.5	0.4
Alewife**	2.0	0.2	3.8	0.6	97.4	0.8
American sandlance	0.0	0.0	0.1	0.3	10.5	12.1
Atlantic silverside	0.0	3.0	0.1	1.0	0.5	16.8
Spotted hake	0.0	0.0	18.1	0.2	36.1	0.7
	Winter - 2009					
White perch	158.8	0.6	8.3	1.3	0.0	0.0
Striped bass**	12.3	0.1	13.7	4.2	<0.1	0.1
Winter flounder*	8.4	0.5	6.8	1.0	1.1	0.1
Alewife**	11.5	0.4	36.7	0.8	88.1	5.4
American sandlance	0.0	0.0	0.1	0.1	0.0	4.2
Atlantic silverside	<0.1	0.7	0.5	0.6	3.6	2.9
Blueback herring**	0.7	3.6	3.1	3.2	55.8	12.4

Table A6 (continued).						
	Winter - 2010					
	AKNBCH	AKNBNC	UBCH	UBNC	LBCH	LBNC
White perch	414.4	1.1	0.2	0.5	<0.1	0.0
Striped bass**	80.7	0.1	1.3	2.1	0.1	<0.1
Winter flounder*	12.2	0.6	3.8	2.9	2.2	0.8
Spotted hake	5.4	0.1	3.8	0.1	2.5	1.2
Atlantic herring*	0.0	0.0	1.7	0.1	2.0	0.8
Atlantic silverside	0.3	3.6	0.7	1.1	19.2	17.6
Red hake	24.1	0.0	24.1	0.3	8.3	1.4
Blueback herring**	<0.1	0.0	0.7	0.3	1.2	0.7
Atlantic menhaden**	0.0	0.0	0.1	0.1	6.1	1.0
American sandlance	0.0	<0.1	<0/1	0.9	<0.1	50.4

* Federally managed (EFH) species
** State managed species of concern

Table A7. Average CPUE of species contributing at least 5% to between Harbor area dissimilarities. Harbor areas were significantly distinct in 2003 and 2004 (Table A3). Fish abundances in 2005 and 2006 are provided for comparative purposes.

	Winter - 2003					
Species	AKNBCH	AKNBNC	UBCH	UBNC	LBCH	LBNC
White perch	36.8	47.0	0.2	0.1	0.1	0.0
Striped bass**	10.0	16.1	3.1	10.8	0.3	0.0
Little skate*	0.0	0.0	1.5	0.2	4.7	1.0
Winter flounder*	2.7	1.9	2.9	1.7	0.7	0.2
Spotted hake	0.1	0.1	3.6	0.9	34.5	0.7
Windowpane*	0.3	0.0	3.0	0.8	1.3	0.8
	Winter - 2004					
Species	AKNBCH	AKNBNC	UBCH	UBNC	LBCH	LBNC
White perch	73.4	10.5	0.2	0.2	0.0	0.0
Striped bass**	68.3	5.3	6.9	6.8	0.0	0.0
Winter flounder*	8.3	1.7	9.7	3.0	3.2	2.3
Blueback herring**	6.5	0.9	11.6	0.3	2.3	0.4
	Winter - 2005					
Species	AKNBCH	AKNBNC	UBCH	UBNC	LBCH	LBNC
White perch	10.2	0.3	0.0	0.0	0.0	0.0
Winter flounder*	0.9	0.4	2.4	0.4	16.5	0.0
Atlantic silverside	0.2	1.5	<0.1	0.4	1.1	0.7
Striped bass**	1.5	0.3	<0.1	0.2	0.0	0.0
Atlantic herring*	0.4	0.3	0.9	2.0	0.5	0.6
	Winter - 2006					
Species	AKNBCH	AKNBNC	UBCH	UBNC	LBCH	LBNC
White perch	79.9	0.0	0.4	0.2	0.0	0.0
Striped bass**	27.0	0.0	6.5	4.3	0.7	0.0
Alewife**	3.5	0.1	10.2	0.0	119.8	1.3
Blueback herring**	0.4	1.9	2.1	18.2	31.8	0.3
Spotted hake	2.5	0.0	18.5	0.1	6.0	0.0
Atlantic silverside	<0.1	0.1	0.1	0.1	0.1	0.4

* Federally managed (EFH) species
** State managed species of concern

Table A8. Average spring CPUE of species contributing at least 5% to between group (Harbor area and channel vs. non-channel) dissimilarities.

	Spring - 2010					
Species	AKNBCH	AKNBNC	UBCH	UBNC	LBCH	LBNC
Spotted hake	113.8	0.0	117.2	0.8	19.9	4.2
Red hake*	29.9	0.0	58.0	0.4	3.8	0.5
Winter flounder*	5.8	0.4	6.4	3.6	5.2	3.0
White perch	6.0	0.6	0.2	1.2	0.0	0.0
Atlantic menhaden**	0.0	2.5	0.8	0.0	0.1	0.0
Alewife**	0.5	0.0	3.3	0.4	3.6	4.8
Bay anchovy	0.0	0.2	0.0	46.7	0.3	2.5
Atlantic butterfish*	0.0	0.0	0.0	0.0	0.0	3.1
Little skate*	0.0	0.0	1.1	0.9	0.0	0.6
Windowpane*	0.4	0.2	2.0	0.2	0.0	0.6
Blueback herring**	0.0	2.2	0.1	0.3	0.0	0.2

* Federally managed (EFH) species
** State managed species of concern

Figures (Part A)

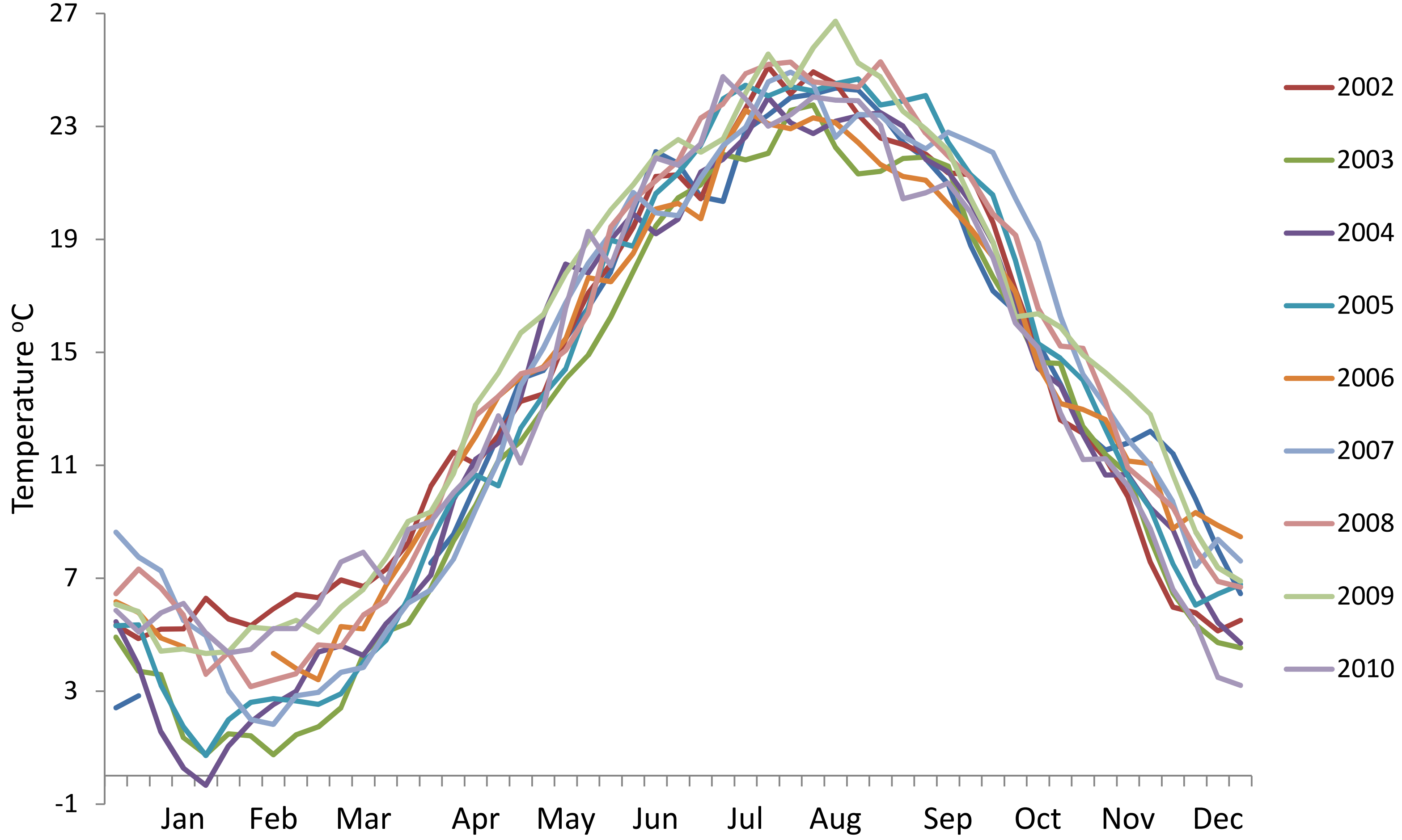


Figure A1. Water temperatures (2002-2010) recorded at NOAA gauge (station ID 8518750) located at the southern tip of Manhattan Island (the Battery).

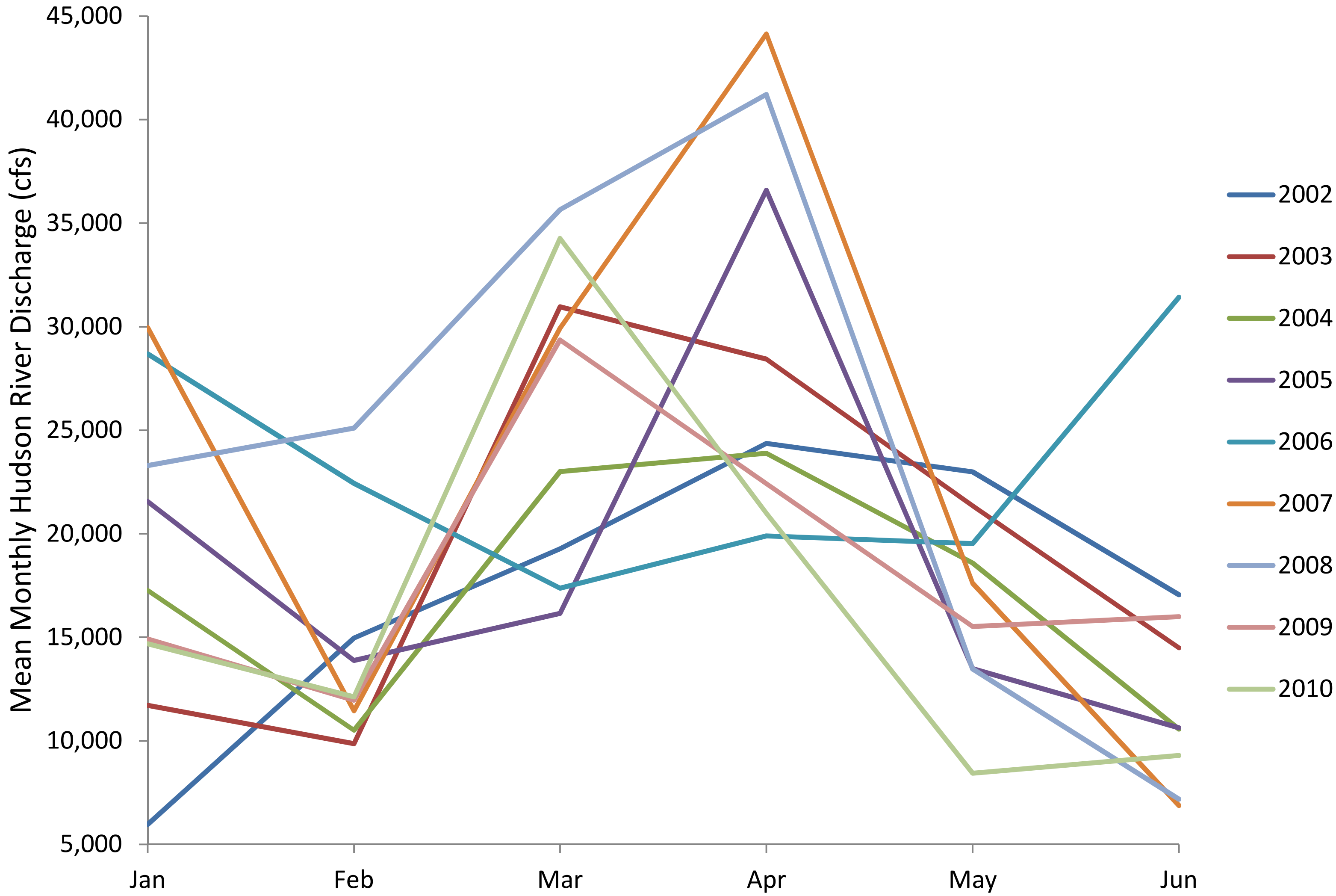


Figure A2. Hudson River discharge data recorded at USGS station 01358000 at Green Island, which is just upstream from the Troy Lock and Dam.

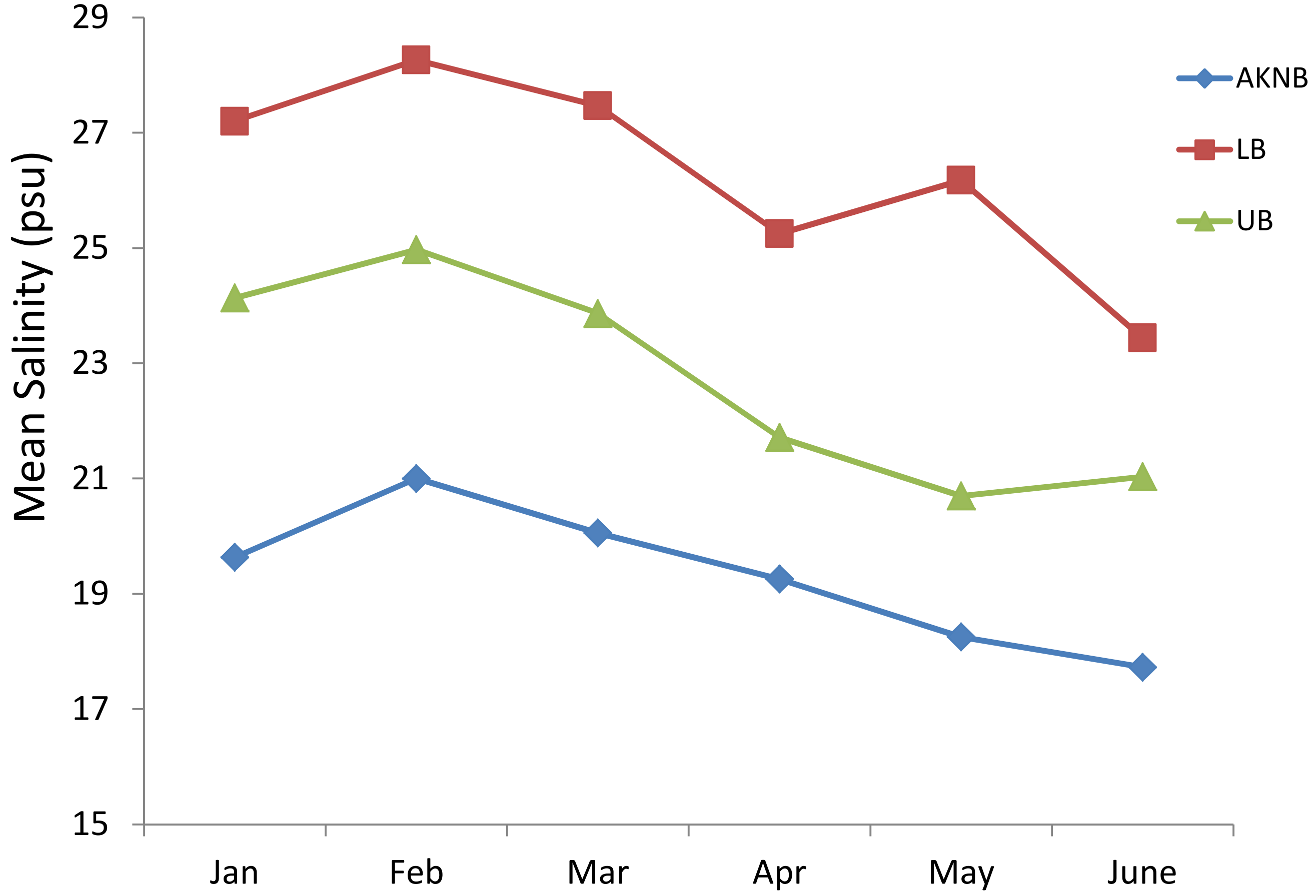


Figure A3. Mean monthly salinity in each Harbor area; Arthur Kill/Newark Bay (AKNB), Lower Bay (LB), and Upper Bay (UB).

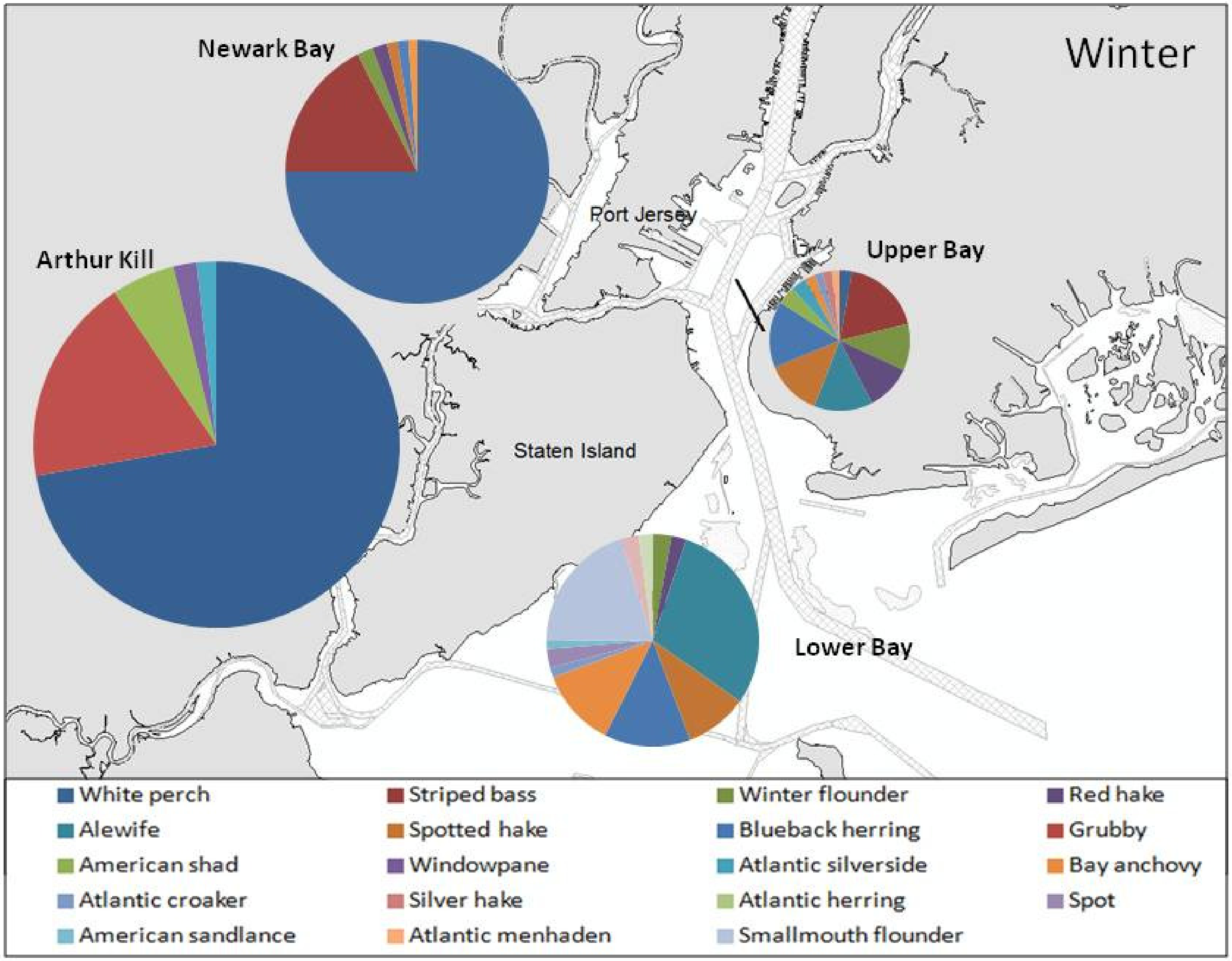


Figure A4. Summary of winter (December through March) demersal finfish communities in NY/NJ Harbor based on ABS bottom trawl data 2002 to 2010. Note: The relative size of each pie chart reflects average CPUEs of finfish at stations in each Harbor area.

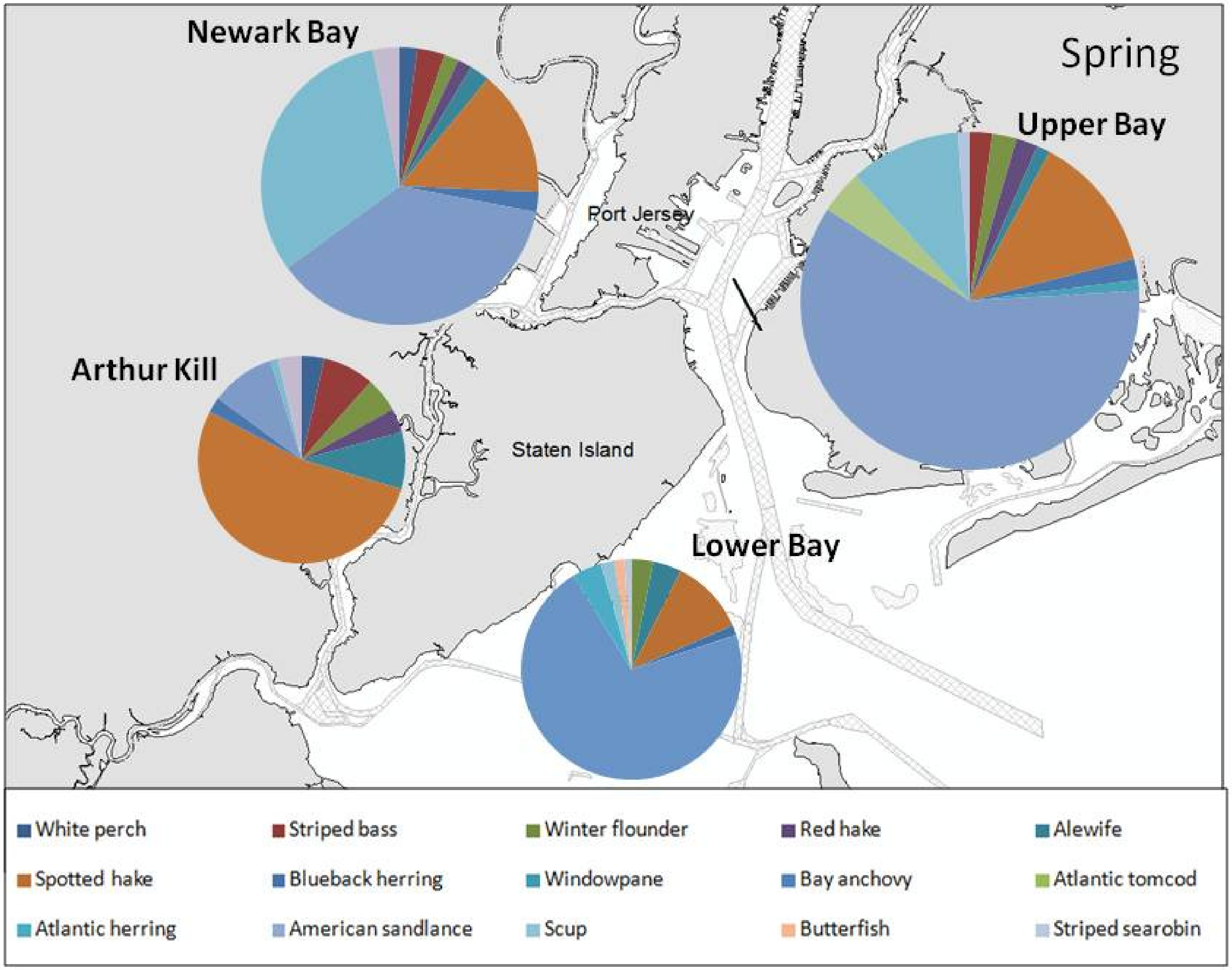


Figure A5. Summary of spring (April through June) demersal finfish communities in NY/NJ Harbor based on ABS bottom trawl data 2002 to 2010. Note: The relative size of each pie chart reflects average CPUEs of finfish at stations in each Harbor area.

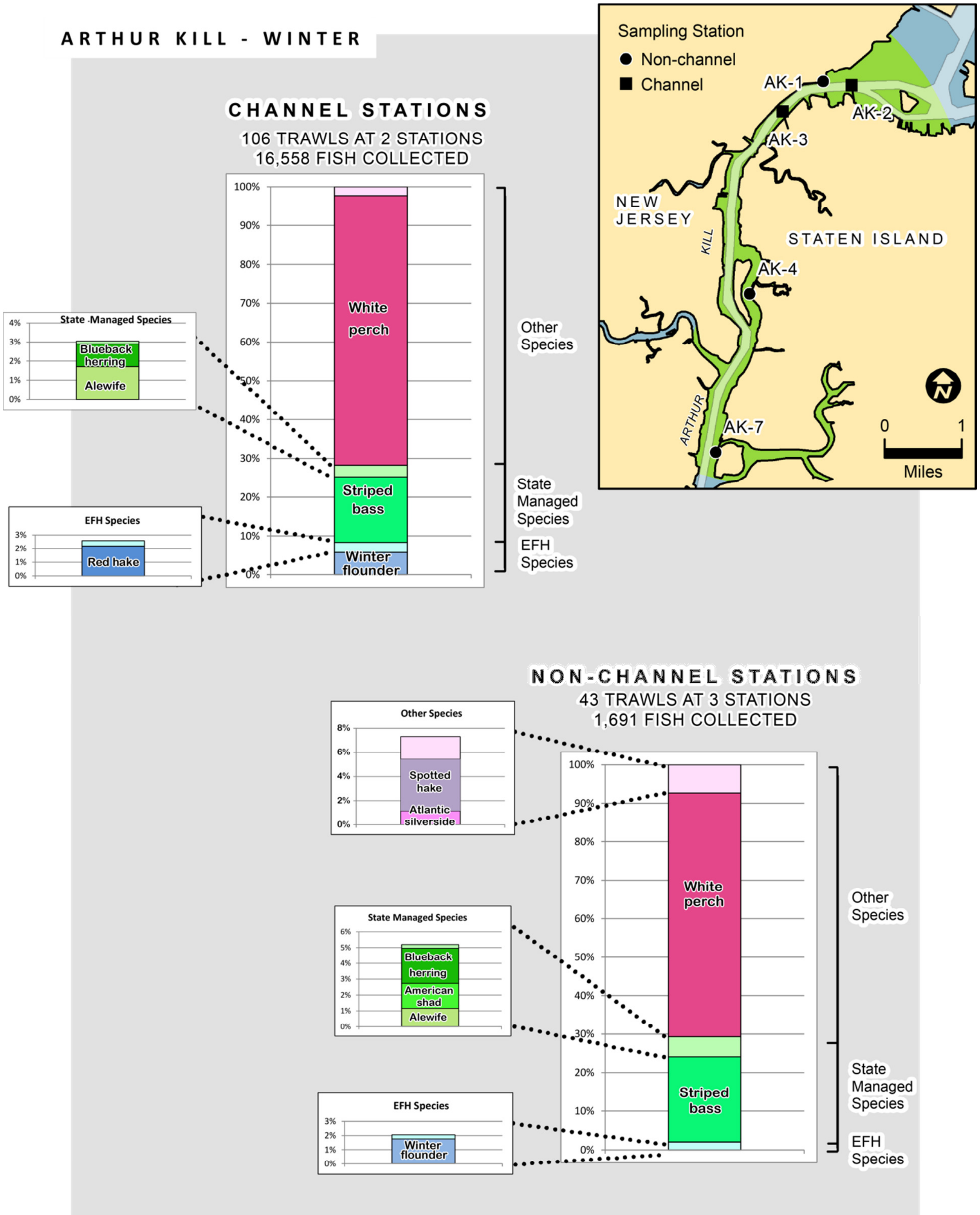


Figure A6. Demersal finfish collections at Arthur Kill channel and non-channel stations in winter (December through March) – ABS bottom trawls 2002 to 2010.

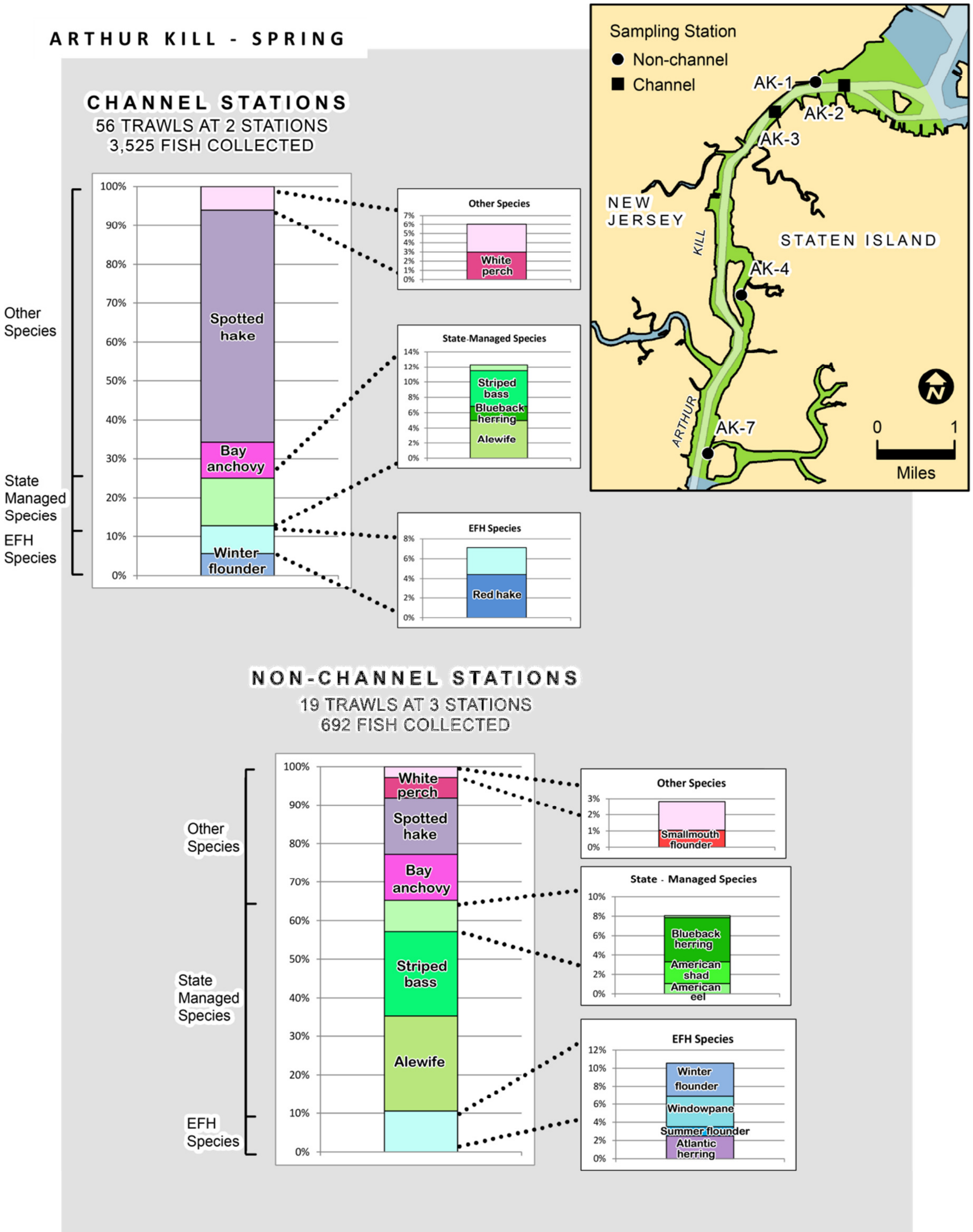


Figure A7. Demersal finfish collections at Arthur Kill channel and non-channel stations in spring (April through June) – ABS bottom trawls 2002 to 2010.

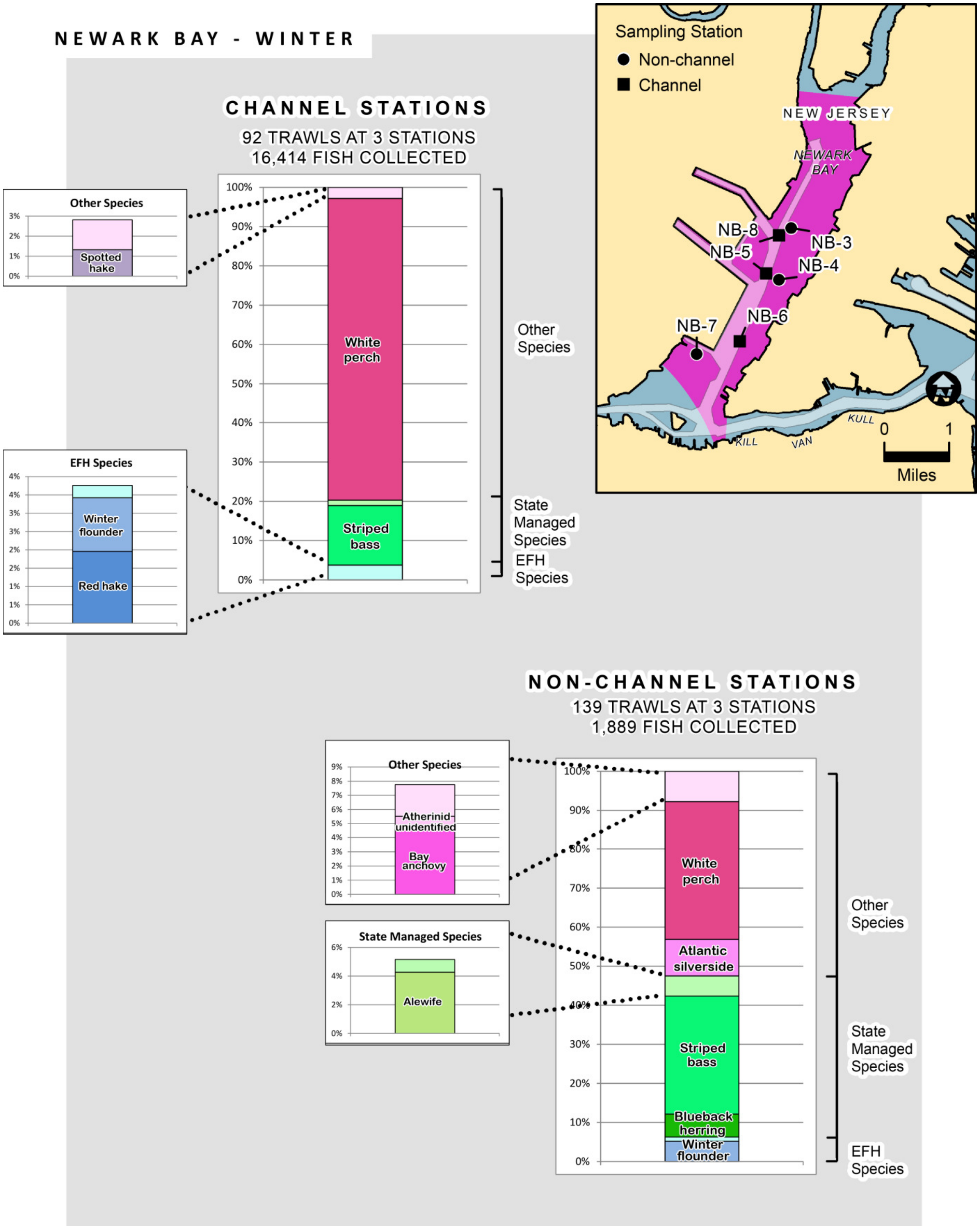


Figure A8. Demersal finfish collections at Newark Bay channel and non-channel stations in winter (December through March) – ABS bottom trawls 2002 to 2010.

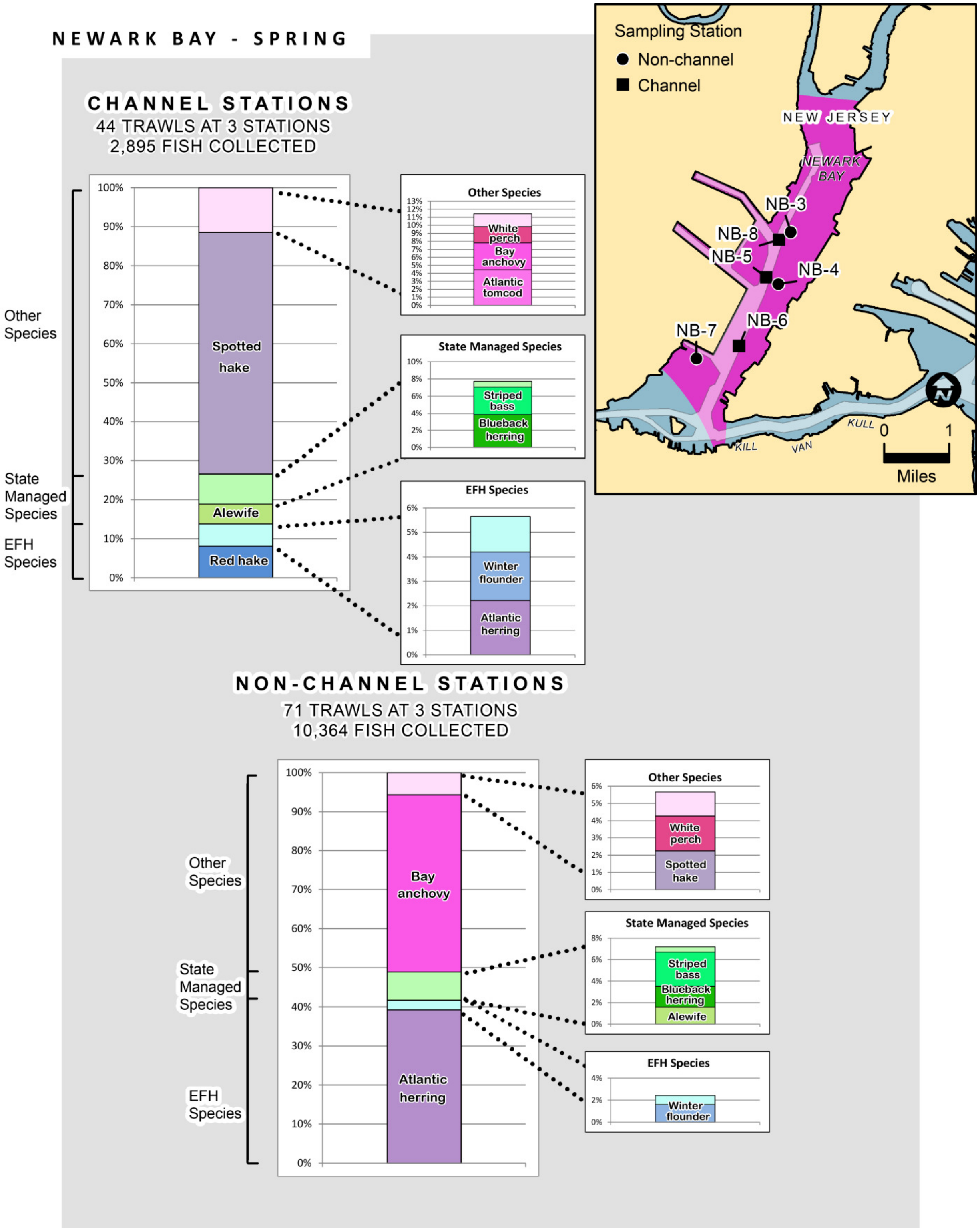


Figure A9. Demersal finfish collections at Newark Bay channel and non-channel stations in spring (April through June) – ABS bottom trawls 2002 to 2010.

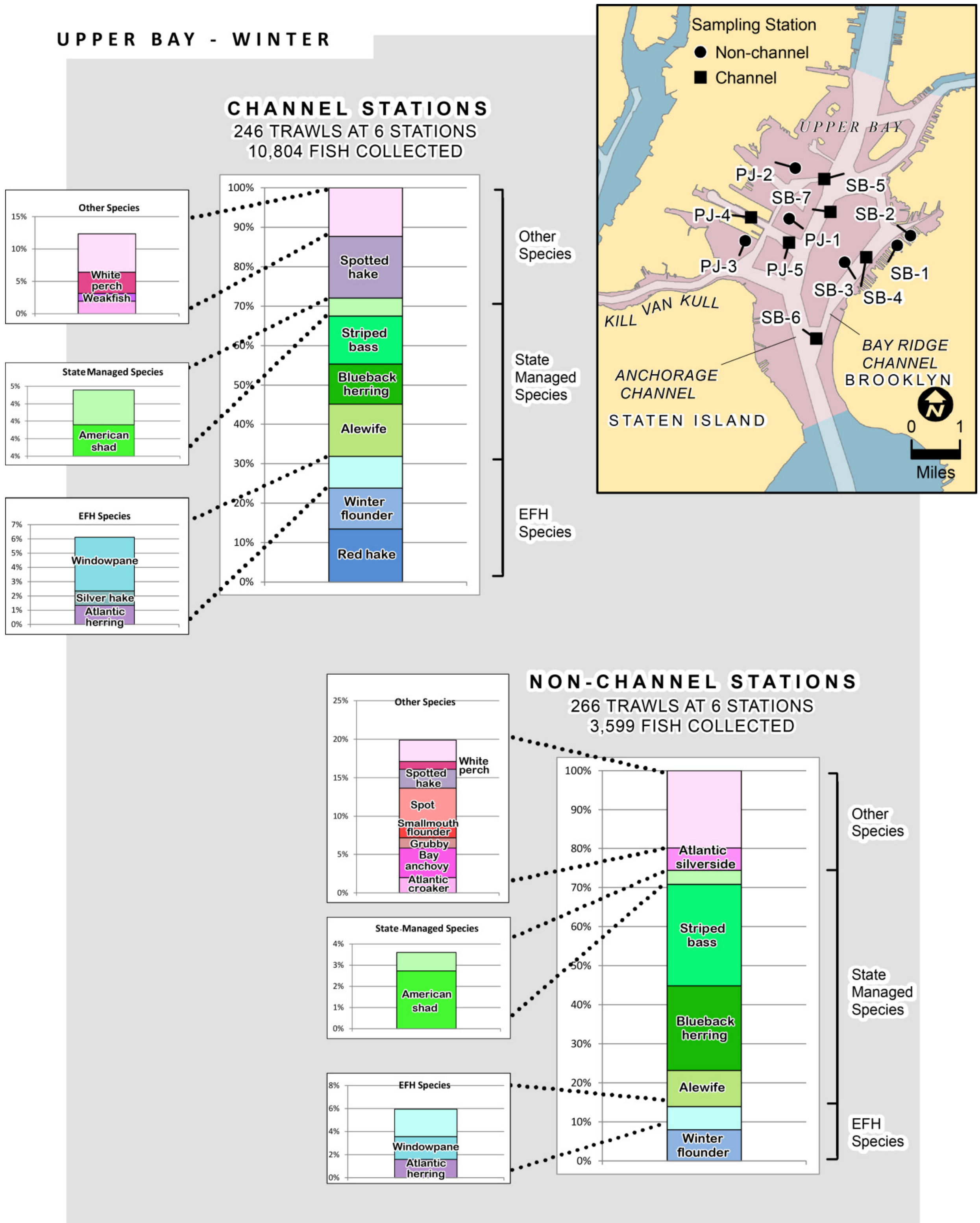


Figure A10. Demersal finfish collections at Upper Bay channel and non-channel stations in winter (December through March) – ABS bottom trawls 2002 to 2010.

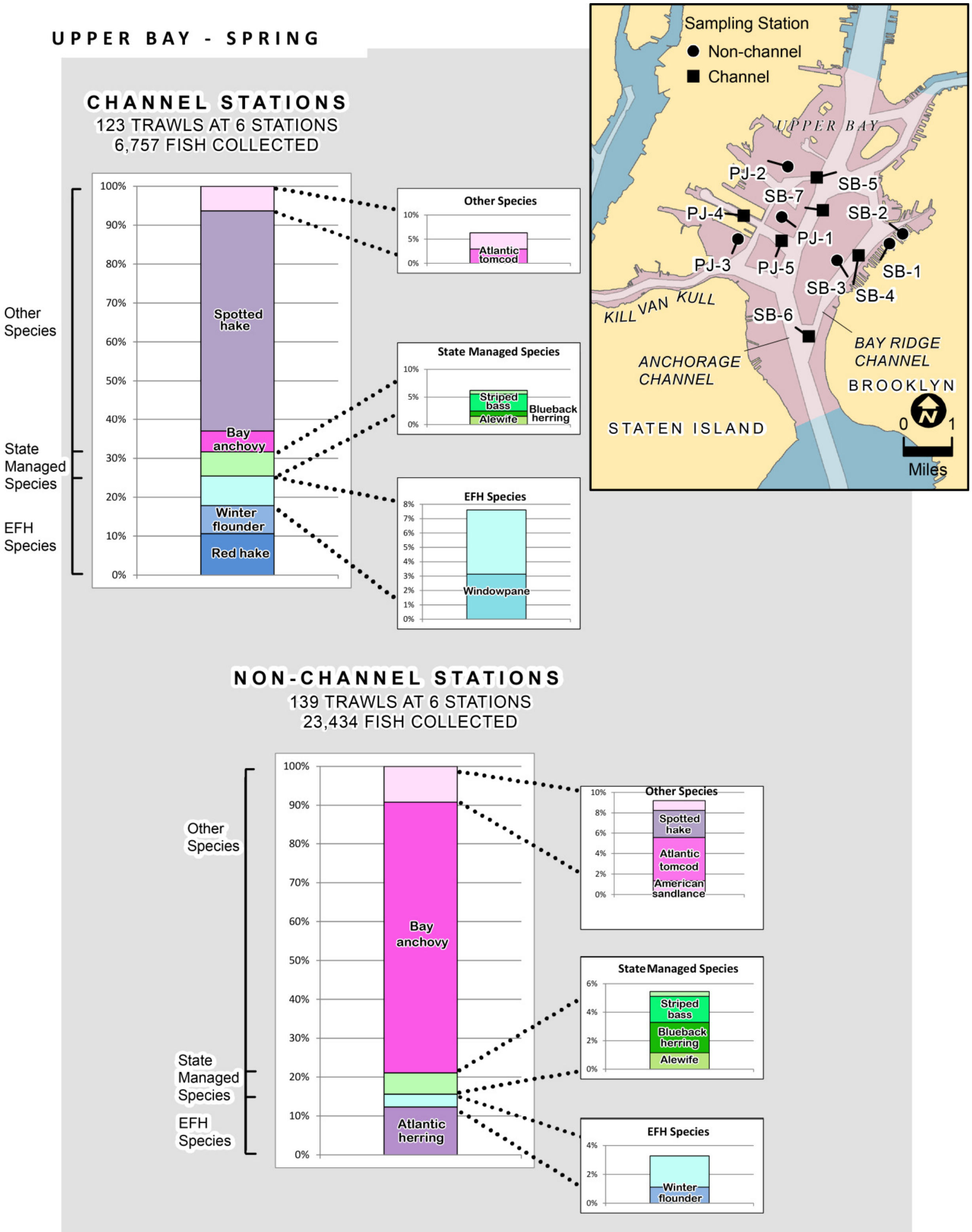


Figure A11. Demersal finfish collections at Upper Bay channel and non-channel stations in spring (April through June) – ABS bottom trawls 2002 to 2010.

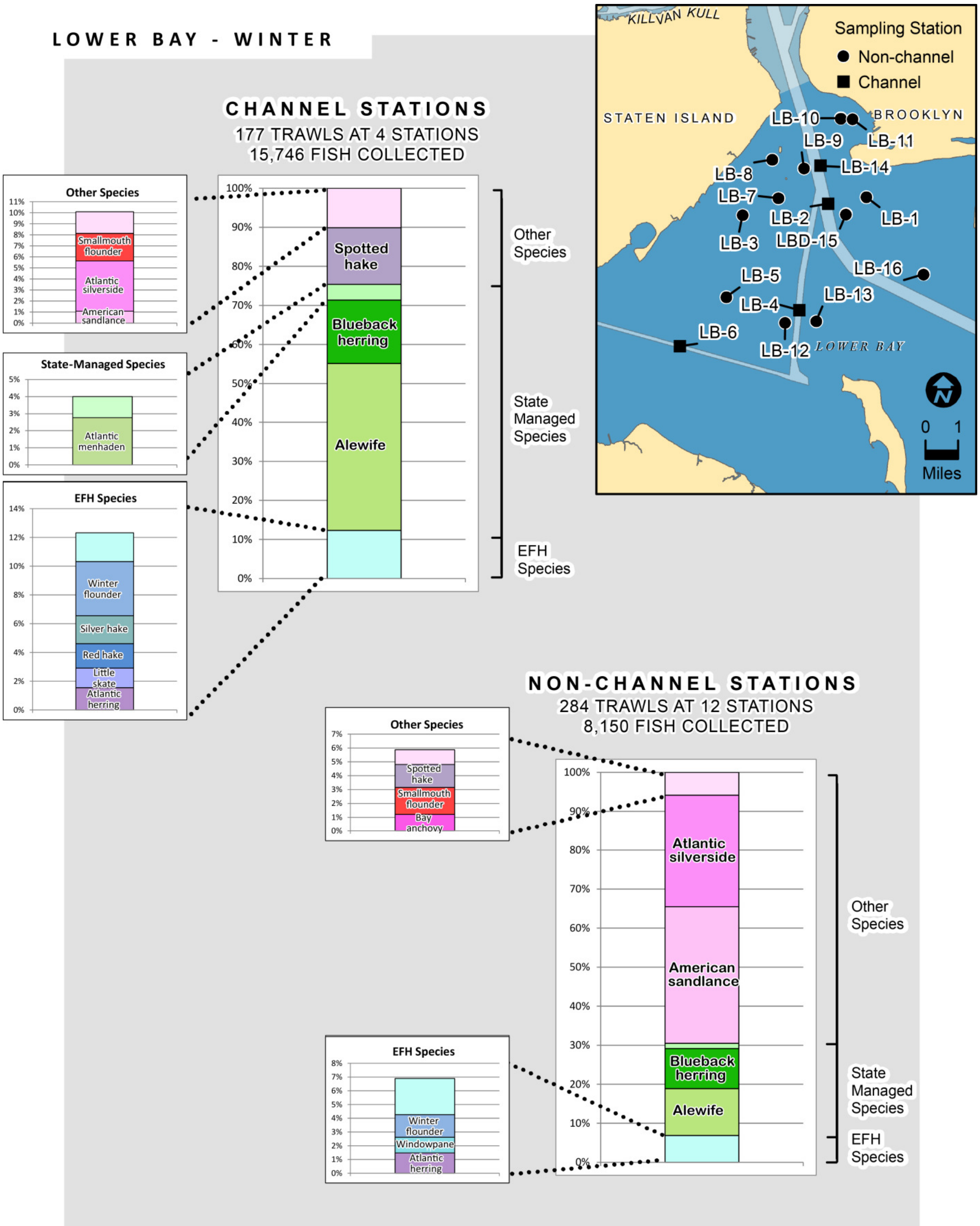


Figure A12. Demersal finfish collections at Lower Bay channel and non-channel stations in winter (December through March) – ABS bottom trawls 2002 to 2010.

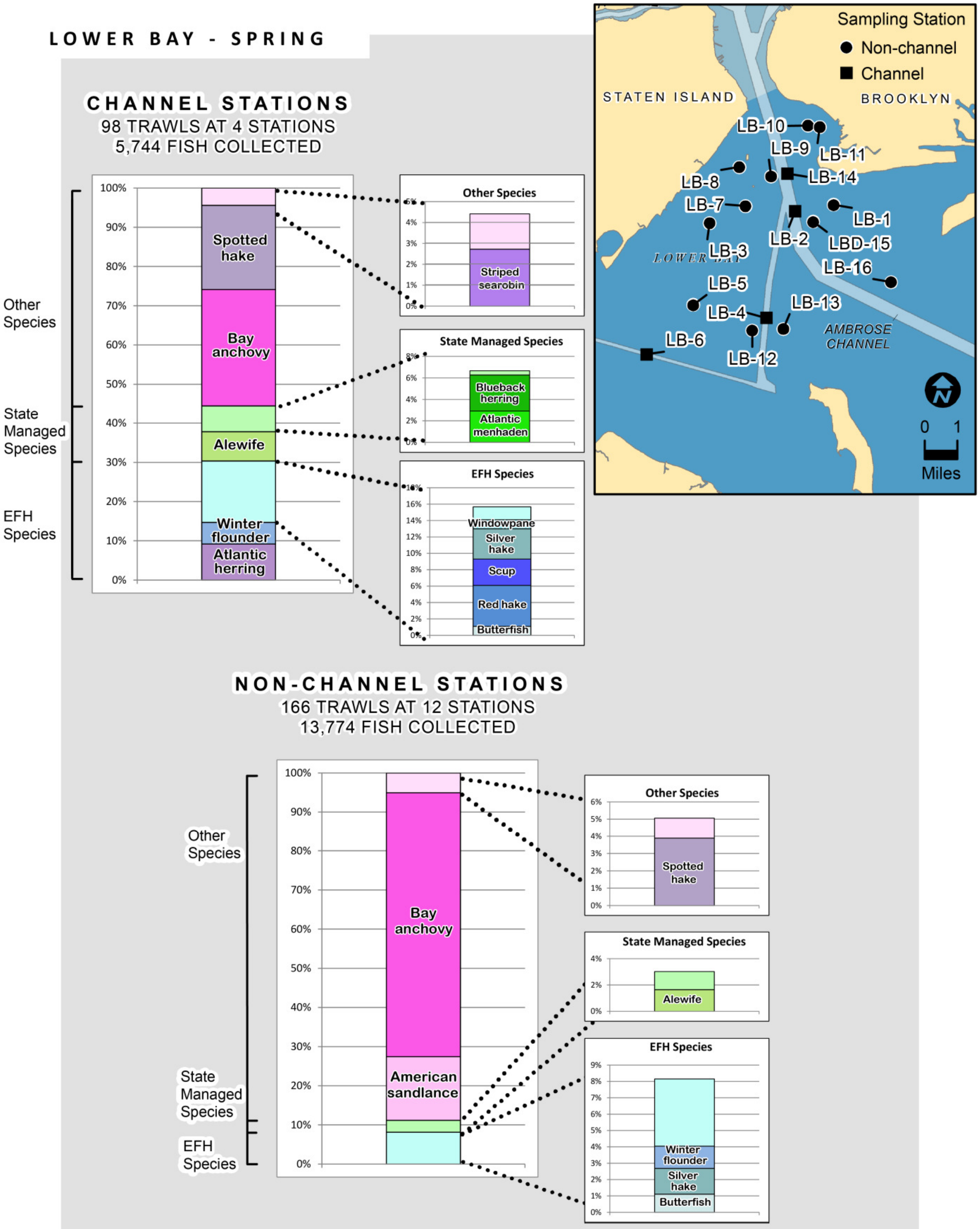


Figure A13. Demersal finfish collections at Lower Bay channel and non-channel stations in spring (April through June) – ABS bottom trawls 2002 to 2010.

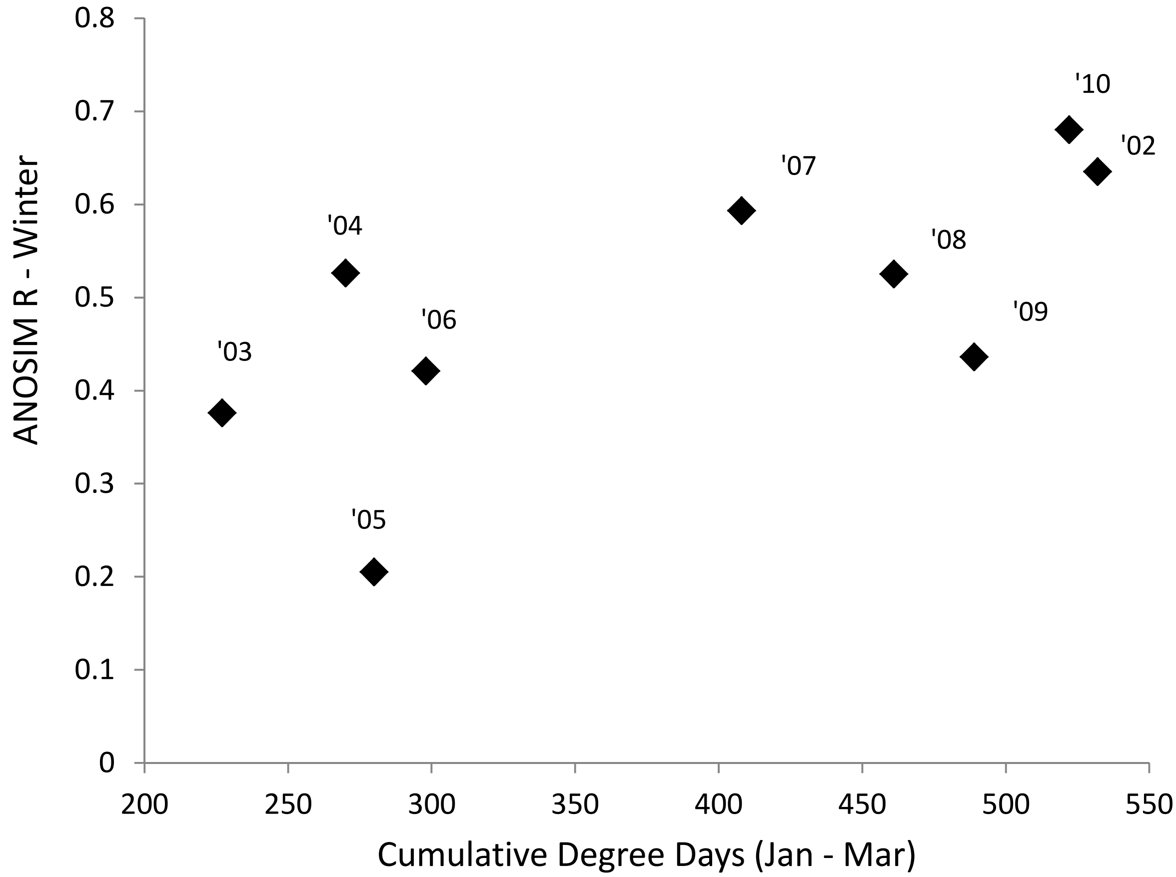


Figure A14. Positive correlation between winter temperature (cumulative degree days from January through March) and the distributions of winter fish assemblages within the Harbor (ANOSIM R).

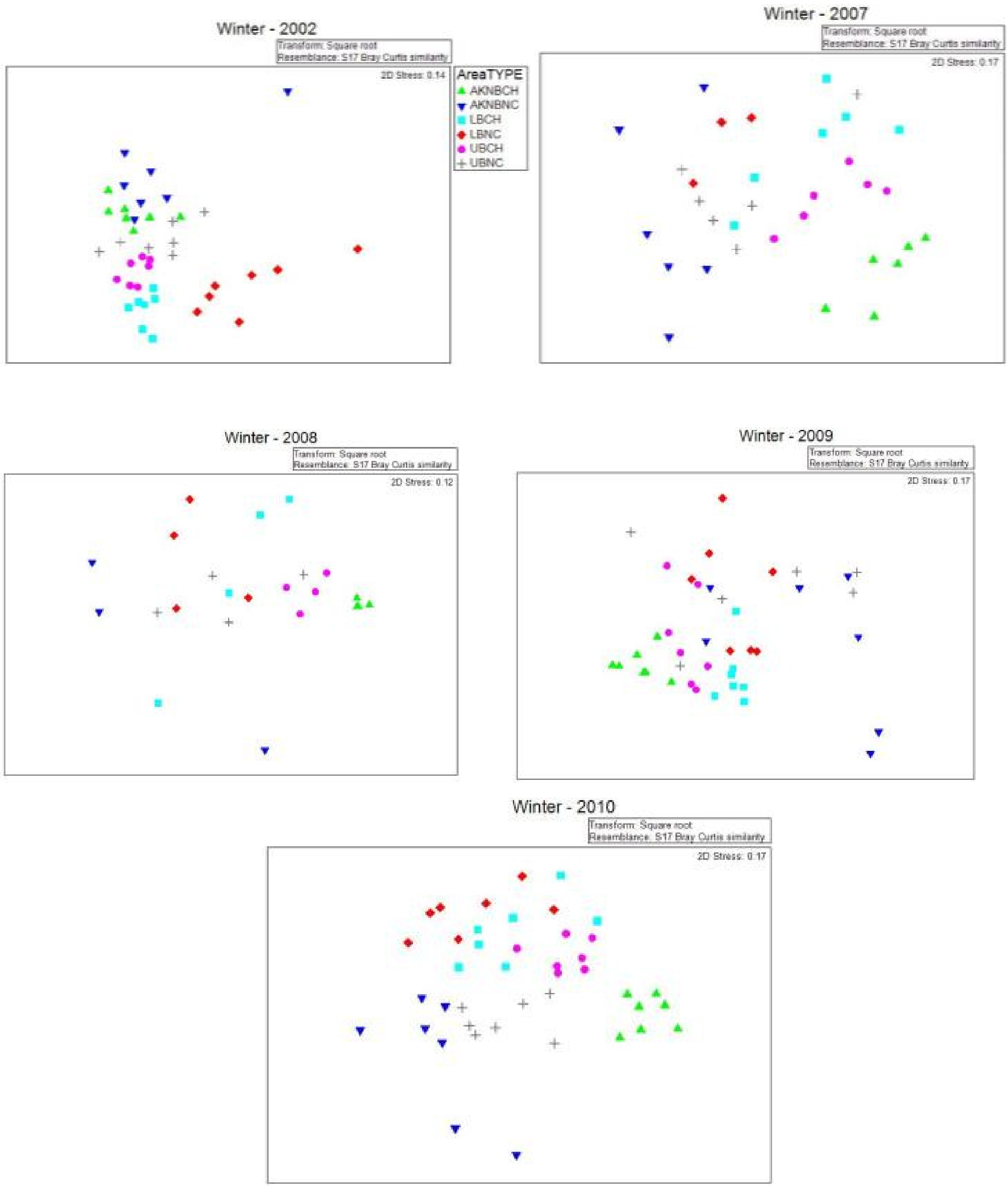
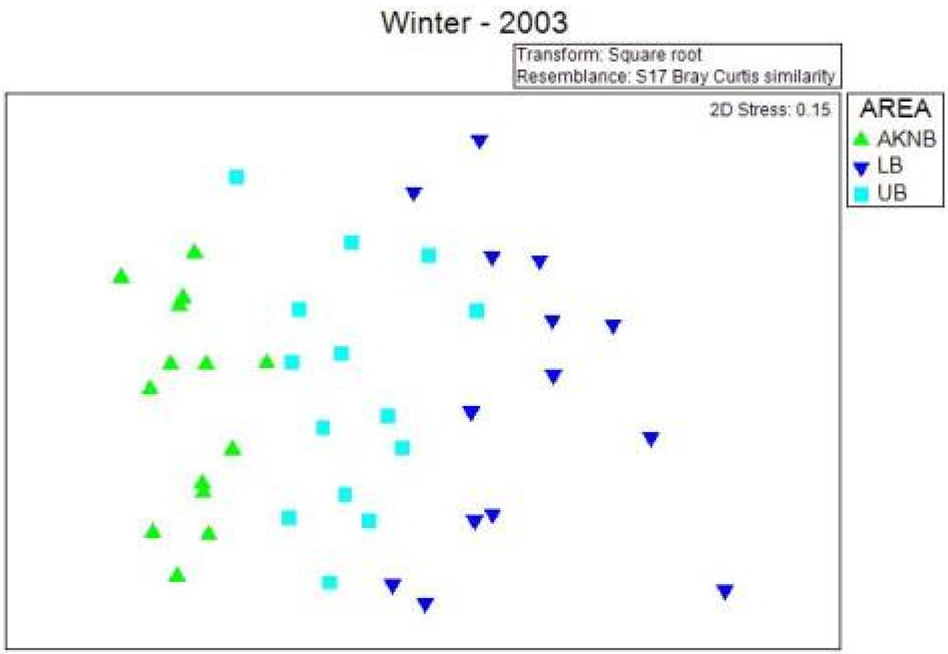


Figure A15. Non-metric multidimensional scaling (nMDS) plots that depict the relative similarities in species composition of winter fish assemblages in Arthur Kill/Newark Bay (AKNB), Lower Bay (LB), and Upper Bay (UB) at channel (CH) and non-channel (NC) stations.



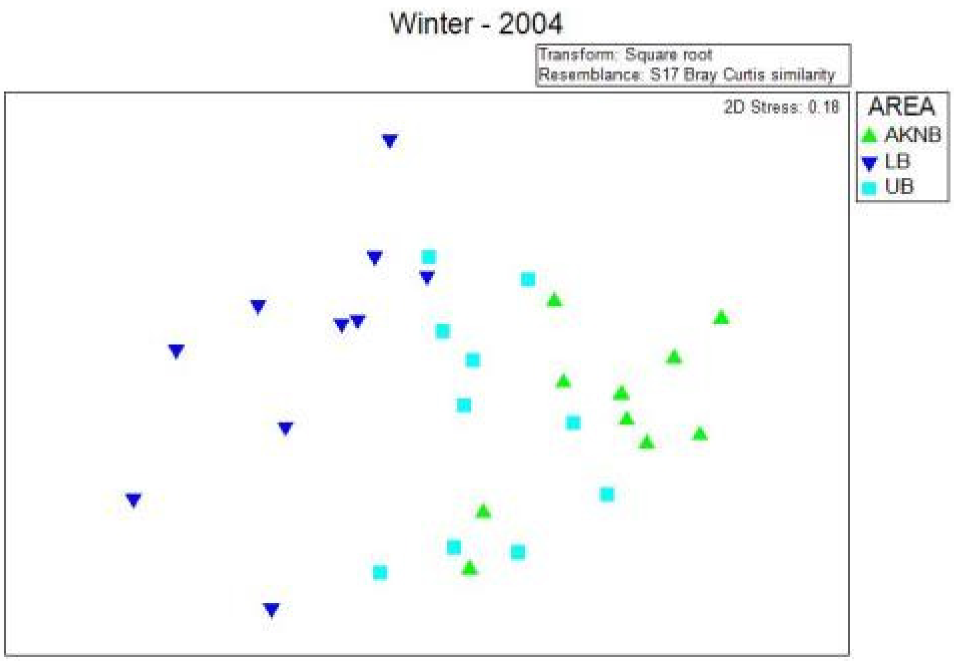


Figure A16. Non-metric multidimensional scaling (nMDS) plots that depict the relative similarities in winter 2003 and 2004 species composition of fish assemblages in Arthur Kill/Newark Bay (AKNB), Lower Bay (LB), and Upper Bay (UB).

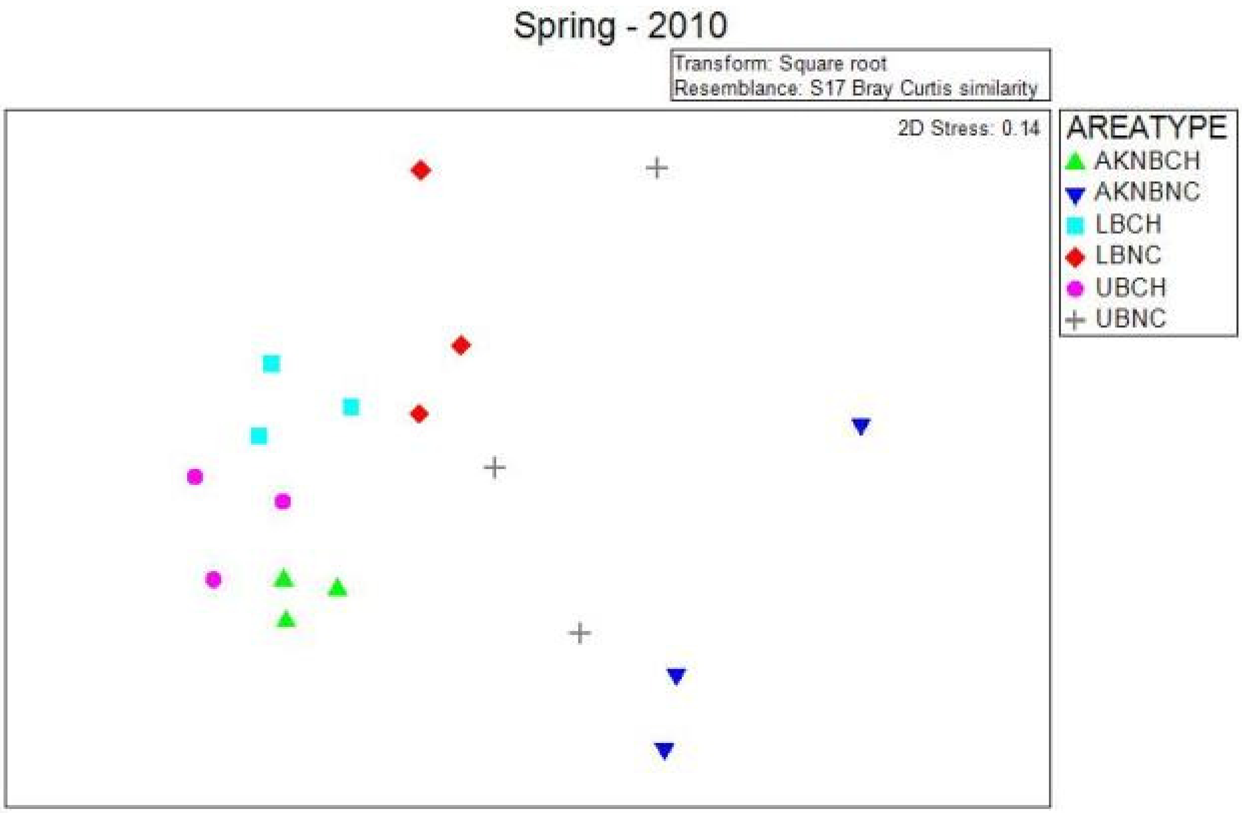


Figure A17. Non-metric multidimensional scaling (nMDS) plots that depict the relative similarities in spring 2010 species composition of fish assemblages in Arthur Kill/Newark Bay (AKNB), Lower Bay (LB), and Upper Bay (UB) at channel (CH) and non-channel (NC) stations.

NEW YORK AND NEW JERSEY HARBOR DEEPENING PROJECT

DEMERSAL FISH ASSEMBLAGES

OF NEW YORK / NEW JERSEY HARBOR

AND NEAR-SHORE FISH COMMUNITIES OF NEW YORK BIGHT

Part B: Ichthyoplankton Distribution

October 2015

U.S. Army Corps of Engineers

New York District

26 Federal Plaza

New York, New York 10278

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Introduction

Part B of this report describes the demersal egg and larval distributions of common finfish other than winter flounder within the New York/New Jersey Harbor (Harbor) using the Aquatic Biological Survey (ABS) ichthyoplankton (fish eggs and larvae) data set. Because potential dredging project related impacts may occur near the bottom, such as elevated suspended sediment concentrations and disturbed habitat, the documentation of finfish species with early life history stages that are demersal, or occurring near bottom, could be useful in future project planning. Ichthyoplankton data collected from 2002 - 2011 helps to identify and document potential spawning periods and areas of common species within the Harbor estuary, which may be important in the planning and management of coastal projects.

Methods

ICHTHYOPLANKTON FIELD COLLECTION

Generally, ichthyoplankton samples were collected from January to June, twice a month from January to May and once a month in June. The survey period was selected because it covered the seasonal distribution of winter flounder eggs and larvae in the Harbor. Ichthyoplankton surveys were conducted at 24 to 29 stations in the four designated regions of the Harbor (Upper Bay, Lower Bay, Arthur Kill and Newark Bay). All samples were collected during daylight hours between one hour after sunrise and one hour before sunset. All pertinent tow information, water quality data at the sample depth, weather, and other observations were recorded on field data sheets.

An aluminum epibenthic sled equipped with a 0.5-m^2 plankton net constructed of 0.5-mm (500 micron) nylon mesh was used to sample ichthyoplankton. The plankton net was fitted with a General Oceanics (GO) Model 2030R flow meter to measure water volume through the net. Ten minute tows were conducted against the prevailing current at a speed of approximately 3.0 to 3.6 ft/sec (90 to 110 cm/sec) through the water. Boat speed was measured using a GO Model 2031 electronic flow meter coupled to a GO Model 2135 deck readout. A minimum ratio of 3:1 tow cable length to maximum station water depth was maintained to ensure that the sled was in contact with the bottom throughout each tow. Valid shorter duration tow times occurred infrequently due to obstructions, limited transect distance, commercial traffic, and other safety considerations. Global Positioning System (GPS) coordinates were recorded at the beginning and end of each tow. GPS coordinates for each station were programmed into the vessel's system to ensure proper station maintenance.

Upon retrieval of the epibenthic sled, the ichthyoplankton net and flow meter reading were checked to ensure that enough water volume had been sampled and that the net had not been ripped or filled with mud/debris. If it was determined to be a valid sample, then the net was washed down from the outside concentrating the sample in the cod-end bucket. Each ichthyoplankton sample was then transferred to an appropriately sized and labeled container(s), filled approximately half way and the remaining volume filled with 10% buffered Formalin containing the vital stain Rose Bengal. Sample date, time, location, and ID# were included on the label and entered onto a chain of custody (COC); the samples were transported to laboratory and turned over with the COC for sorting and identification.

ICHTHYOPLANKTON SORT AND INDENTIFICATION

The samples were sorted and all specimens were identified to the lowest taxonomic level practicable, assigned a life stage based on morphometric characteristics (i.e., egg, yolk-sac larvae, post yolk-sac larvae, or juvenile) and a laboratory data sheet was completed. After analysis, the sorted samples were placed in vials, labeled (including sample ID#) and preserved for storage. For some larvae it was not possible to discern between yolk-sac and post yolk-sac life stages because the specimens were damaged by natural causes and/or during sample collection. These were classified as unidentified larval stage. Quality control procedures consisted of a continuous sampling plan to assure an Average Outgoing Quality Limit (AOQL) of < 0.10 ($\geq$ 90% accuracy) during sample sorting, enumeration, identification, life stage designation and meristics.

DATA ANALYSIS

Multivariate analyses were used to examine whether the taxonomic composition of eggs and larvae differed among Harbor areas and between channel and non-channel stations. Analysis of Similarities (ANOSIM) tests were used on ranked similarity matrices based on Bray-Curtis similarity measures of log(x+1) transformed data and were distinguished on a scale of $R = 0$ (areas were indistinguishable from each other) to $R = 1$ (no similarity between areas). A significant result from the ANOSIM test was followed by pairwise comparisons between areas using Similarity Percentages (SIMPER) to identify the fish taxa contributing the most to observed dissimilarities between Harbor areas. All multivariate statistics were conducted using Primer 7.0 software (Clarke *et al*. 2014).

Results

The eggs of 22 fish taxa were collected from January to June during the 10 year program (2002 to 2011) of ichthyoplankton sampling (Table B1). Bay anchovy, wrasses (including cunner and tautog), Atlantic menhaden, and windowpane were the numerically dominant egg taxa, collectively accounting for 95% of all eggs collected. Federally managed species collected as eggs include winter flounder, windowpane, and Atlantic mackerel (Table B2). Windowpane and winter flounder eggs were collected in the estuary every year of sampling, whereas Atlantic mackerel eggs were collected in six of the ten years of sampling.

Twenty-five fish taxa were collected in the yolk-sac larval stage, including eleven taxa that were not collected as eggs, which included herrings, northern pipefish, rock gunnel, Atlantic tomcod, Atlantic silverside, sea raven, yellow perch, longhorn sculpin, feather blenny, fourspot flounder, and common carp (Table B4). Many of the taxa collected as yolk-sac larvae, but not eggs, were relatively uncommon and may have been advected into the estuary on tidal currents from near-shore spawning sites. Alternatively, the egg stage may have been pelagic, whereas the larvae are more widely distributed within the water column and more likely to be collected by the epibenthic sled.

Fifty-one fish taxa were collected in the larval (yolk-sac and post-yolk-sac) stage (Table B1). Ten fish taxa accounted for 98% of all larvae collected during the study and include bay anchovy, gobies, winter flounder, grubby, Atlantic menhaden, windowpane, herrings, American sandlance, northern pipefish, and weakfish (Table B1). Federally managed species collected as both yolk-sac and post yolk-sac larvae include winter flounder, windowpane, Atlantic herring, Atlantic mackerel, summer flounder, Atlantic butterfish, and black sea bass (Table B2). Winter flounder, windowpane, and summer flounder post yolk-sac larvae were collected every year of sampling, whereas black sea bass larvae were uncommon, collected only in June 2008 samples.

TEMPORAL VARIATION

Seasonal

Within the January to June sampling period, demersal egg densities were highest in May and June, with the eggs of fifteen species collected during these months (Table B3). Winter spawners included American sandlance and winter flounder, from which eggs of both species were collected in higher densities than other fish during January – March. Other species' eggs collected during the same period but were more uncommon included Atlantic menhaden, the cods (Gadidae), fourbeard rockling, grubby, sand flounders and spotted hake. Further evidence of winter spawning was provided by collections of yolk-sac larvae for American sandlance, winter flounder, grubby, rock gunnel, Atlantic tomcod, sea raven and longhorn sculpin, however the latter two were uncommon (Table B4). Total demersal larval densities increased progressively from January through April (Figure B1), in large part due to increasing densities of grubby and winter flounder (Table B5) and reached a peak in June, when densities of spring spawning fish increased, for example bay anchovies, gobies, Atlantic menhaden, and windowpane.

Inter-annual

Inter-annual variation in both egg and larval densities may be magnified by the fact that not all eggs and larvae were collected in some years for species that continue to spawn in the summer and fall. If substantial spawning and larval development occurred after June, the ABS program did not collect these individuals. Annual peaks in egg abundances were not consistent across species for any particular year (Figure B2). Likewise, post yolk-sac larval densities varied considerably among years, but with no consistent pattern across species (Figure B3). This lack of synchrony among species is not surprising because the January to June sampling program was designed to focus on the primary species of concern, winter flounder, and did not fully capture the entire spawning season for many species; therefore their total annual densities are unknown.

SPATIAL VARIATION

The multivariate analysis of all eggs collected in the Harbor reveals that fish species differ in their use of Harbor areas as spawning habitat (ANOSIM R = 0.22, p = 0.001). In particular, pairwise comparisons of the taxonomic composition of eggs between Harbor areas and channel vs. non-channel locations revealed differences between Arthur Kill/Newark Bay non-channel stations and Lower Bay channel (R = 0. 54, p = 0.001), Lower Bay non-channel (R = 0.57, p = 0.001), and Upper Bay channel (R = 0.52, p = 0.001) locations. Lower egg abundances of the following species in the Arthur Kill/Newark Bay non-channel locations accounts for these differences: searobins, windowpane, cods, weakfish, Atlantic menhaden, fourbeard rockling, and winter flounder (SIMPER).

Post yolk-sac larvae were more homogeneously distributed throughout the Harbor, with no overall significant difference in the taxonomic composition of larvae based Harbor area and channel vs. non-channel station type (ANOSIM R = 0.04, p = 0.12). Similar to the egg distributions, there were some significant pairwise comparisons between Harbor locations, i.e., post yolk-sac larval assemblages collected at Arthur Kill/Newark Bay non-channel stations differed from that of Lower Bay channel (R = 0. 31, p = 0.005), Lower Bay non-channel (R = 0.23, p = 0.008), and Upper Bay channel (R = 0. 22, p = 0.008) locations. These differences were due to high larval abundances in Arthur Kill/Newark Bay non-channel locations of bay anchovy, gobies, and northern pipefish and lower larval abundances of winter flounder, windowpane, and grubby (SIMPER).

SPECIES DISTRIBUTION

The distributions of individual species eggs and larvae are briefly summarized and depicted on Harbor maps for the more commonly collected species and life stages (Figures B4 through B23).

American sandlance

American sandlance spawn during the late fall and winter. American sandlance eggs were only collected in 2011 and were collected in Lower Bay and Upper Bay, with 99% of the eggs contained in a single Lower Bay non-channel (LB-13) sample. American sandlance larvae comprised 1.2% of all the larvae collected during the ABS (Table B1). Their larvae were found in all Harbor regions at channel and non-channel stations (Figure B4). American sandlance yolk-sac and post yolk-sac larvae were collected in all years of sampling and were concentrated in Lower Bay non-channel locations, with intermediate densities in Upper Bay and lowest densities in Arthur Kill/Newark Bay (Figure B4). Larvae were found at all the Lower Bay stations and at most of the Upper Bay and Arthur Kill/Newark Bay stations. Both yolk-sac and post yolk-sac larvae were found primarily in January 2010 (Tables B4 and B5), with low densities in other years (Figure B3).

American shad

American shad typically spawn up-river of the Harbor. Eggs were collected at a single Upper Bay non-channel station (SB-2) in 2006 and a single non-channel Lower Bay station (LB-3) in 2008. Larvae also were infrequently collected, appearing in only three samples during the 10-year ABS program. American shad larvae were collected in Arthur Kill/Newark Bay and Upper Bay only.

Atlantic croaker

Atlantic croaker eggs and yolk-sac larvae were not collected within the Harbor, whereas post yolk-sac larvae were collected in all Harbor areas at channel and non-channel locations. The absence of eggs and yolk-sac larvae in ABS samples may result from a combination of sampling occurring after their fall/winter spawning season and spawning occurring primarily over the continental shelf. The presence of post yolk-sac larvae in the Harbor indicates spawning is occurring in near-shore coastal habitats and larvae are transported into the Harbor via currents.

Atlantic herring

Atlantic herring spawn in coastal habitats and larvae move into estuaries during their development (Able and Fahay 2010). Atlantic herring were only collected as post yolk-sac larvae within ABS samples. Larvae were collected in all Harbor areas and at both channel and non-channel locations. Atlantic herring spawn in the fall, therefore the ABS program collected samples after eggs and yolk-sac larvae would have been present.

Atlantic mackerel

Atlantic mackerel eggs were collected primarily in Lower Bay and Upper Bay in both channel and non-channel locations. Larval densities were highest in Lower Bay, intermediate in Upper Bay, and uncommon in Arthur Kill/Newark Bay (Figure B5). Atlantic mackerel larvae comprised 0.1% of all the larvae collected during the ABS (Table B1). Their larvae were found in low densities in all Harbor regions at channel and non-channel stations, however, they were not found at all stations (Figure B5). They were found at three channel stations in the Arthur Kill/Newark Bay region; at five channel and three non-channel stations in the Upper Bay; and at three channel and three non-channel stations in the Lower Bay. Both yolk-sac and post yolk-sac larvae were found primarily in May and June (Tables B4 and B5).

Atlantic menhaden

Atlantic menhaden have two prolonged spawning periods: one during the late winter to early summer and another in the fall (Able and Fahay 2010). Atlantic menhaden eggs comprised 8.9% of all the eggs collected during the ABS (Table B1) and were consistently collected in all Harbor areas at both channel and non-channel locations, with highest densities in Lower Bay and much lower densities in Arthur Kill/Newark Bay (Figure B6). A few eggs were found in February and March, and then egg densities increased in April and reached peaks in May and June, suggesting that eggs were likely present into the summer months (Table B3). Atlantic menhaden egg densities were higher from 2002 to 2006 when their densities peaked, since then the densities were lowest from 2007 to 2011 (Figure B2).

Atlantic menhaden larvae comprised 3.1% of all the larvae collected and were also widely distributed, with highest concentrations in Upper Bay (Figure B7). Larval densities were low from January to May, increased in June and likely peak in early summer after the ABS sampling ended (Tables B4 and B5). Atlantic menhaden larval densities were higher in 2003 to 2005, and

2007 with peak densities in 2004; low densities occurred in 2002, 2006 and from 2008 to 2011 (Figure B3). Atlantic menhaden spawn primarily offshore in oceanic habitat, but eggs and larvae have been collected in other northwestern Atlantic estuaries (Able and Fahay 2010).

Atlantic tomcod

Atlantic tomcod eggs were not collected in the Harbor and yolk-sac larvae were only collected in one year (2004) at both channel and non-channel stations in Newark Bay. Atlantic tomcod typically spawn from November to February in freshwater above the salt front (Able and Fahay 2010), therefore the absence of their demersal eggs in the ABS samples and rare collections of yolk-sac larvae confirms spawning within the Harbor is limited and the rare occurrence of yolk-sac larvae likely the result of high spring flows from upriver spawning areas.

Bay anchovy

Bay anchovy eggs were collected in all Harbor areas at both channel and non-channel locations, with highest densities in Arthur Kill/Newark Bay and Lower Bay (Figure B8). Bay anchovy spawn from late spring to early fall and their eggs comprised 68.0% of all the eggs collected during the ABS (Table B1). Eggs were collected in high densities in all Harbor regions at channel and non-channel stations (Figure B8). Eggs were first found in May and densities increased rapidly to higher densities in June, suggesting that eggs were likely present into the summer after ABS sampling ended (Table B3). Bay anchovy eggs were collected in all years with the higher densities in 2004, 2008, and 2009 and lower densities in 2002, 2003, and 2006 (Figure B2).

Bay anchovy larvae also were widely distributed (Figure B9) and were collected in low densities compared to eggs probably because spawning occurred in May and June. Bay anchovy larvae comprised 40.7% of all the larvae collected during the ABS (Table B1), with their larvae being found in high densities in all Harbor regions at channel and non-channel station. Larvae were found at low densities primarily in June. Considering the high egg densities found June, it may further be suggested that larvae were likely present at high densities into the summer after ABS sampling was concluded (Tables B4 and B5). Bay anchovy larvae were collected in all years with the higher densities in 2004, 2007, and 2008 and lower densities in 2006 and 2009 to 2011 (Figure B3).

Black sea bass

Black sea bass spawn offshore on the continental shelf from April through October (Able and Fahay 2010). Post yolk-sac larvae were collected in one Lower Bay non-channel sample in 2008. No eggs or yolk-sac larvae were collected, suggesting black sea bass spawning within the Harbor is limited if it occurs at all and advection of larvae into the Harbor does not commonly occur during the spring.

Atlantic butterfish

Atlantic butterfish eggs and yolk-sac larvae were not collected during Aquatic Biological Survey (ABS) sampling and post yolk-sac larvae were collected in low numbers in Lower Bay and Upper Bay. Atlantic butterfish spawn offshore starting in May and June, therefore the timing of ABS sampling was not appropriate for collecting eggs if Atlantic butterfish used the Harbor as spawning habitat.

Cods (including Atlantic cod)

Cod eggs were widely distributed throughout the NY/NJ Harbor, occurring in both channel and non-channel locations (Figure B10). Because cod spawn in the summer, in most years the larval stage occurred after ABS sampling ended in June. Cod larvae were only collected in 2004 and 2005.

Fourbeard rockling

Fourbeard rockling eggs were collected in all Harbor areas at both channel and non-channel locations in low to moderate densities, with higher densities in Lower Bay and Upper Bay (Figure B11). Fourbeard rockling have a prolonged spawning period from mid winter to early fall and their eggs comprised 0.1% of all the eggs collected during the ABS (Table B1). Eggs were found from February through June with a peak density in April and a lower peak in June, suggesting that eggs were likely present into the summer after ABS sampling ended (Table B3). Although found at most stations in each Harbor region, fourbeard rockling larvae were not common in ABS samples, which may indicate a more pelagic life stage.

Gobies

Goby eggs were collected in low numbers in Upper Bay only, however, post yolk-sac larvae were very abundant throughout the Harbor at both channel and non-channel locations. Their larvae comprised 23.5% of all the larvae collected during the ABS (Table B1) and were found in moderate densities in all Harbor regions, densities being generally lower in Lower Bay (Figure B12). Goby spawn from late spring to mid fall and a few larvae were present from February to May with low densities followed by a sharp increase in densities in June. Densities likely peak during summer after the ABS sampling ends (Tables B4 and B5). Goby larval densities were higher in 2002, 2005, 2007 and 2008 and very low densities occurred in 2003, 2004 and from 2009 to 2011 (Figure B3).

Grubby

Grubby eggs were collected in only three years in Upper Bay only, however, grubby larvae were collected in all Harbor areas at both channel and non-channel stations (Figure B13). Grubby spawn from mid winter through spring, and their larvae comprised 8.6% of all the larvae collected during the ABS (Table B1). A few larvae were present in January, February and May with higher densities in March and April (Tables B4 and B5). Grubby larval densities were higher in 2004, 2005, 2008 to 2010 and lower densities occurred in the other five years (Figure B3).

Hogchoker

Hogchoker spawn from late spring through early fall, with their eggs comprising 0.3% of all the eggs collected during the ABS (Table B1). Their eggs were found in low densities in all Harbor regions at channel and non-channel stations (Figure B14). Hogchoker eggs were collected in all Harbor areas in 2002, were sporadically collected in 2003 and 2004 and were not collected any other year. A few eggs were found in April and May then density increased sharply in June, suggesting that eggs were likely present into the summer after ABS sampling concluded (Table B3). Egg densities were generally higher in Lower Bay and Upper Bay. However, they were not found at all stations, instead they were found at four channel stations and three non-channel stations in the Arthur Kill/Newark Bay region; at five channel and seven non-channel stations in the Upper Bay; and at three channel and three non-channel stations in the Lower Bay (Figure B14). Hogchoker larvae were only collected in one sample in Arthur Kill/Newark Bay in 2005.

Northern pipefish

Northern pipefish were not collected as eggs because males maintain eggs in a brood pouch. Pipefish larvae were abundant and widely distributed with highest abundances in the Upper Bay and Arthur Kill/Newark Bay (Figure B15). Northern pipefish larvae comprised 1.2% of all the larvae collected during the ABS (Table B1) and their larvae were found in low densities in all Harbor regions at channel and non-channel stations (Figure B15). A few larvae were present in May with an increase in density in June (Tables B4 and B5). Northern pipefish larval densities were higher in 2002, 2005, 2007, and 2008 and lower densities occurred in 2006, 2010 and 2011 (Figure B3).

Searobins (Northern searobin & Striped searobin)
Searobin eggs were abundant and widely distributed throughout the Harbor, with highest densities in channel areas of the Upper Bay and Lower Bay (Figure B16). Searobin larvae were not as abundant in samples as eggs which may reflect their pelagic life stage and that sampling was not conducted in the summer when larvae were most abundant.

Silver hake
Silver hake eggs were uncommon and collected in only Lower Bay and Upper Bay. Silver hake eggs are pelagic, therefore, may not be reliably sampled by the epibenthic sled. Silver hake larvae were not collected during ABS sampling, in part because sampling stopped in June when eggs were first collected.

Weakfish
Weakfish eggs were consistently collected in all Harbor areas at both channel and non-channel locations (Figure B17). Weakfish eggs comprised 1.4% of all the eggs collected during the ABS (Table B1), with their eggs being found in moderate to high densities in all Harbor regions at channel and non-channel (Figure B17). The higher egg densities were in the Upper Bay channel and non-channel stations, followed by Newark Bay channel stations. Densities were lowest in the Lower Bay. Eggs were found in April and May and at higher densities in June, suggesting that eggs were likely present into the summer after ABS sampling ended (Table B3). Weakfish egg densities were higher from 2002 to 2004 when their densities peaked in 2002 followed by 2004, since then the densities were lowest in 2007, 2008, 2010, and 2011 (Figure B2).

Weakfish larvae also were widely distributed throughout the Harbor in June, but ABS sampling did not coincide with anticipated peak larval densities in the summer (Able and Fahay 2010). Weakfish larvae comprised 1.0% of all the larvae collected during the ABS (Table B1), their larvae were found in low to moderate densities in all Harbor regions at channel and non-channel stations (Figure B18). The higher larval densities were in the Upper Bay channel and non-channel stations, followed by Newark Bay channel and non-channel stations. Densities were lowest in the Lower Bay, especially at channel stations. Larvae were found in June at low densities, suggesting that eggs were likely present into the summer after ABS sampling ended (Tables B4 and B5). Weakfish larval densities were higher in 2002 and 2004 followed by 2005, 2007 and 2008; the lowest densities occurred in 2006 and from 2009 to 2011 (Figure B3).

Windowpane

Windowpane eggs were among the most abundant demersal eggs collected and were widely distributed in all Harbor areas at both channel and non-channel stations, with highest abundances in Upper Bay and Lower Bay (Figure B19). Windowpane spawn from late spring to mid summer and their eggs comprised 5.3% of all the eggs collected during the ABS (Table B1). Their eggs were found in high densities in all Harbor regions at channel and non-channel stations. Eggs densities increased from April to May then June, suggesting that eggs were likely present into the summer after ABS sampling ended (Table B3). Windowpane egg densities were higher from 2002 to 2004 and slightly lower from 2007 to 2009; the lowest densities were in 2006 and 2011 (Figure B2).

Larval densities were more strongly concentrated in Lower Bay (Figure B20). Windowpane larvae comprised 3.1% of all the larvae collected during the ABS (Table B1) and their larvae were found in low to moderate densities in all Harbor regions at channel and non-channel stations. Larval densities were low in April, then increased slightly in May and June and likely peaked in early summer after the ABS sampling ended (Tables B4 and B5). Windowpane larval densities were highest in 2007 followed by 2005 and were very low in 2006, 2010, and 2011 (Figure B3).

Wrasses: Family Labridae (Cunner and Tautog)

Wrasse eggs were highly abundant in all years and were widely distributed in all Harbor areas at both channel and non-channel locations (Figure B21). The identification of wrasse eggs at the family level (Labridae) include cunner which spawn from late spring to early fall and tautog which spawn from late spring to mid summer (Able and Fahay 2010). Wrasse eggs comprised 11.9% of all the eggs collected during the ABS (Table B1) and their eggs were found at high densities in all Harbor regions (Figure B21). Eggs were first collected in April, with an increase in density in May and then increased sharply in June, suggesting that eggs were likely present into the summer months (Table B3). Eggs were collected in all years with the highest density in 2008 followed by 2007 and the lowest density in 2011 (Figure B2).

Cunner larvae comprised 0.2% of all the larvae collected during the ABS (Table B1). Their larvae were found in low densities in all Harbor regions at channel and non-channel stations (Figure B22). However, they were not found at all stations. They were found at four channel stations and one non-channel station in the Arthur Kill/Newark Bay region; at five channel and seven non-channel stations in the Upper Bay; and at four channel and nine non-channel stations in the Lower Bay. Cunner larvae were found primarily in June at low densities, suggesting that larvae were likely present at high densities into the summer months after ABS sampling ended (Tables B4 and B5). Tautog larvae comprised 0.3% of all larvae collected (Table B1) and were collected in all Harbor areas at both channel and non-channel locations but in low numbers with highest densities in Upper Bay (Figure B23).

Discussion

In the winter and primarily during the spring, the Harbor is used as spawning habitat by a diverse assemblage of fish. ABS sampling was conducted to characterize habitat used in the Harbor by winter flounder (USACE 2012, Wilber *et al.* 2013), therefore, the timing (January to June) and method (epibenthic sled) of sampling does not provide information on species that spawn in the summer and fall or species with pelagic eggs and larvae. Another Harbor fish survey conducted in the 1990s (Wilk *et al*. 1998) was conducted year-round, but was limited to bottom trawl sampling, therefore did not provide any information on the locations of spawning habitat. The ten year (2002 – 2011) ABS ichthyoplankton dataset, therefore, provides a valuable resource that can be used to document Harbor areas used as spawning habitat in the winter and spring by fish species with demersal eggs. In addition, the full species list collected during the study can serve as a characterization of eggs and larvae during the study period that can be referenced by future studies that examine fish range expansions and retractions.

The numerically dominant egg species collected included bay anchovy, wrasses, Atlantic menhaden, and windowpane and their densities increased through the spring into June. A few species (e.g., winter flounder and Amercian sandlance) spawned in the Harbor in the winter, but egg densities of these species were relatively low compared to egg densities of spring spawning species. Infrequent winter collections of fourbeard rockling, grubby, sand flounders and spotted hake eggs and yolk-sac larvae of rock gunnel, Atlantic tomcod, sea raven and longhorn sculpin indicate winter spawning occurs near the Harbor and these early life history stages may be advected into the estuary.

The abundance and distribution of Atlantic menhaden, bay anchovy, windowpane, and wrasse eggs suggest spawning throughout the Harbor; while the abundance and distribution of fourbeard rockling, hogchoker, and weakfish eggs seem to suggest they may spawn primarily in the Upper Bay and Newark Bay and that the lower densities and reduced distribution of eggs found in the Lower Bay and Arthur Kill may suggest some tidal transport of developing eggs and limited spawning. The abundance and distribution of winter flounder eggs suggests primary spawning occurs in non-channel habitats of the Lower Bay and secondarily Upper Bay; higher densities occurred at non-channel stations compared to adjacent or nearby channel stations. The lowest densities were found in the Arthur Kill/Newark Bay region, both channel and non-channel station densities where eggs were collected were 1 egg/1000 m^3 or less. Eggs were not collected at two of the six non-channel stations and at three of the six channel stations, while most of the Lower Bay and Upper Bay stations collected winter flounder eggs.

Eggs of three federally managed species, windowpane, winter flounder and Atlantic mackerel, were collected. Winter flounder spawn over shallow, sandy habitat, with low % total organic carbon and eggs are most commonly collected at Lower Bay and Upper Bay non-channel stations (USACE 2012, Wilber *et al.* 2013). The windowpane spawning season was only partially captured by ABS sampling with densities progressively increasing through the spring months, presumably continuing into the summer. Windowpane eggs were widely distributed in Lower Bay and Upper Bay and were collected at similar densities in both channel and non-channel locations and few were collected in the Arthur Kill/Newark Bay area. Atlantic mackerel eggs and larvae also were concentrated in Lower Bay and Upper Bay and were uncommon in

Arthur Kill/Newark Bay. Thus, the Arthur Kill/Newark Bay Harbor subarea does not appear to be used extensively as spawning habitat for the federally managed species with winter/spring spawning and demersal early life history stages.

Multivariate results revealed that egg densities of other (non-EFH) fish species like searobins, cods, weakfish, Atlantic menhaden, and fourbeard rockling were lower at Arthur Kill/Newark Bay than other Harbor areas as well. Benthic habitats, sediment types, and disturbance histories differ among Harbor areas. In general, Lower Bay is the most distant from urban and industrial influences and has sandy sediments, extensive shellfish beds, and ampeliscid mats (Iocco *et al*. 2000). Bacterial mats and other evidence of anoxic conditions were not observed in Lower Bay. Therefore, fish species that can tolerate relatively high salinities as eggs and larvae may spawn over the less disturbed benthic habitat in Lower Bay, where industrial pollution and other forms of habitat degradation are not prevalent. Benthic habitat in Upper Bay includes patches of shellfish beds and areas with silty sediments dominated by opportunistic infauna that are associated with disturbed or polluted habitat. Arthur Kill/Newark Bay is the most highly industrialized Harbor area included in ABS sampling, with sediments comprised primarily of muddy materials and few infauna dominated by opportunistic polychaetes (Iocco *et al*. 2000). Salinities also are lower in Arthur Kill/Newark Bay, therefore, site selection for spawning may include an aversion to disturbed benthic habitat and preference for higher salinities for egg and larval development.

Larvae were more evenly distributed among Harbor areas than eggs, probably because mixing and transport from spawning sites occurs on tidal currents. There were, however, some differences in larval taxonomic composition between Arthur Kill/Newark Bay non-channel areas and other Harbor areas. Bay anchovy, goby, and northern pipefish larvae were relatively more abundant in Arthur Kill/Newark Bay than in Lower Bay and Upper Bay channel locations, whereas winter flounder, windowpane, and grubby larvae were not as abundant in Arthur Kill/Newark Bay. Differences in physical tolerances, larval durations, and capacity for active transport (via vertical migration to take advantage of transport by tidal currents) may explain these spatial distribution patterns.

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Tables (Part B)

Table B1. Fish taxa for which eggs and total larvae were collected in epibenthic sled samples from January to June in the NY/NJ Harbor from 2002 - 2011. *Percentages indicate the overall proportion each species contributed to the total collection based on CPUE (#/1000 m^3).*

Eggs	%	Larvae	%	Larvae continued	%
Bay anchovy	68.0	Bay anchovy	40.7	Atlantic cod	<0.1
Wrasses	11.9	Gobies	23.5	Lined seahorse	<0.1
Atlantic menhaden**	8.9	Winter flounder*	14.1	Cods	<0.1
Windowpane*	5.3	Grubby	8.6	Temperate basses	<0.1
Searobins	3.5	Atlantic menhaden**	3.1	Striped cusk-eel	<0.1
Weakfish**	1.4	Windowpane*	3.1	Sturgeons**	<0.1
Hogchocker	0.3	Herrings**	1.4	Black sea bass*	<0.1
Cods	0.3	American sandlance	1.2	Inshore lizardfish	<0.1
American sandlance	0.1	Northern pipefish	1.2	Yellowtail flounder	<0.1
Winter flounder*	0.1	Weakfish**	1.0	Hogchocker	<0.1
Fourbeard rockling	0.1	Rock gunnel	0.6	Sand flounders	<0.1
Tautog**	<0.1	Tautog**	0.3	Radiated shanny	<0.1
Cunner	<0.1	Cunner	0.2	Sea raven	<0.1
Goosefish	<0.1	Atlantic tomcod**	0.2	Yellow perch	<0.1
Atlantic mackerel*	<0.1	Atlantic mackerel*	0.1	Common carp	<0.1
Silver hake*	<0.1	Atlantic croaker**	0.1		
American shad**	<0.1	Atlantic herring*	0.1		
Gobies	<0.1	Summer flounder*	0.1		
Grubby	<0.1	Atlantic butterfish*	0.1		
Sand flounders	<0.1	Feather blenny	<0.1		
Spotted hake	<0.1	Fourbeard rockling	<0.1		
White perch	<0.1	Atlantic silverside	<0.1		
		Longhorn sculpin	<0.1		
		American shad**	<0.1		
		Searobins	<0.1		
		Northern kingfish	<0.1		
		White perch	<0.1		
		Northern puffer	<0.1		
		Striped bass	<0.1		
		Fourspot flounder	<0.1		
		Conger eel	<0.1		
		Spot**	<0.1		
		Smallmouth flounder	<0.1		
		Combtooth blennies	<0.1		
		Goosefish	<0.1		
		Walleye	<0.1		

* Federally managed (EFH) species
** State managed species of concern

Table B2. Number of years that eggs, yolk-sac (YS) and post yolk-sac (PYS) larvae of Federally managed species (EFH) were collected in NY/NJ Harbor from 2002 to 2011.

Common Name	Scientific Name	Eggs	YS Larvae	PYS Larvae
Atlantic butterfish	*Peprilus tricanthus*	0	0	6
Atlantic herring	*Clupea harengus*	0	0	7
Atlantic mackerel	*Scomber scombrus*	6	1	3
Black sea bass	*Centropristus striata*	0	0	1
Bluefish	*Pomatomus saltatrix*	0	0	0
Red hake	*Urophycis chuss*	0	0	0
Scup	*Stenotomus chrysops*	0	0	0
Summer flounder	*Paralichthys dentatus*	0	0	10
Windowpane	*Scophthalmus aquosus*	10	10	10
Winter flounder	*Pseudopleuronectes americanus*	10	10	10
Little skate	*Raja erinacea*	0	0	0
Clearnose skate	*Raja eglanteria*	0	0	0
Winter skate	*Leucorja ocellata*	0	0	0

Table B3. Monthly mean egg CPUE (# /1000m^3) collected in NY/NJ Harbor from 2002 – 2011.

Common Name	Scientific Name	Jan	Feb	Mar	Apr	May	Jun
Bay anchovy	*Anchoa mitchilli*					151.3	9,168.2
Wrasses	Family Labridae				1.7	312.7	1,411.3
Atlantic menhaden	*Brevoortia tyrannus*		<0.1	0.4	138.1	558.3	696.1
Windowpane	*Scophthalmus aquosus*				43.3	247.0	505.7
Searobins	*Prionotus* sp.				0.6	57.3	440.0
Weakfish	*Cynoscion regalis*				25.0	31.4	139.0
Hogchocker	*Trinectes maculatus*				<0.1	1.0	39.2
Cods	Family Gadidae	<0.1	0.1	0.9	5.6	4.5	28.6
American sandlance	*Ammodytes americanus*	38.9	<0.1				
Winter flounder	*Pseudopleuronectes americanus*	0.8	22.8	19.9	4.6		
Fourbeard rockling	*Enchelyopus cimbrius*		<0.1	1.9	6.3	1.4	3.5
Tautog	*Tautoga onitis*				3.9		
Cunner	*Tautogolabrus adspersus*						3.5
Goosefish	*Lophius americanus*					<0.1	2.6
Atlantic mackerel	*Scomber scombrus*				<0.1	2.7	<0.1
Silver hake	*Merluccius bilinearis*					<0.1	1.3
American shad	*Alosa sapidissima*					0.2	0.2
Gobies	*Gobiosoma* sp.						0.2
Grubby	*Myoxocephalus aenaeus*		0.1	<0.1			
Sand flounders	*Lophopsetta maculata*		<0.1		<0.1		
Spotted hake	*Urophycis regia*	<0.1			<0.1		
White perch	*Morone americana*				<0.1		

Note: Empty cells indicate no eggs were collected that month for that species.

Table B4. Monthly mean yolk-sac larval CPUE (# /1000m^3) collected in NY/NJ Harbor from 2002 – 2011.

Common Name	Scientific Name	Jan	Feb	Mar	Apr	May	Jun
Bay anchovy	*Anchoa mitchilli*						3.2
Gobies	*Gobiosoma spp.*						0.2
Winter flounder	*Pseudopleuronectes americanus*	<0.1	0.8	4.2	12.0		
Grubby	*Myoxocephalus aenaeus*	0.3	2.3	4.0	3.4		
American sandlance	*Ammodytes americanus*	183.1	25.2	3.2	0.5		
Atlantic menhaden	*Brevoortia tyrannus*				<0.1	2.9	3.5
Windowpane	*Scophthalmus aquosus*				0.1	0.2	0.2
Herrings	*Clupea and Alosa spp.*						0.1
Northern pipefish	*Syngnathus fuscus*					<0.1	<0.1
Weakfish	*Cynoscion regalis*						0.1
Rock gunnel	*Pholis gunnellus*	0.3	0.5	0.1			
Tautog	*Tautoga onitis*					<0.1	0.3
Atlantic tomcod	*Microgadus tomcod*		0.1	0.2			
Cunner	*Tautogolabrus adspersus*						<0.1
Atlantic mackerel	*Scomber scombrus*					0.1	
Atlantic silverside	*Menidia menidia*					0.1	0.1
White perch	*Morone americana*				<0.1	0.3	0.1
American shad	*Alosa sapidissima*						0.1
Goosefish	*Lophius americanus*						0.1
Sea raven	*Hemitripterus americanus*		<0.1				
Yellow perch	*Perca flavescens*				<0.1		
Longhorn sculpin	*Myoxocephalus octodecemspinosus*		<0.1	<0.1			
Feather blenny	*Hypsoblennius hentzi*				<0.1	<0.1	
Fourspot flounder	*Hippoglossina oblonga*					<0.1	<0.1
Common carp	*Cyprinus carpio*					<0.1	

Note: Empty cells indicate no larvae were collected that month for that species.

Table B5. Monthly mean post yolk-sac larval CPUE (# /1000m^3) for those taxa collectively comprising 99.7% of all post yolk-sac larvae collected in NY/NJ Harbor from 2002 – 2011.

Common Name	Scientific Name	Jan	Feb	Mar	Apr	May	Jun
Bay anchovy	*Anchoa mitchilli*	<0.1			<0.1		647.9
Gobies	*Gobiosoma spp.*		<0.1	0.9	1.1	<0.1	371.5
Winter flounder	*Pseudopleuronectes americanus*		1.6	10.3	186.4	36.0	1.4
Grubby	*Myoxocephalus aenaeus*	0.1	11.0	63.0	73.8	4.2	
Atlantic menhaden	*Brevoortia tyrannus*	0.2	0.3	0.5	0.1	1.8	48.0
Windowpane	*Scophthalmus aquosus*	<0.1			0.4	25.2	32.6
Herrings	*Clupea and Alosa spp.*				<0.1		21.9
American sandlance	*Ammodytes americanus*	30.9	2.2	3.2	1.0	<0.1	
Northern pipefish	*Syngnathus fuscus*					0.5	18.9
Weakfish	*Cynoscion regalis*						16.2
Rock gunnel	*Pholis gunnellus*	2.1	4.6	2.9	2.9	0.1	
Tautog	*Tautoga onitis*					<0.1	5.1
Cunner	*Tautogolabrus adspersus*						2.6
Atlantic tomcod	*Microgadus tomcod*		0.3	1.3	1.1	0.2	
Atlantic mackerel	*Scomber scombrus*					0.7	1.4
Atlantic croaker	*Micropogonias undulatus*	3.7	0.1	<0.1			
Atlantic herring	*Clupea harengus*		0.1	0.8	0.6	0.2	<0.1
Summer flounder	*Paralichthys dentatus*	0.6	0.4	0.6	0.3	<0.1	
Atlantic butterfish	*Peprilus triacanthus*						0.8
Other		<0.1	<0.1	<0.1	<0.1	<0.1	2.7

Note: Empty cells indicate no larvae were collected that month for that species.

Figures (Part B)

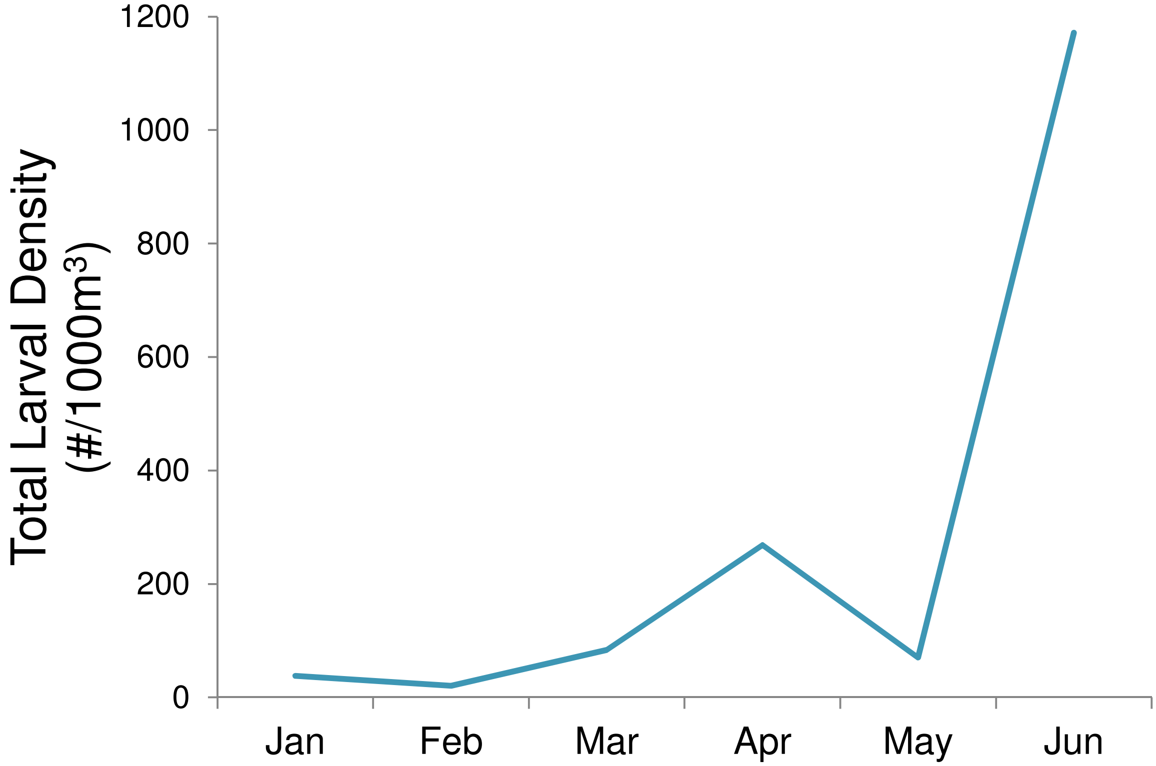

Figure B1. Mean monthly demersal larval densities for all fish species collected in NY/NJ Harbor from 2002 - 2011. Larval densities include both yolk-sac and post-yolk-sac densities.

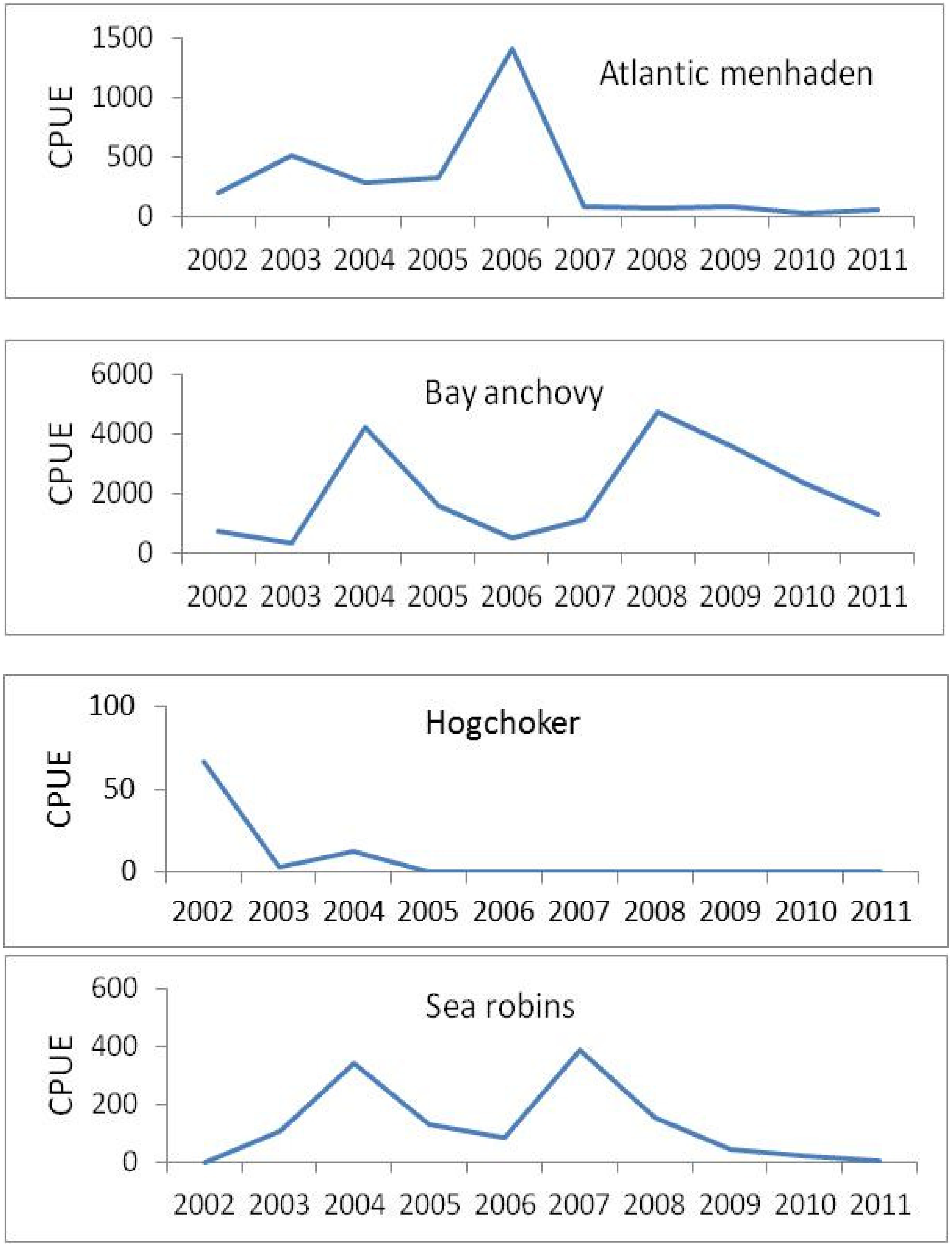

Figure B2. Inter-annual variation in demersal fish egg densities (#/1000m^3) collected in NY/NJ Harbor from 2002 - 2011.

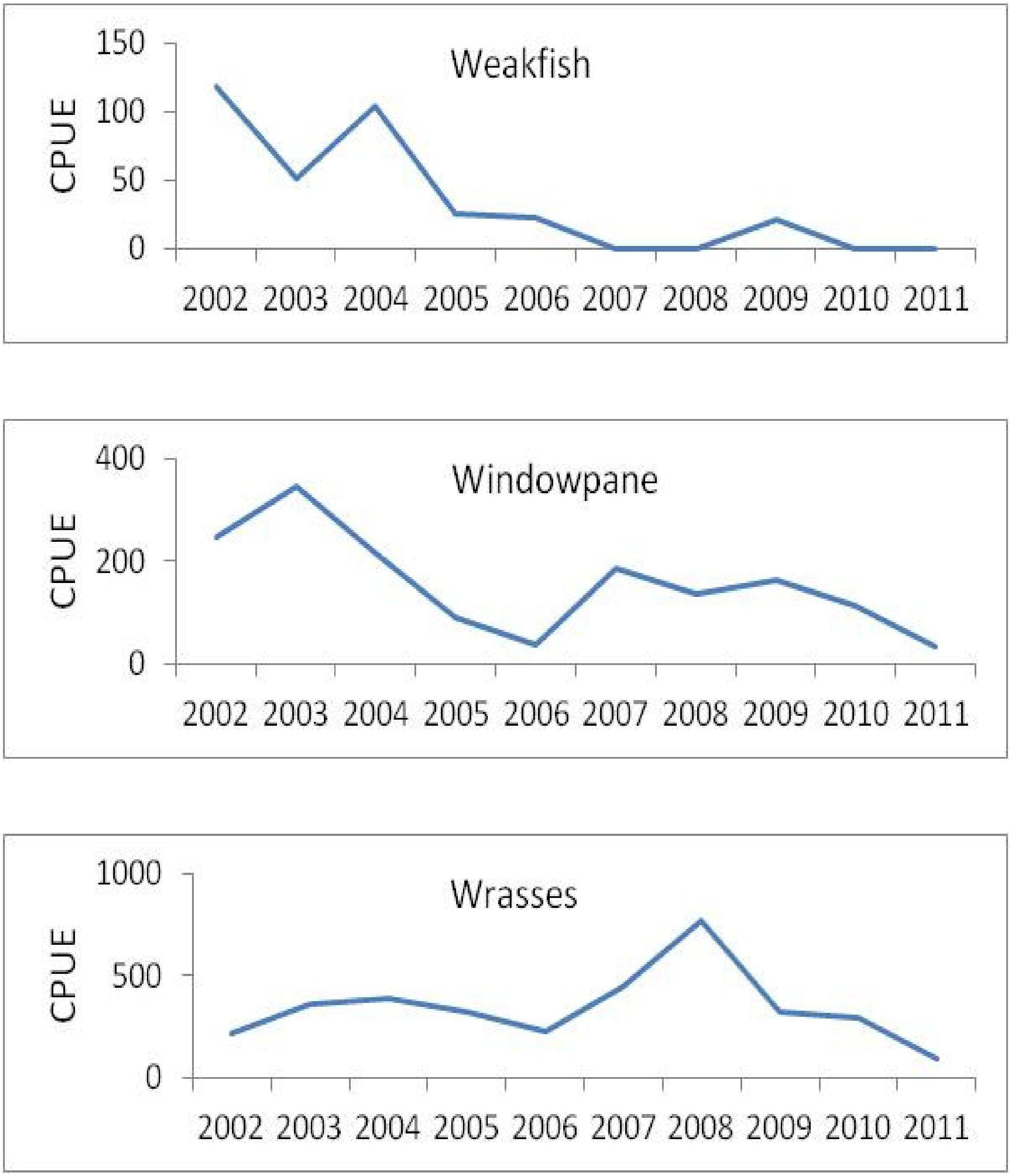

Figure B2 (cont.). Inter-annual variation in demersal fish egg densities (#/1000m^3) collected in NY/NJ Harbor from 2002 - 2011.

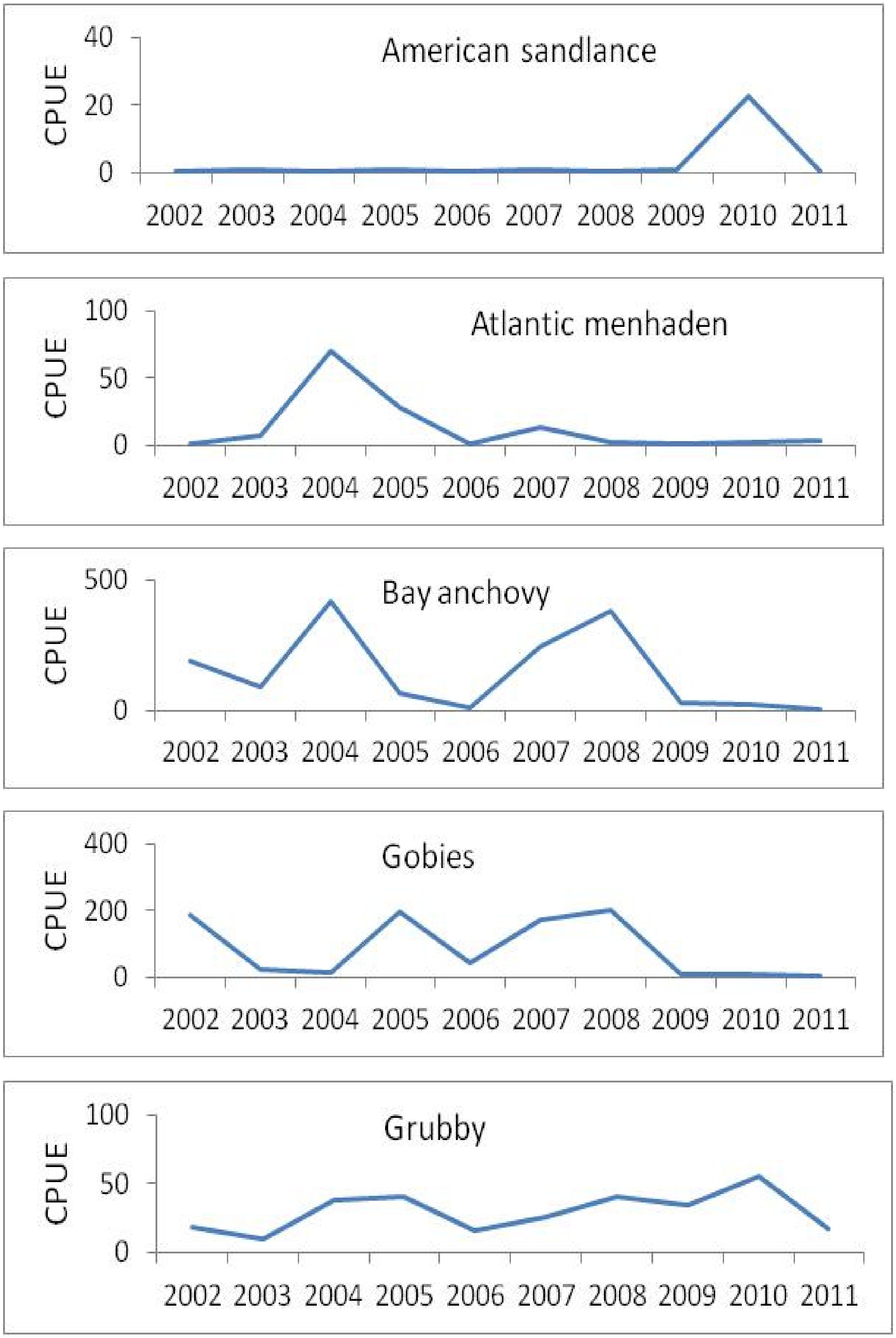

Figure B3. Inter-annual variation in demersal fish post yolk-sac larval densities (#/1000m^3) collected in NY/NJ Harbor from 2002 - 2011.

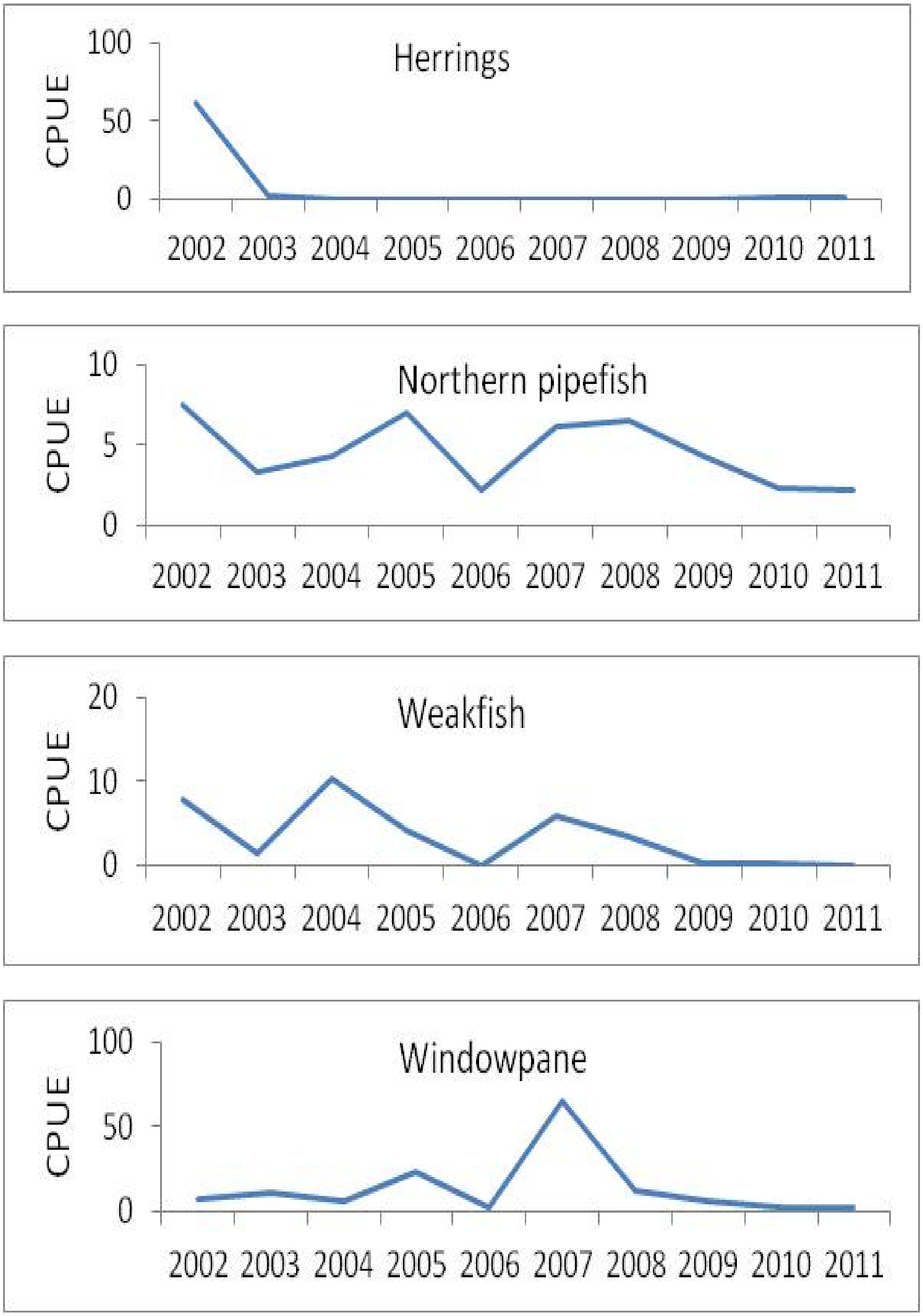

Figure B3 (cont). Inter-annual variation in demersal fish post yolk-sac larval densities (#/1000m^3) collected in NY/NJ Harbor from 2002 - 2011.

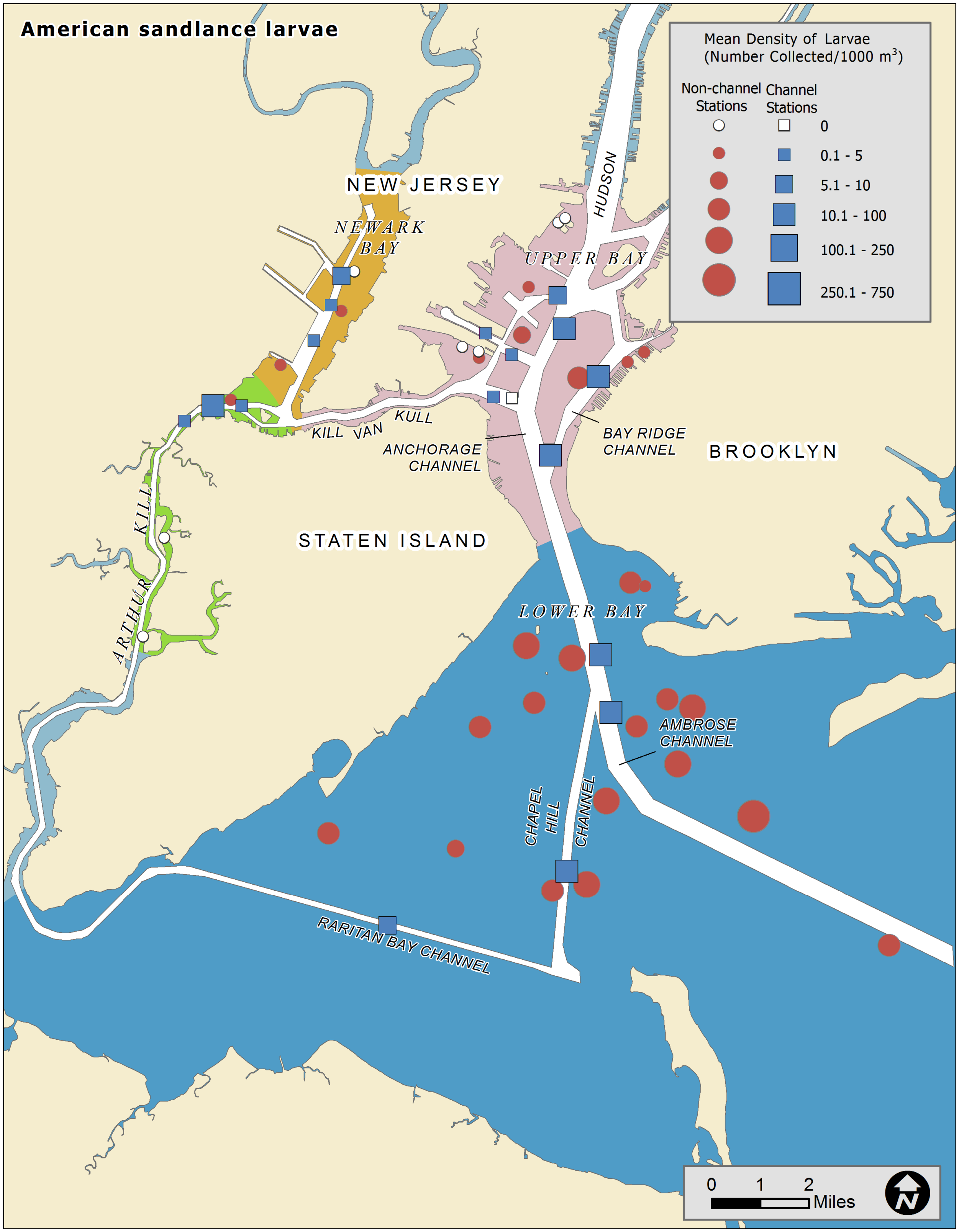

Figure B4. American sandlance larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

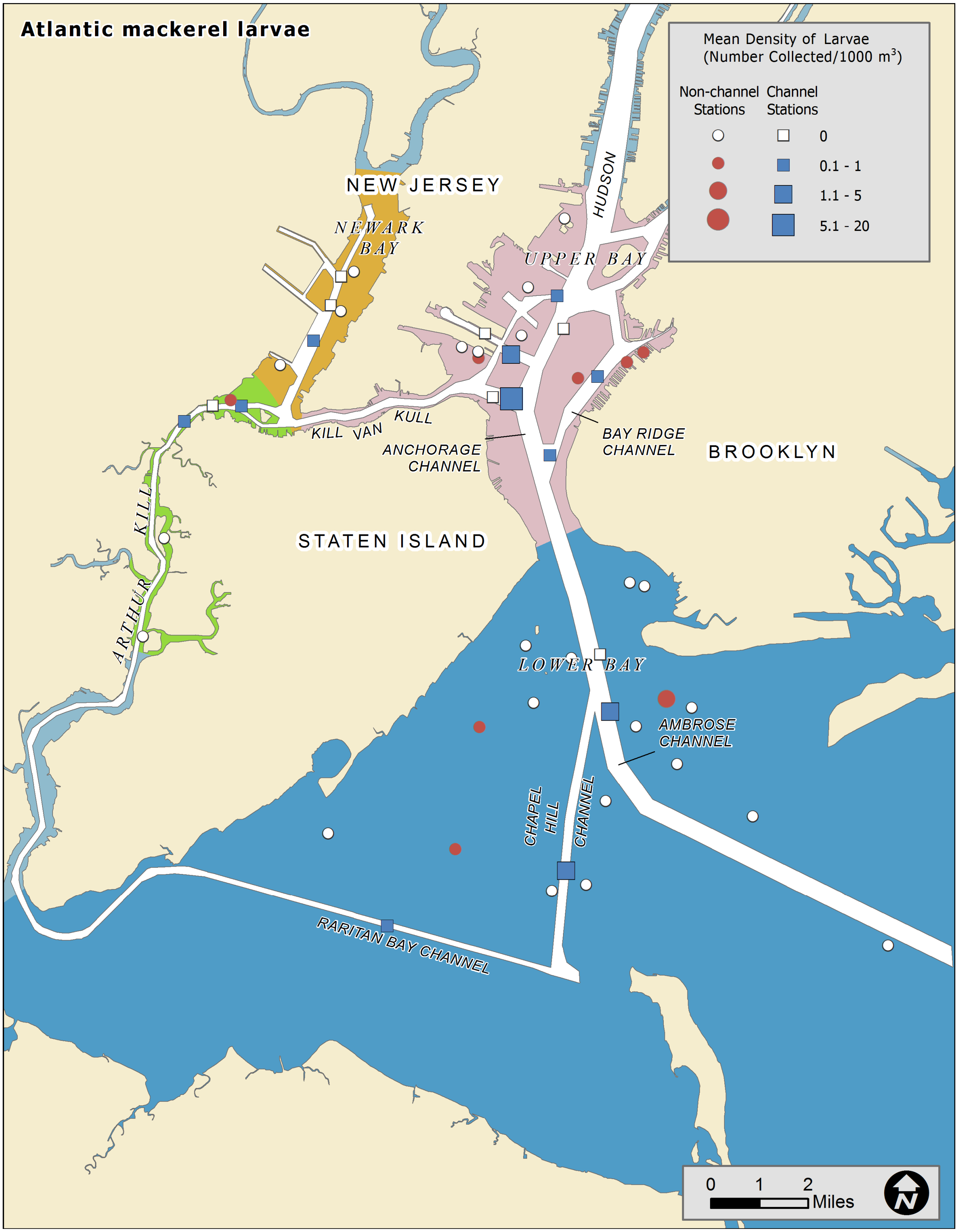

Figure B5. Atlantic mackerel larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

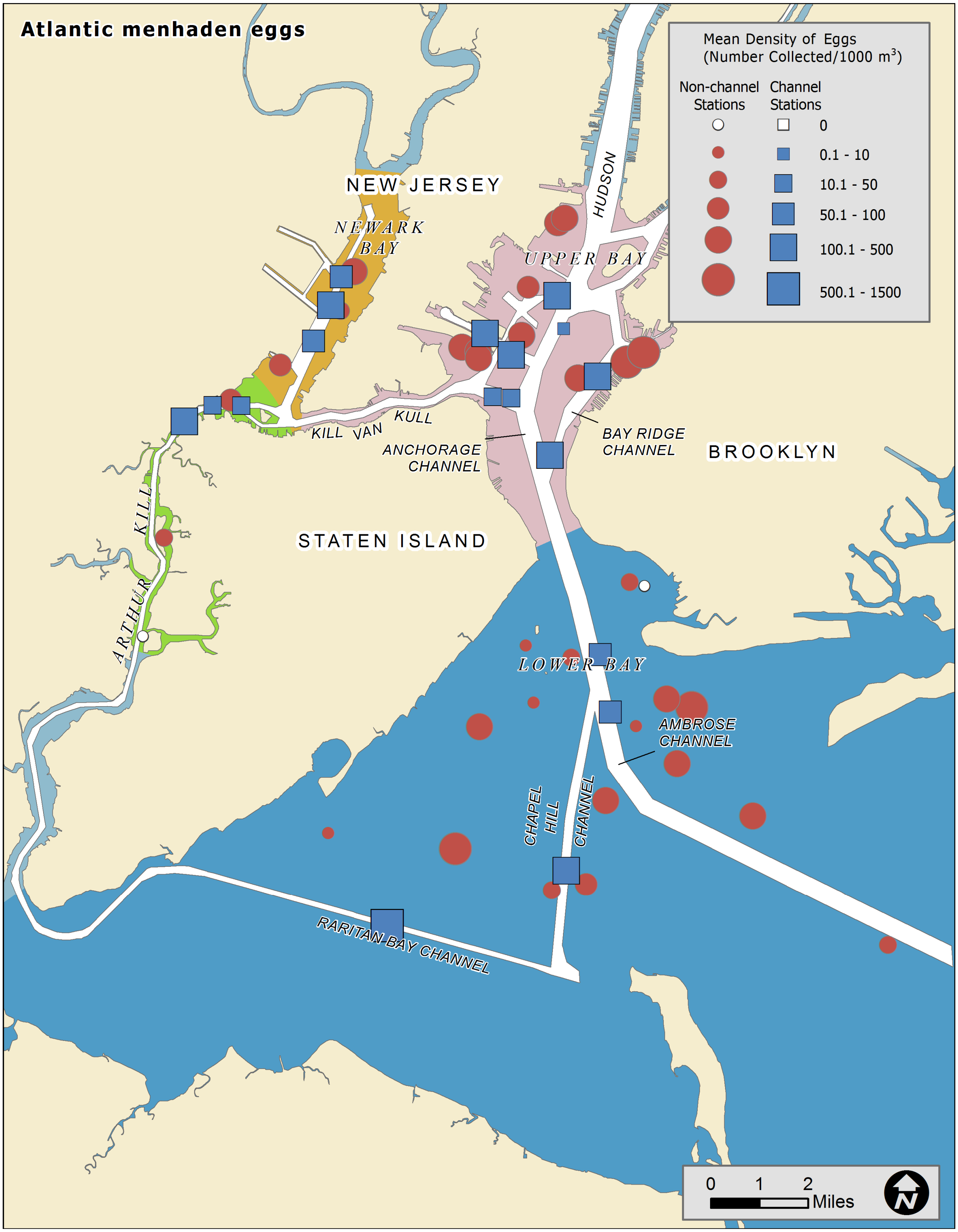

Figure B6. Atlantic menhaden egg abundance and distribution in NY/NJ Harbor 2002 – 2011.

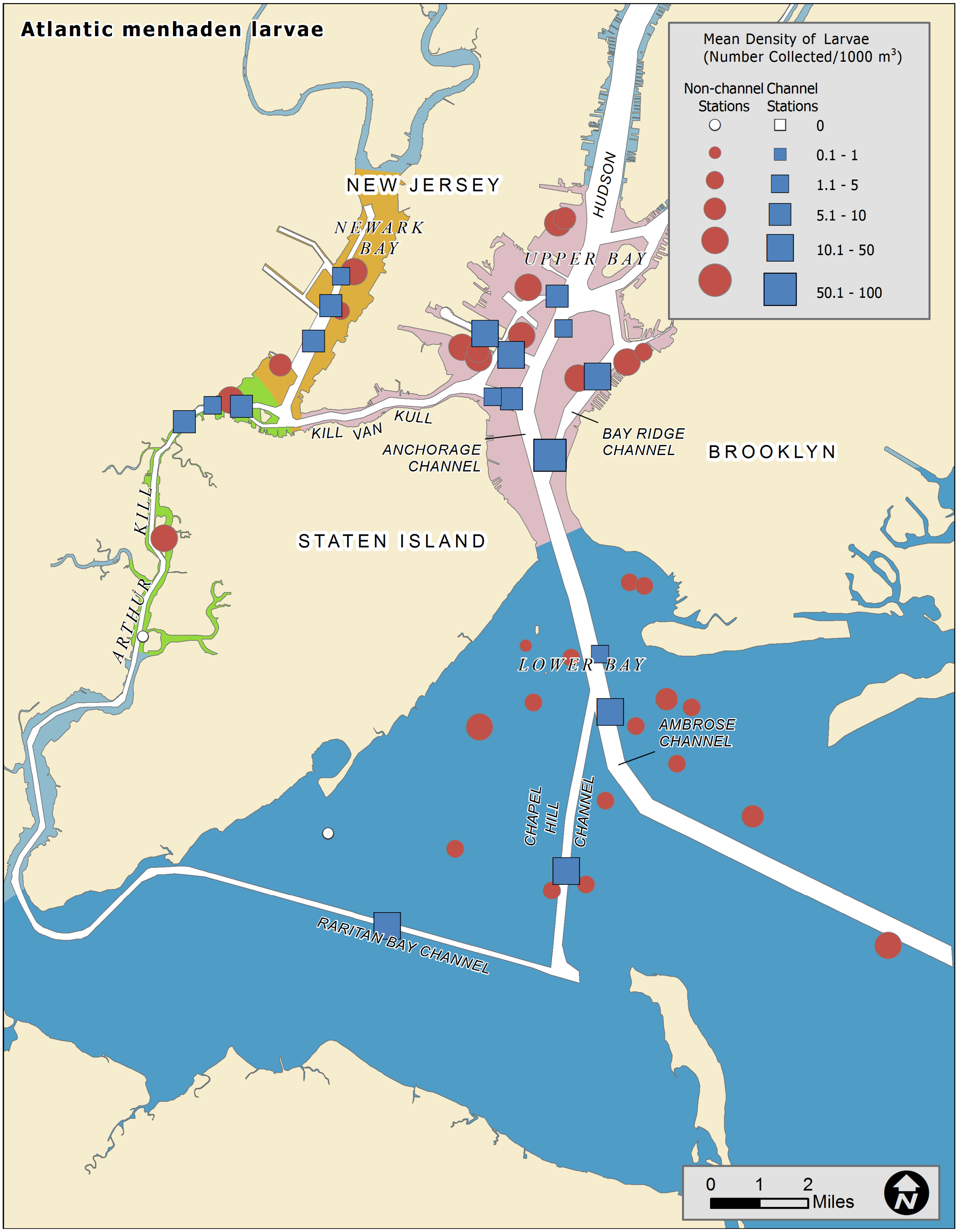

Figure B7. Atlantic menhaden larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

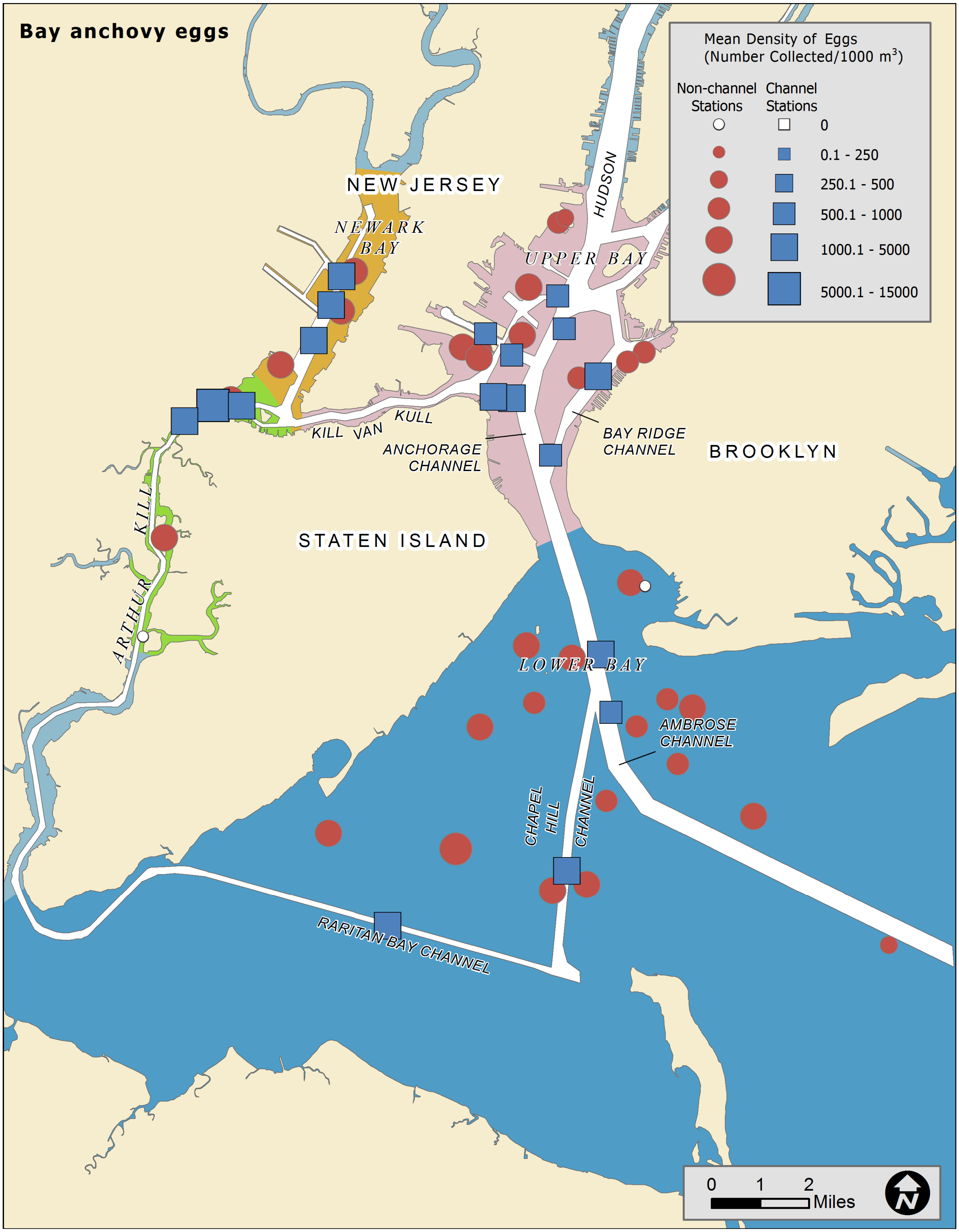

Figure B8. Bay anchovy egg abundance and distribution in NY/NJ Harbor 2002 – 2011.

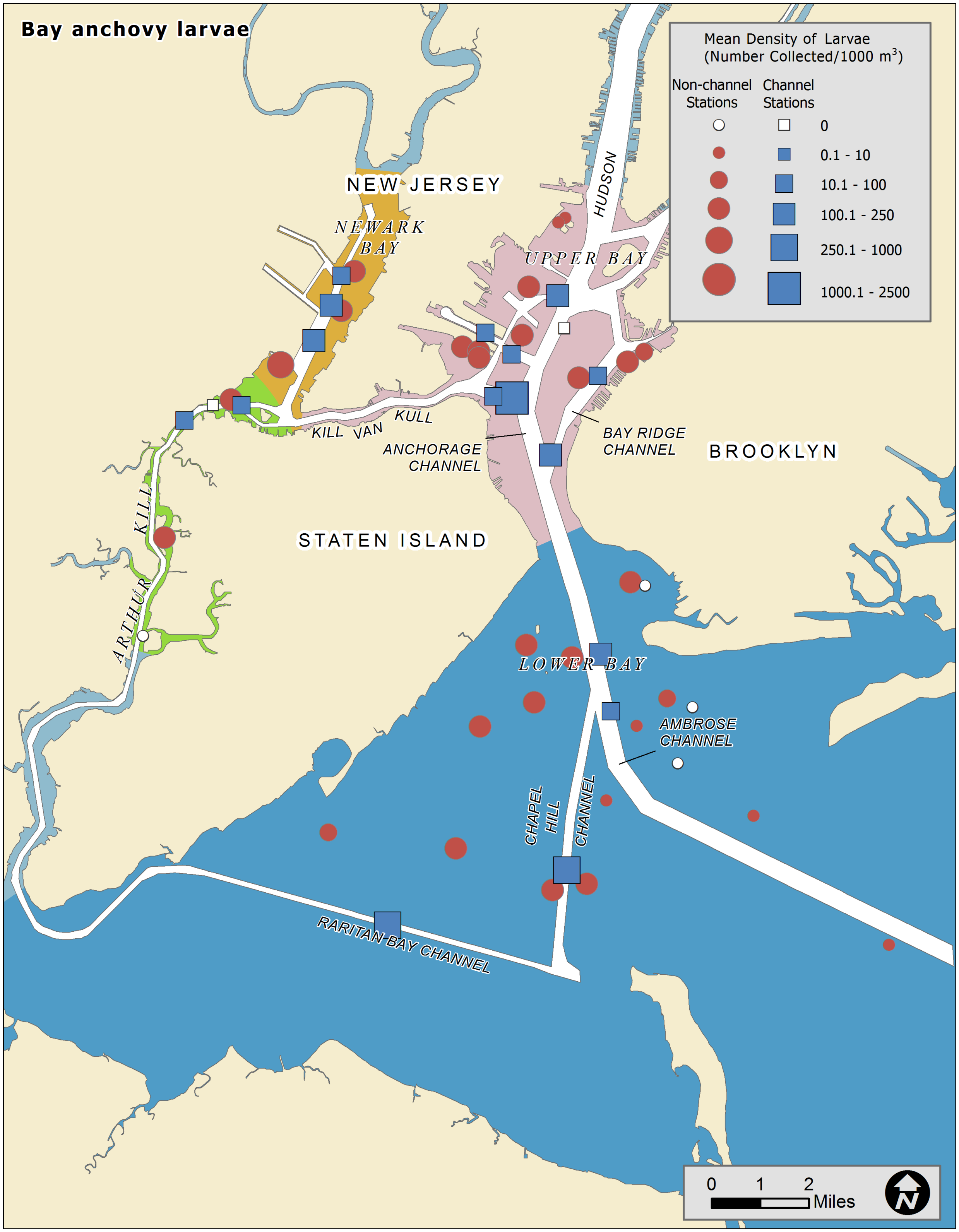

Figure B9. Bay anchovy larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

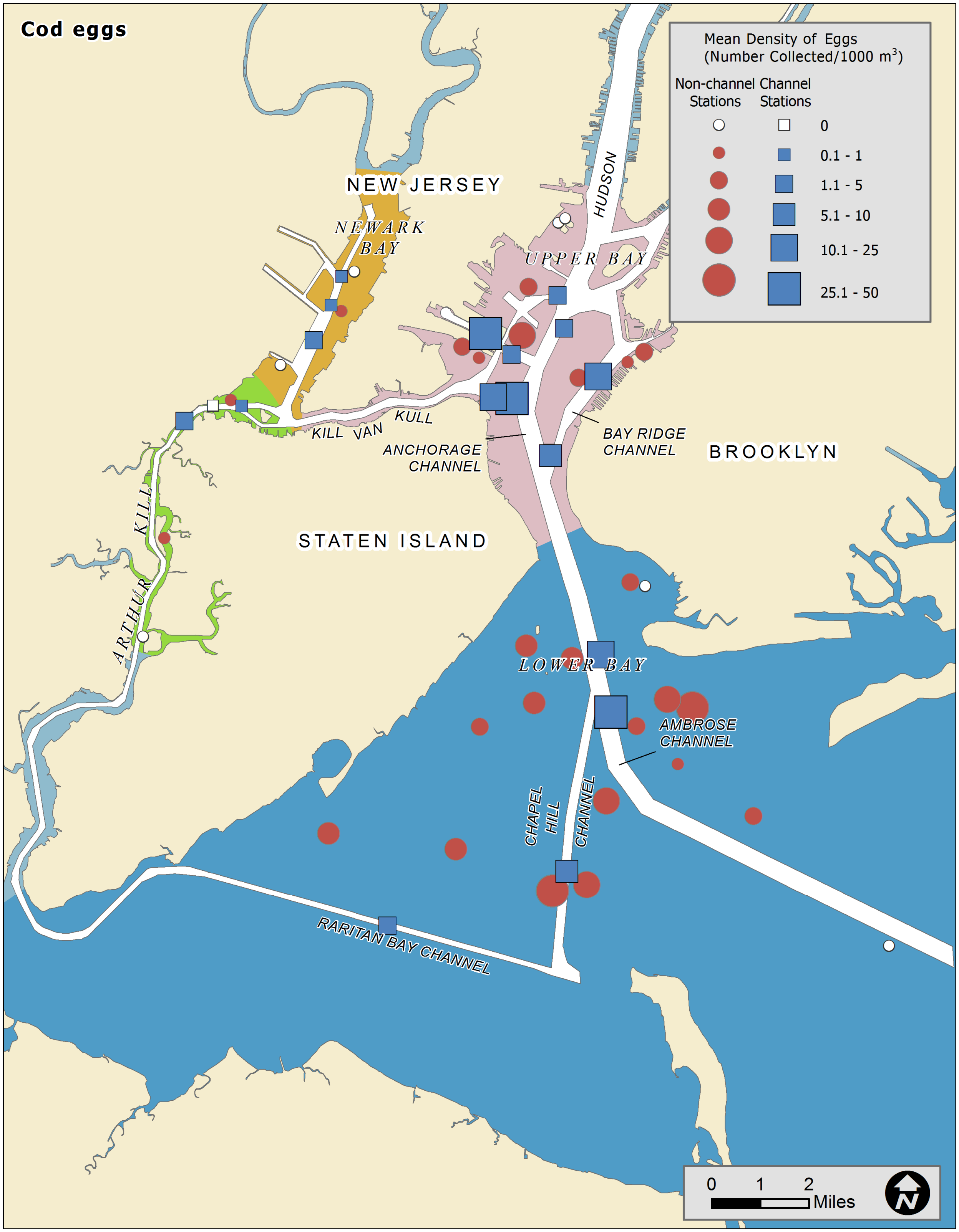

Figure B10. Cod egg abundance and distribution in NY/NJ Harbor 2002 – 2011.

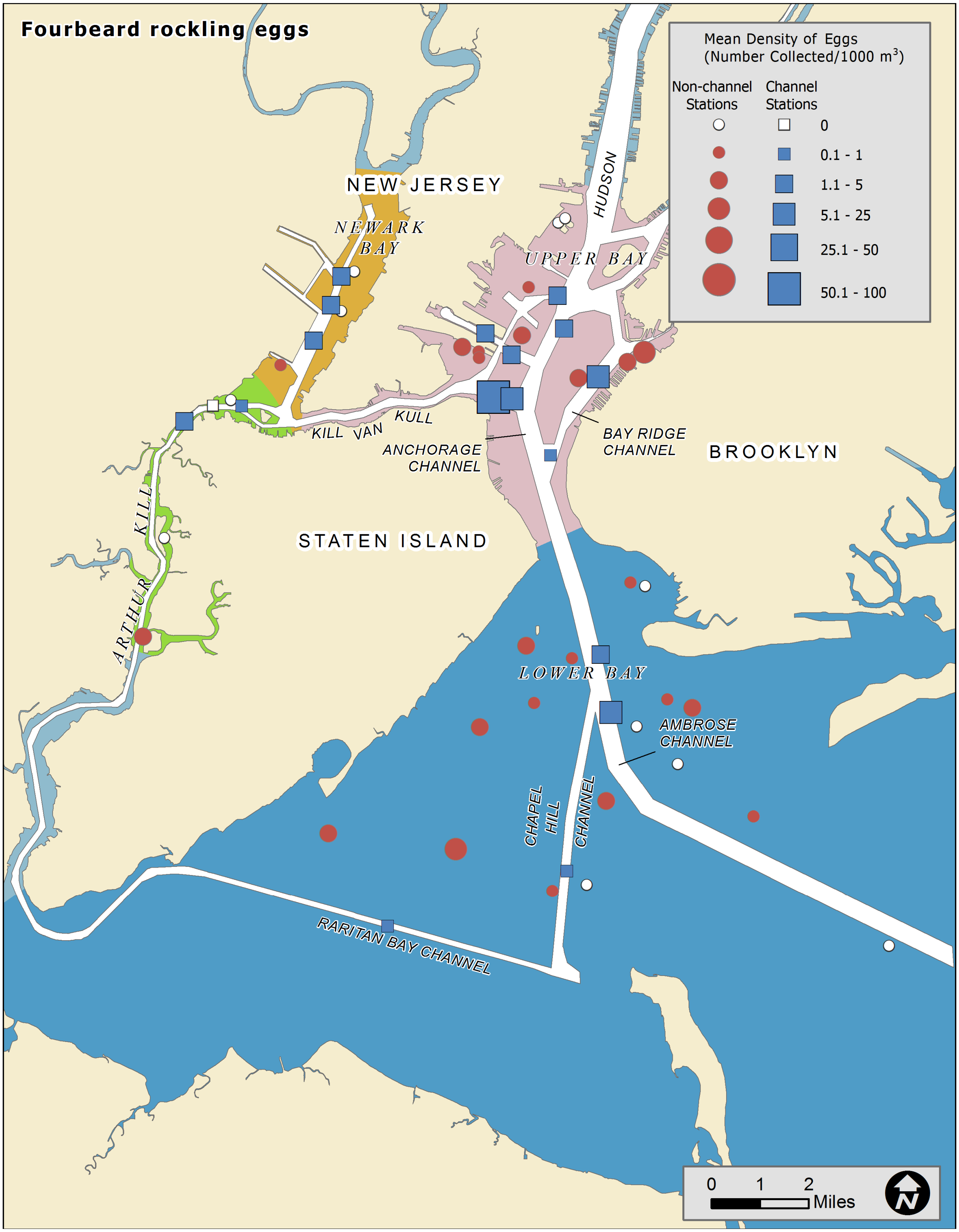

Figure B11. Fourbeard rockling egg abundance and distribution in NY/NJ Harbor 2002 – 2011.

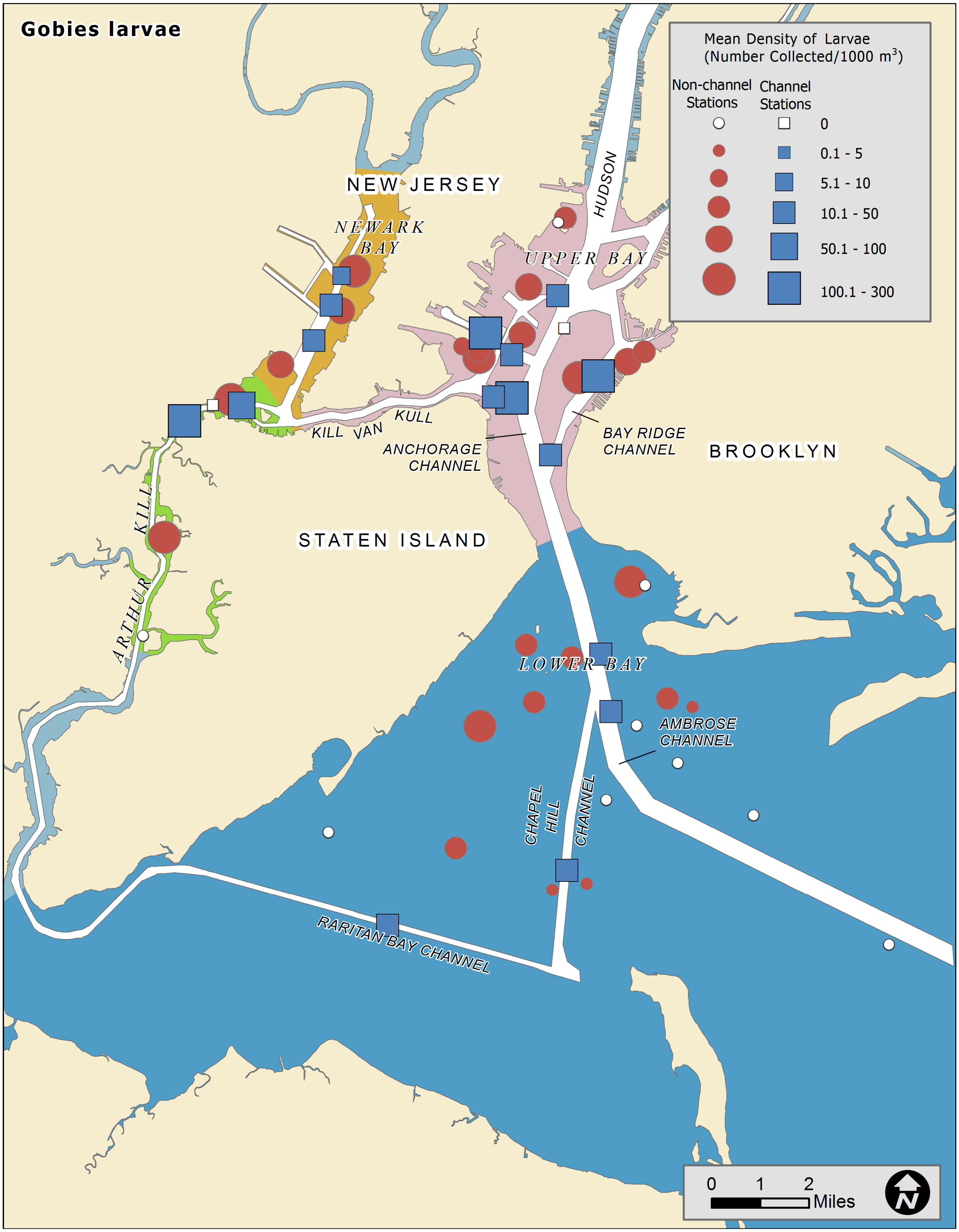

Figure B12. Goby larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

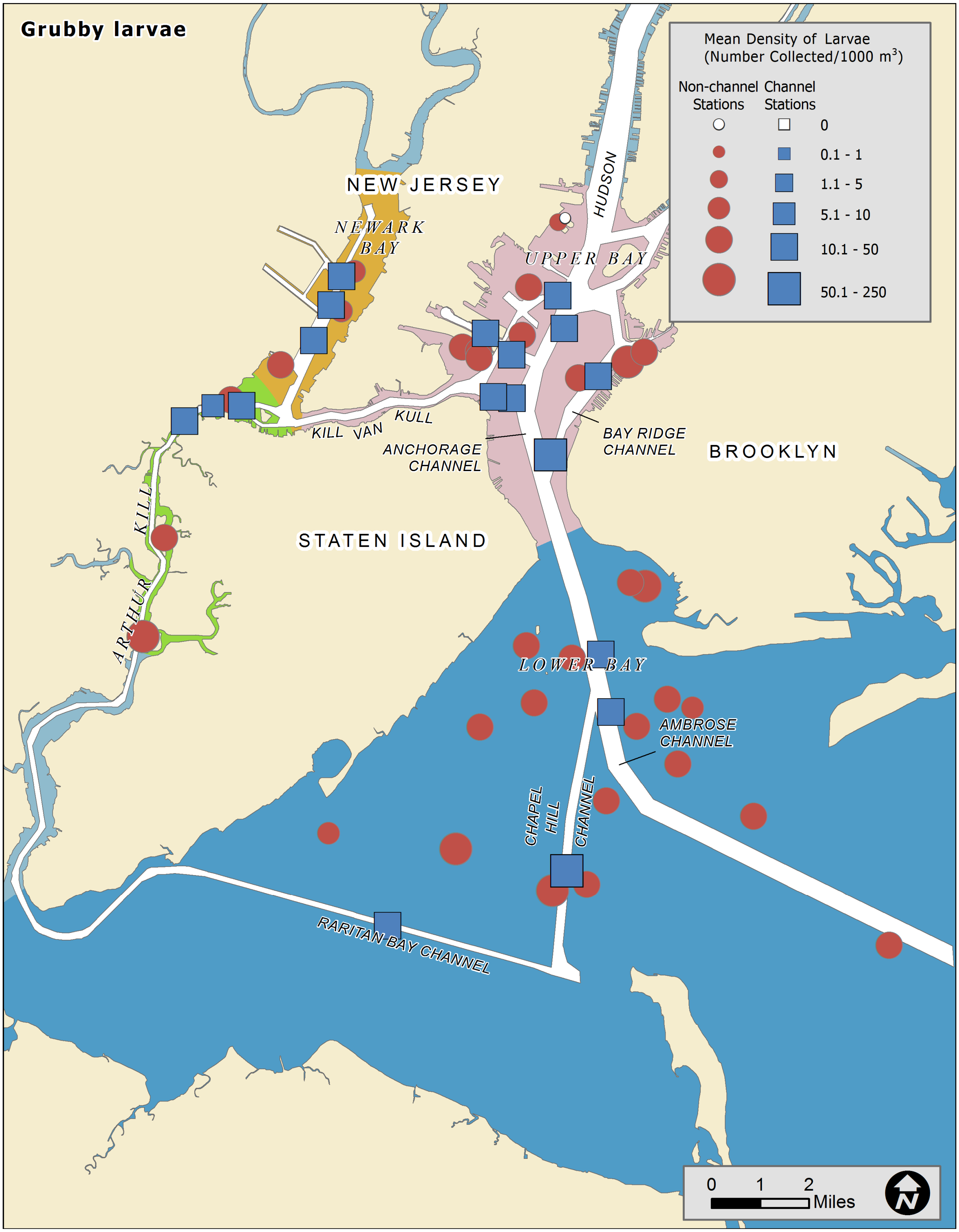

Figure B13. Grubby larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

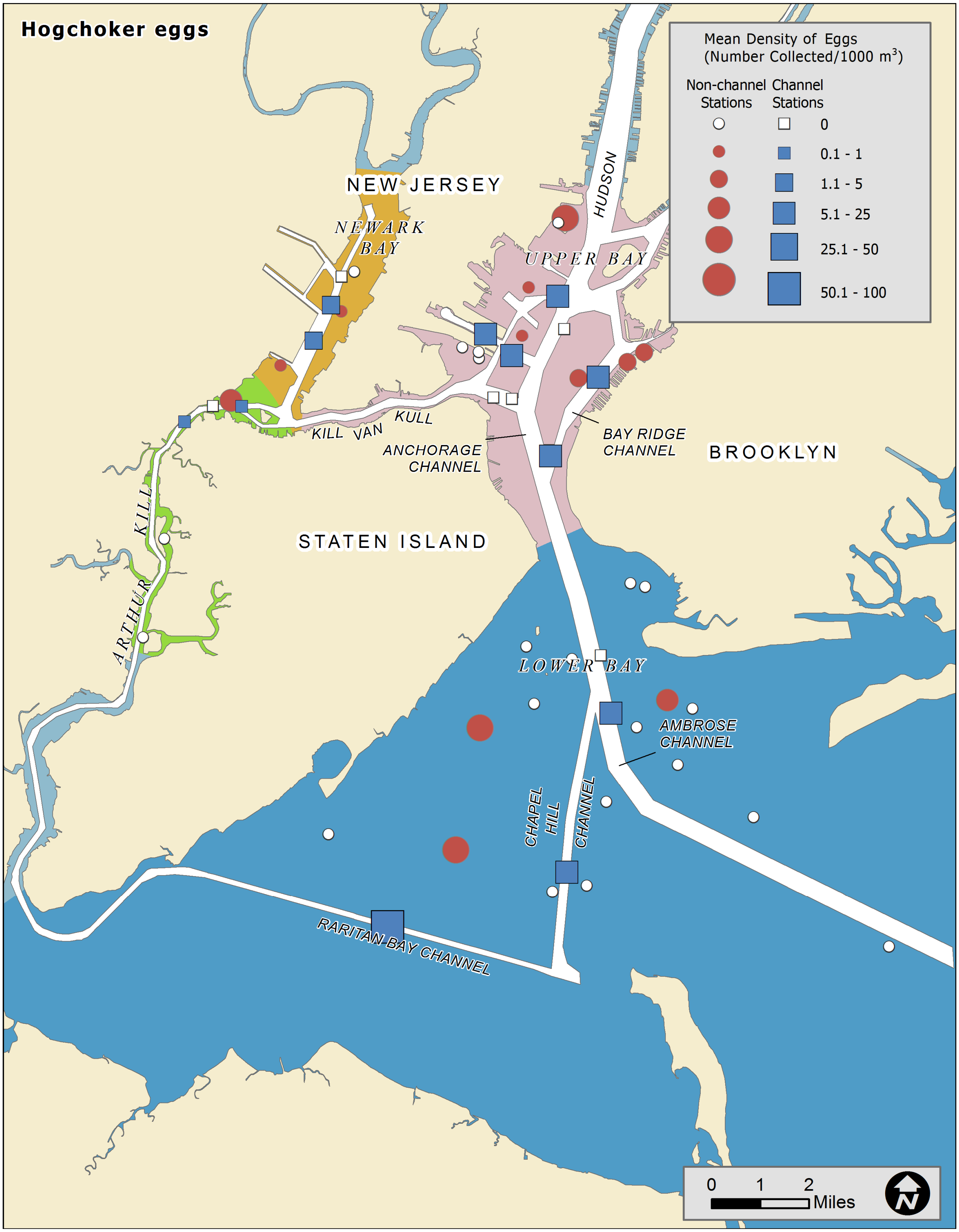

Figure B14. Hogchocker egg abundance and distribution in NY/NJ Harbor 2002 – 2011.

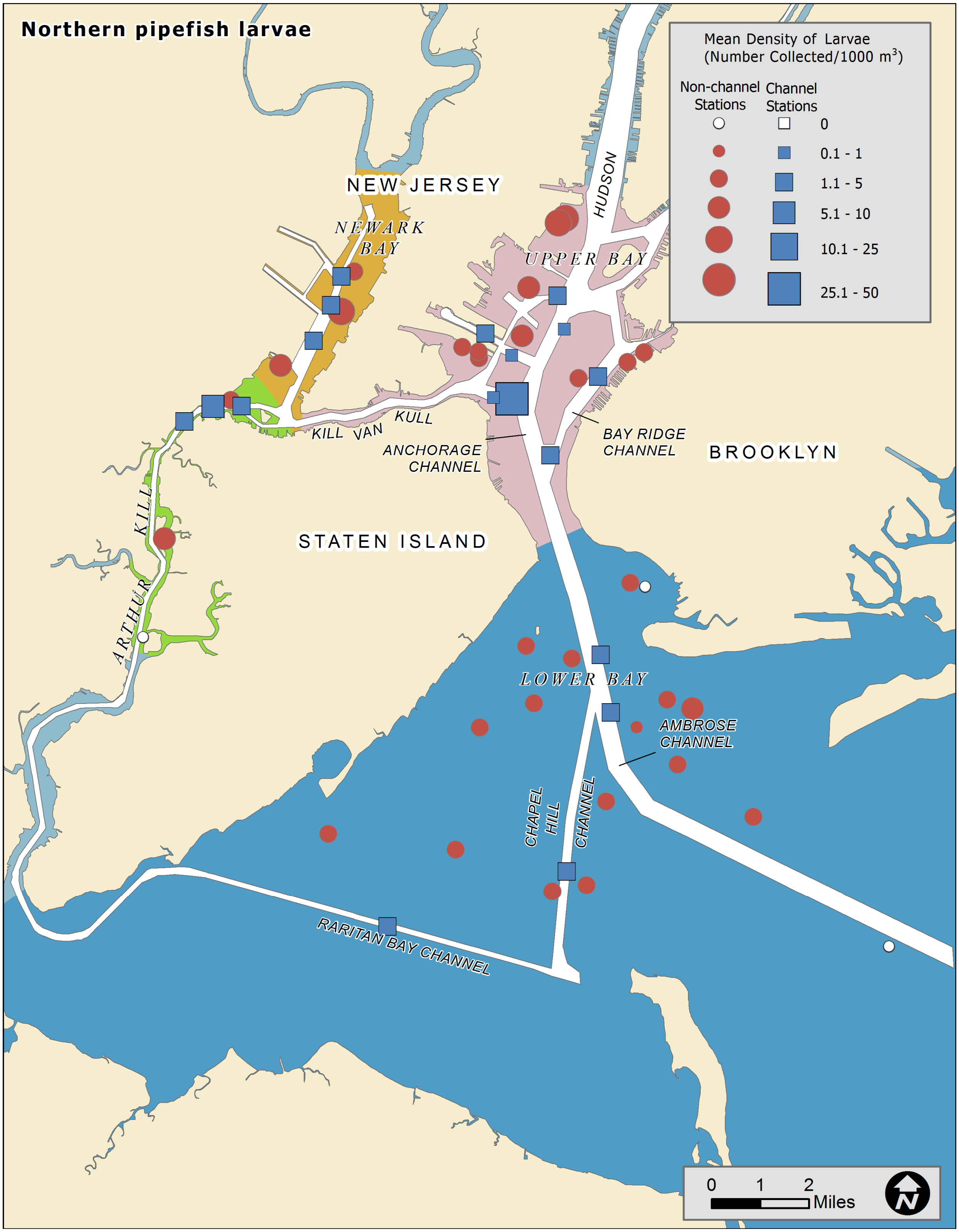

Figure B15. Northern pipefish larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

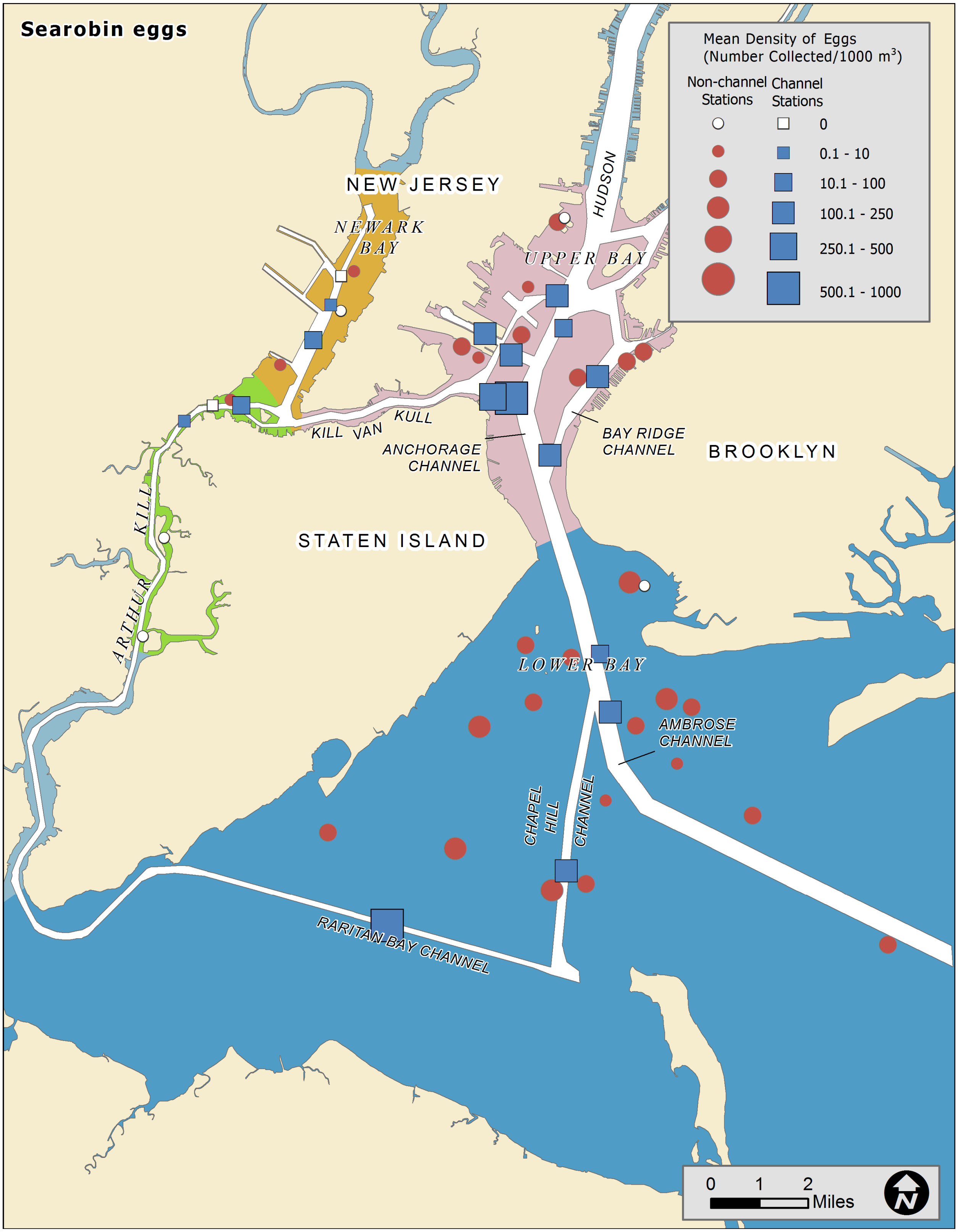

Figure B16. Searobin egg abundance and distribution in NY/NJ Harbor 2002 – 2011.

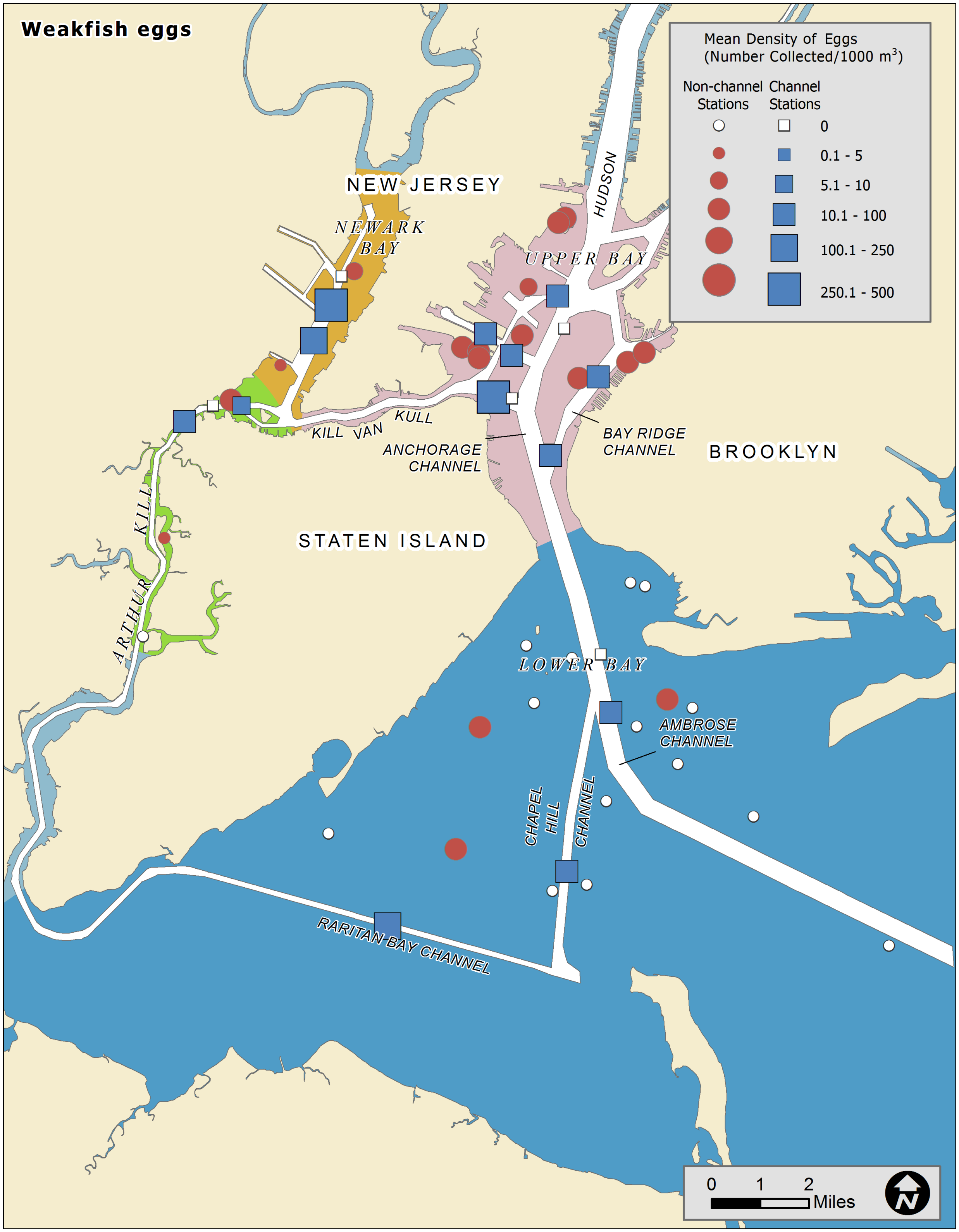

Figure B17. Weakfish egg abundance and distribution in NY/NJ Harbor 2002 – 2011.

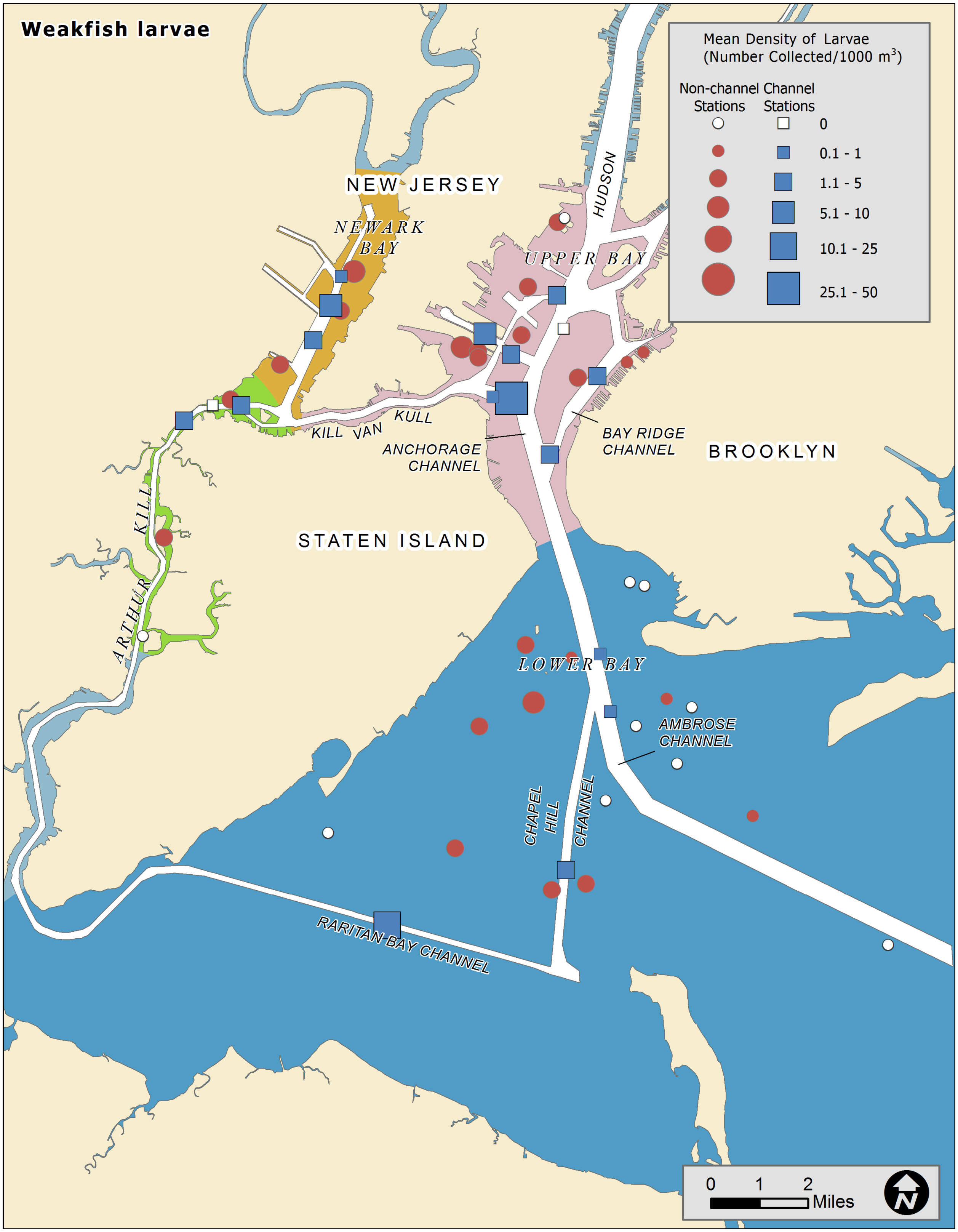

Figure B18. Weakfish larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

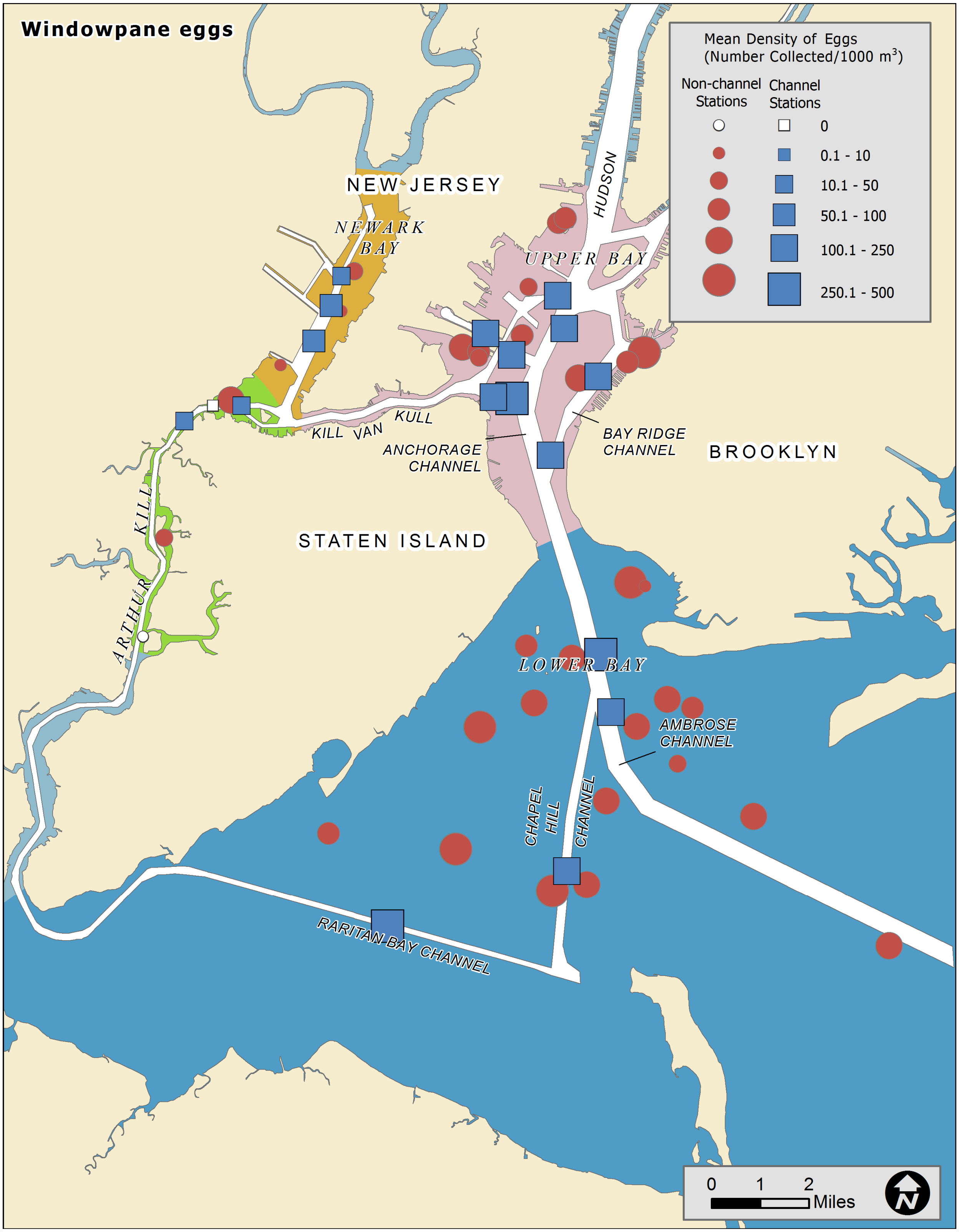

Figure B19. Windowpane egg abundance and distribution in NY/NJ Harbor 2002 – 2011.

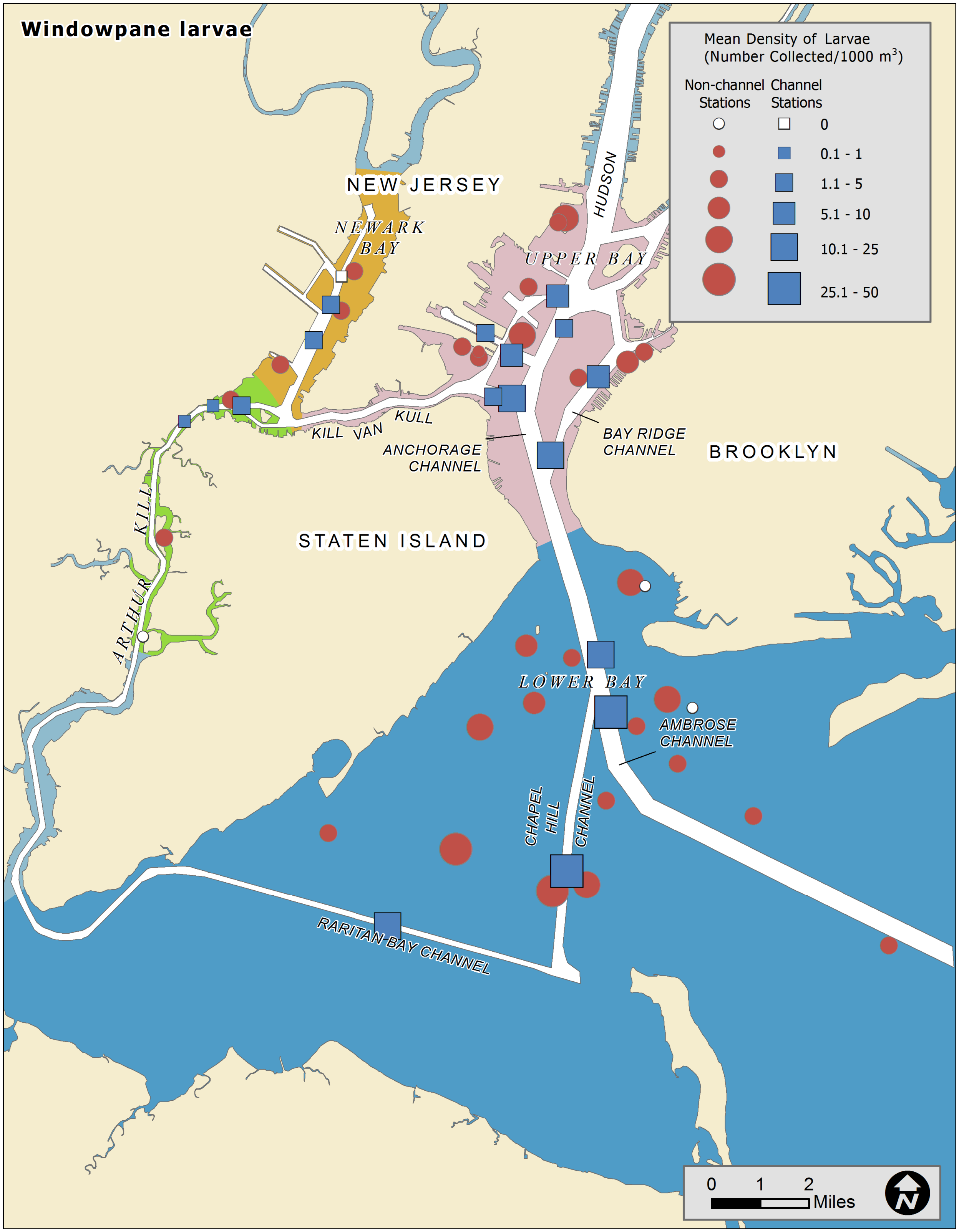

Figure B20. Windowpane larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

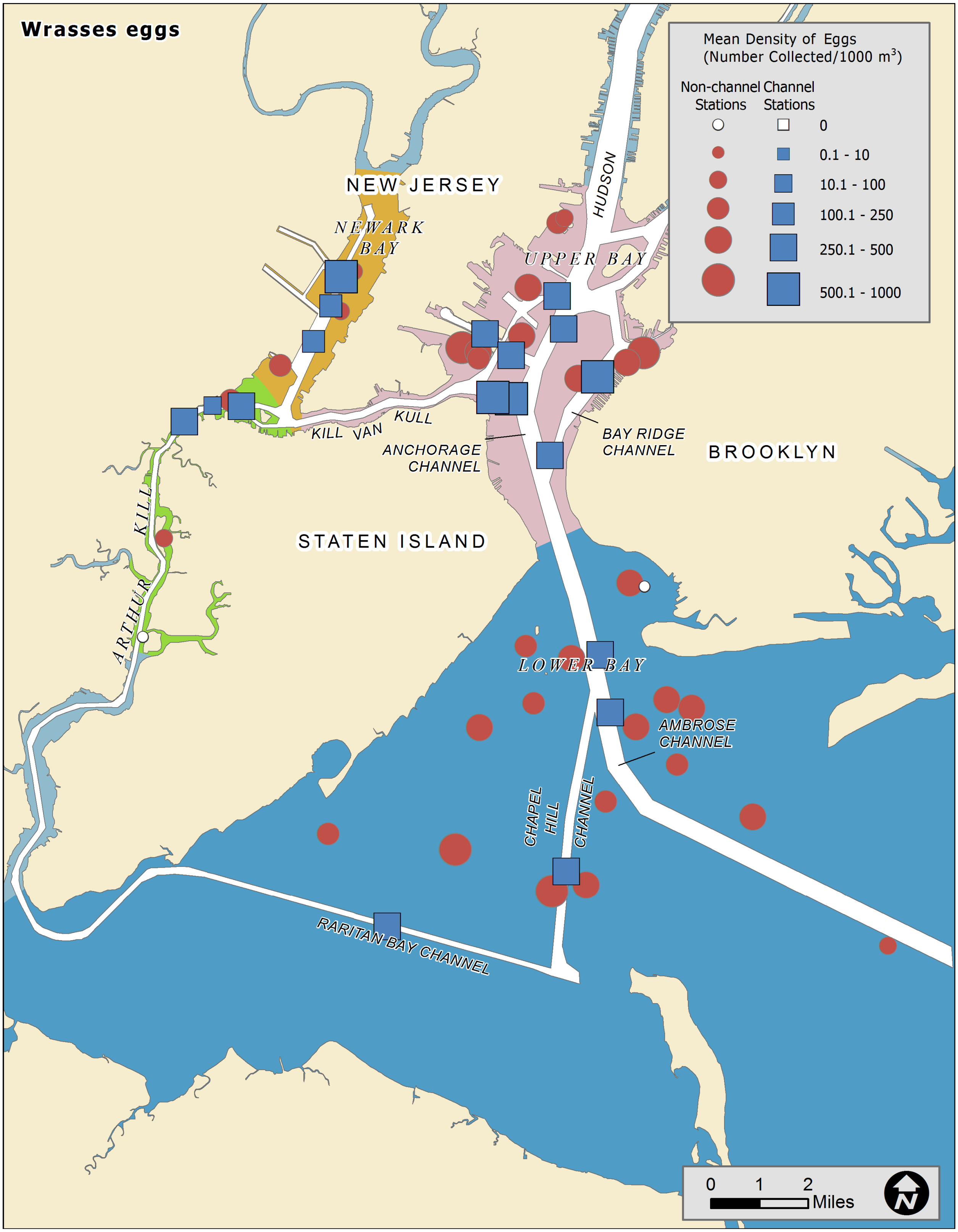

Figure B21. Wrasse egg abundance and distribution in NY/NJ Harbor 2002 – 2011.

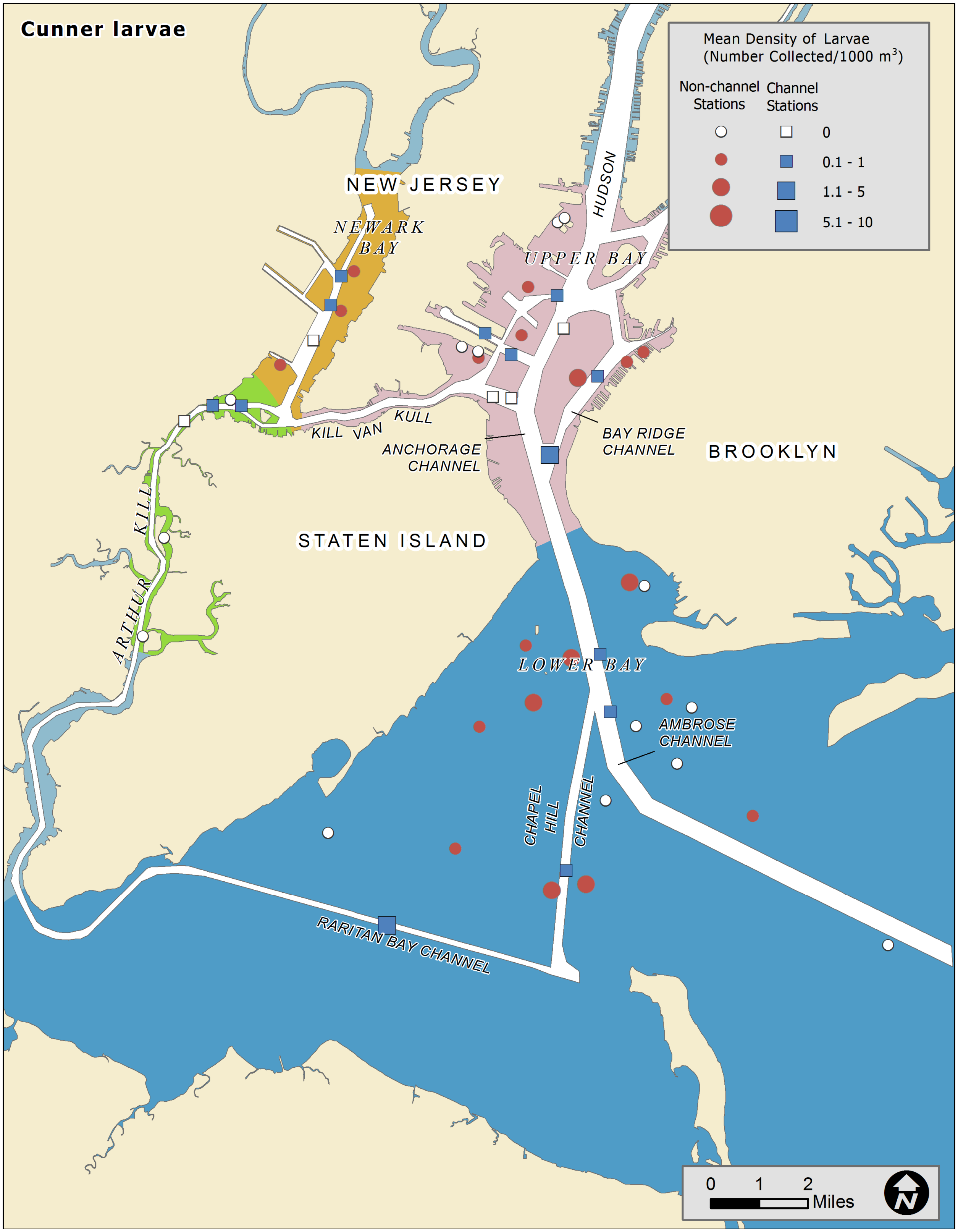

Figure B22. Cunner larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

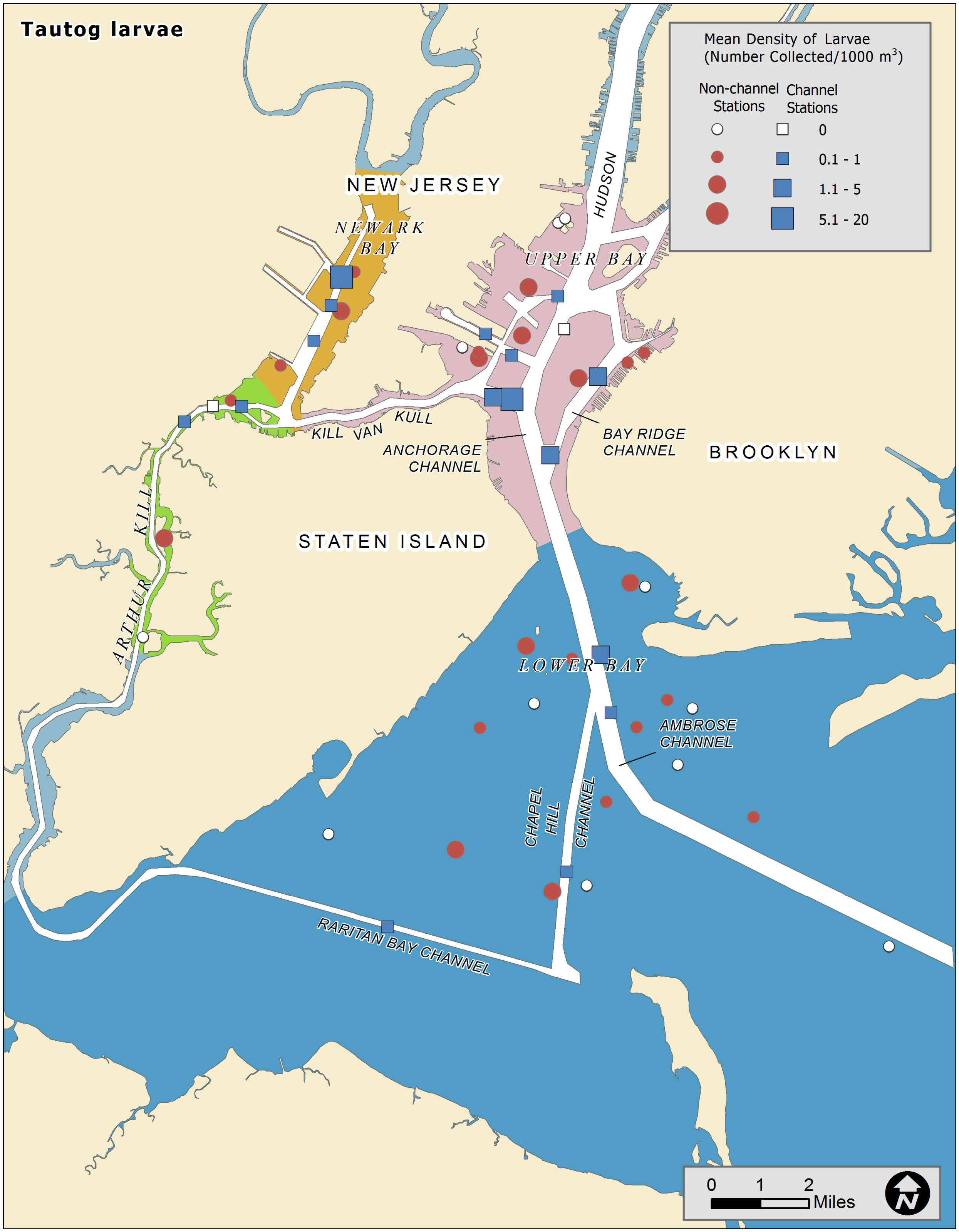

Figure B23. Tautog larvae abundance and distribution in NY/NJ Harbor 2002 – 2011.

NEW YORK AND NEW JERSEY HARBOR DEEPENING PROJECT

DEMERSAL FISH ASSEMBLAGES

OF NEW YORK / NEW JERSEY HARBOR

AND NEAR-SHORE FISH COMMUNITIES OF NEW YORK BIGHT

Part C: Evaluation of State-Managed and Forage Species Habitat Use in NY/NJ Harbor and Near-shore Communities

October 2015

U.S. Army Corps of Engineers

New York District

26 Federal Plaza

New York, New York 10278

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Introduction

This section (Part C) of the report documents state-managed and forage species habitat use in the Harbor and linkages to near-shore habitat for juvenile and adult fish assemblages (i.e., groups of species that frequently co-occur) in the Harbor, which can be used to evaluate future maintenance projects both within the Harbor and in near-shore coastal areas. The focus is on demersal fish species and the ABS bottom trawl data (the methods for which are described in Part A) is the primary data set used in the analysis with references when relevant to existing data. The abundance and distributions of the following important forage and state-managed species are examined for patterns of habitat use within the Harbor and connections to near-shore habitat.

a. Alewife
b. American eel
c. American sandlance
d. American shad
e. Atlantic croaker
f. Atlantic menhaden
g. Atlantic silverside
h. Atlantic tomcod
i. Bay anchovy
j. Blueback herring
k. Spiny dogfish
l. Spot
m. Silver hake
n. Spotted hake
o. Striped bass
p. Tautog
q. White perch

Data Analysis Methods

The seasonal and spatial occurrences of the numerically dominant species are depicted by plotting the mean monthly catch-per-unit-effort (CPUE) for important forage and state-managed species not already examined in the Essential Fish Habitat (EFH) Assessment, which focused on winter flounder and other EFH species (USACE 2013). These forage and state-managed species include: Alewife, American eel, American sandlance, American shad, Atlantic croaker, Atlantic menhaden, Atlantic silverside, Atlantic tomcod, bay anchovy, blueback herring, spiny dogfish, spot, spotted hake, striped bass, tautog, and white perch. Inter-annual variation in species abundances are depicted by plots of mean annual CPUEs.

For those species with sufficient sample sizes (> five individuals/cell) of juveniles and adults, Kruskal-Wallis One-Way Analysis of Variance tests were used to examine whether the distribution of juveniles and adults differed between channel and non-channel stations. The percentages of adults at each station type were used as the dependent variable. Variability in fish abundance over time also was examined using coefficients of variation (CV), which is the ratio of the standard deviation to the mean. This metric can be used as a measure of population stability in an area over multiple years, for instance species with large values have less stable occupancy patterns than those with lower values (Hurst *et al.* 2004). Variation was also calculated across months to estimate seasonal stability for the more abundant fish species.

The species composition of demersal fish communities in the Harbor was compared to fish species collected in nearby near-shore (Rockaway Borrow Area and Shinnecock) and surf zone (northern New Jersey) habitats. Sampling in near-shore habitat was conducted for these coastal projects with bottom trawls and a beach seine was used to sample the northern New Jersey surf zone habitat. The species lists are provided as a record of presence/absence for each location.

Results

CHANNEL OCCUPANCY BY AGE (ADULTS VS. JUVENILES)

There were sufficient numbers of both juvenile and adult white perch in Arthur Kill/Newark Bay, Atlantic silversides in Lower Bay, and alewife and bay anchovies throughout the Harbor to test whether use of channel locations differed by age classes. Adults and juveniles did not differ in abundance between channel and non-channel locations for any of these species. White perch distributions in Arthur Kill/Newark Bay did not differ between juveniles and adults (Mann-Whitney U = 52.0, $p > 0.05$). Likewise, Atlantic silverside distributions at Lower Bay channel and non-channel stations did not differ between adults and juveniles ($F = 0.05$, $p > 0.8$). In the spring, bay anchovy distributions did not differ between channel and non-channel stations based on age (adult vs. year-1 sub-adult) ($F = 0.1$, $p > 0.7$). Approximately 50% of both adult and juvenile alewife were collected from channel stations in the spring in all Harbor areas ($p > 0.3$).

SEASONAL AND ANNUAL ABUNDANCE PATTERNS

Although this chapter concentrates on non-EFH species because EFH species in the Harbor were examined in a previous report (EFH Assessment Part I), the inter-annual and monthly variation in abundances for EFH species are included here for comparative purposes. Variation in monthly CPUE of individual species (Figure C1) indicate that some fish species occurred in the Harbor for short durations, with distinct monthly peaks, for example in March (American shad), April and May (spotted hake), and May (Atlantic herring). Other fish exhibited less monthly variation in abundance patterns, with the lowest monthly variation in abundance estimated for two flatfish, windowpane and winter flounder (Table C1). The average monthly CPUE by fish species are listed for Arthur Kill/Newark Bay (Table C2), Upper Bay (Table C3) and Lower Bay (Table C4).

Annual fluctuations in total abundances are depicted for the more common species (Figure C2, Table C1). Species with highly variable annual abundances include American sandlance (CV = 208%), red hake (CV = 170%), Atlantic silversides (CV = 145%), and Atlantic tomcod (CV = 131%), whereas annual abundances of winter flounder (CV = 35%) and striped bass (CV = 55%) were relatively consistent (Table C1). There was no indication of long-term trends (either increasing or decreasing) in abundance for any species; however, the nine-year duration of the time series is relatively short for detecting this type of temporal pattern. A previous study of mesohaline fish community composition in the Hudson River found inter-annual variation in species composition was related to river flow (Hurst *et al.* 2004). However, this relationship was restricted to summer flows and fall fish collections. ABS sampling was not conducted in the fall and there were no significant correlations between Hudson River flow and winter/spring annual abundances of any species examined.

CONNECTIVITY BETWEEN HARBOR AND NEAR-SHORE FISH COMMUNITIES

The majority of the demersal fish species collected in the Harbor during the nine years of ABS sampling (Table C5) were also collected in either near-shore areas off the south shore of Long Island (USACE 2008a and 2008b) or in the surf zone of northern New Jersey (Wilber *et al.* 2003). Differences in average fish size between Harbor and near-shore samples are apparent for some species (Table C6). For instance, average sizes of blueback herring, alewife, black sea bass, striped bass, windowpane, and winter flounder are considerably smaller in the Harbor than in near-shore habitat because small juveniles of these species are more common in the estuary. Alternatively, larger adults of American shad, Atlantic menhaden, winter skate, red hake, and spotted hake were more common in the Harbor than in near-shore habitat.

HARBOR DISTRIBUTIONS BY SPECIES

Alewife

Alewife are an anadromous herring 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. Alewife move through the Harbor in February and March on their spawning migrations and adults pass through the Harbor after spawning. Juveniles and sub-adults often follow the migrations through the Harbor. Young-of-the-year (YOY) alewife move down river into the Harbor and coastal estuaries in the fall. In the Harbor, alewife abundances peaked in February, declining throughout the spring with only a few alewife captured in June (Figure C1). Inter-annual variation in alewife abundance was moderate (CV = 101%). Abundances were highest in 2006, 2008 and 2009 (Figure C2). These years did not coincide with any temperature or river discharge patterns. Relatively high abundances may have been due to sampling coinciding with spawning runs. Alewife an obligate estuarine-dependent species were common during winter and spring in all Harbor regions at both channel and non-channel stations (Figure C3). 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.

American eel

American eel spend their juvenile stage in freshwater and near-shore habitat and migrate to the Sargasso Sea as adults to spawn. As juveniles, they bury in mud and also occur in rocky habitat near the mouths of embayments. In the glass eel stage, American eels are unpigmented post-larvae that drift on incoming tides and are bottom oriented on ebb tides. Glass eels become pigmented upon entering freshwater. Juveniles are nocturnal and bury in mud and sandy sediments during the day. In ABS sampling, American eels were collected primarily in April, May, and June (Figure C1) and was most abundant in 2002 (Figure C2). This temporal variation was moderate compared to other species examined (Table C1). American eel in low CPUEs were present primarily in the Arthur Kill and Newark Bay region during spring, however a few were also found in this region during winter. A few were found in the Upper Bay and Lower Bay during spring as well (Figure C4).

American sandlance

American sandlance are an important prey species for commercial and recreational fisheries. In the Harbor, sandlance abundances were highest in January and February (Figure C1) and this species had high inter-annual variation in abundance (208%, Table C1), which was due to no collections until 2008 and then very high abundances in 2010 (Figure C2). American sandlance, a facultative estuarine-dependent species, were primarily collected in the Lower Bay at non-channel stations during winter and spring (Figure C5). They were also collected at Upper Bay non-channel stations during spring.

American shad

American shad live at sea as sub-adults and adults and make spawning runs through the Harbor to spawn in freshwater habitat during the spring, with a strong peak in abundance in March (Figure C1). American shad abundances were highest in 2006, which corresponded to unusually low river discharge in March (Figure C2). American shad were collected throughout the Harbor at channel and non-channel stations during winter and spring but were more common in Lower Bay and Upper Bay channel stations during winter and non-channel areas of the Arthur Kill during winter and spring (Figure C6).

Atlantic croaker

Atlantic croaker is a demersal species that occurs over sandy and muddy habitat. It feeds upon polychaetes, crustaceans, mollusks and small fish and is fed upon by larger fish such as bluefish, weakfish, and striped bass. Within the Harbor, Atlantic croaker were collected primarily in January and were not collected in the spring (Figure C1). Abundances were relatively high in 2003 and 2006 (Figure C2), with an overall inter-annual variation CV = 154% (Table C1). Atlantic croaker in low CPUEs were found primarily during winter in channel areas of the Upper Bay and Arthur Kill/Newark Bay region with very few collected at Lower Bay channel stations during winter (Figure C7).

Atlantic menhaden

Atlantic menhaden are a prey and schooling species that support an important commercial fishery. Atlantic menhaden were present in the Harbor in January and February (Figure C1), primarily as juveniles (Table A3). Atlantic menhaden abundances fluctuated annually (CV = 120%; Table C1) with highest collections recorded in 2008 followed by 2010. Atlantic menhaden were distributed throughout the Harbor with highest abundances in the Lower Bay channel stations during spring and winter (Figure C8).

Atlantic silverside

The Atlantic silverside is an important prey species for many commercially and recreationally important species such as striped bass, Atlantic mackerel, and bluefish and is often among the most abundant species in near-shore and estuarine environments. Silverside abundances were higher in January and February (Figure C1) and varied substantially among years (CV = 145%;

Table C1). Like Atlantic menhaden, the highest abundances were observed in 2008 and 2010. Although tolerant of a wide salinity range, silversides were concentrated in the higher salinity Lower Bay area of the Harbor at non-channel stations during winter (Figure C9).

Atlantic tomcod

Atlantic tomcod are a bottom feeding fish that consume small crustaceans and polychaetes. They are fed upon by predaceous fish such as striped bass and bluefish. Atlantic tomcod were collected in the Harbor in May and June (Figure C1) and were present during most years (Figure C2). Atlantic tomcod can tolerate salinities from freshwater to seawater, but occur in highest abundances in low salinity estuarine environments. Within the Harbor, Atlantic tomcod abundances were highest in the Upper Bay during spring in non-channel areas (Figure C10). They were also collected in higher CPUEs at channel stations in Newark Bay during winter and spring and a very few were collected in the Arthur Kill and Lower Bay.

Bay anchovy

Bay anchovy, the most abundant demersal fish in the Harbor, is ecologically important because of its trophic relationship to other fish within the estuary. Bay anchovies feed primarily on zooplankton, such as fish larvae, and thus may affect recruitment success of other fish species and it is a critical food resource for larger fish predators such as bluefish, weakfish, and striped bass. Bay anchovy were most abundant in the Harbor in May and June (Figure C1) and peaked in abundance in 2006 and 2008 (Figure C2). Few bay anchovy, a facultative estuarine-dependent species, were collected in the Harbor during winter, however collections increased substantially during spring in all Harbor regions (Figure C11). The highest collections occurred in non-channel areas of the Upper Bay followed by non-channel areas of Newark Bay and Lower Bay. They were also collected in lower amounts in channel areas of the Lower Bay and both areas of the Arthur Kill during spring.

Blueback herring

Blueback herring are anadromous, entering estuaries in the spring, migrating into freshwater habitat to spawn. 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 C1). Also similar to alewife, peak abundance years occurred in 2006 and 2009 (Figure

C2). Blueback herring, an obligate estuarine-dependent species 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 C12).

Silver hake

Silver hake, also known as whiting, are widely distributed and support important commercial fisheries. During ABS sampling in the Harbor, silver hake abundances were highest in January (Figure C1) and annual abundances were highest in 2006 and 2010 (Figure C2), which corresponds to annual abundance trends for red hake. Silver hake were found in all Harbor regions but were collected primarily in Lower Bay channel and non-channel stations during winter and spring (Figure C13).

Spiny dogfish

Spiny dogfish are the target of a commercial fishery and also collected as bycatch in the groundfish fishery. Spiny dogfish are the most abundant and highly migratory coastal shark in the northwest Atlantic and feed on fish, squid, and ctenophores. Both monthly and inter-annual variation in spiny dogfish abundances were relatively high (Table C1) with monthly collections only in January and June (Figure C1) and peak annual collections in 2007 and 2010 (Figure C2). Spiny dogfish were found primarily in Lower Bay channel and non-channel stations during winter and spring (Figure C14).

Spot

Spot is a pelagic, schooling species that feeds upon benthic prey such as bivalves, crustaceans, and detritus. It is preyed upon by larger fish, such as sharks, striped bass, and weakfish. Spot spawn over the outer continental shelf from October to March. Larvae develop offshore and are transported by currents to estuarine inlets where they metamorphose into bottom dwellers and enter estuaries in the winter and early spring. In the Harbor, spot were collected exclusively in January and February (Figure C1) and were collected only in 2002 and 2007 (Figure C2, Table 1). Spot were collected primarily from the Upper Bay during winter and mostly from channel stations (Figure C15). Few were collected in the Arthur Kill and Newark Bay region and none were collected in the Lower Bay.

Spotted hake

Spotted hake are of limited commercial importance marketed as fish meal. Juveniles reside in estuaries and spawning occurs offshore. In the Harbor, peak spotted hake collections occurred in April and May (Figure C1) and annual abundances were highest in 2006 and 2010 (Figure C2), which corresponds to annual abundance trends for red hake and silver hake. Spotted hake were present in all Harbor regions during winter and spring, however, they were less common during winter than in the spring (Figure C16). Spotted hake, a facultative estuarine-dependent species, were collected primarily at channel stations in Lower Bay and Upper Bay during winter but in the spring moved into the Upper Bay and Arthur Kill/Newark Bay channel areas in greater abundances (Figure C16).

Striped bass

Striped bass is an important, recreationally-harvested, anadromous species that uses the Harbor as a juvenile nursery and for over-wintering. Striped bass populations declined in the 1980s due to commercial overfishing and stress from degraded environmental conditions. Recovery of the stock is attributed to fishery closures in the 1990s and currently the species is considered a model for successful fisheries management (Levinton and Waldman 2006). The recovery of striped bass in the Hudson River may have increased predation on blueback herring, alewife, Atlantic tomcod, and white perch (Heimbuch 2008). These prey species are among the numerically dominant fish in the Harbor (Table A2). Striped bass abundances were highest during ABS sampling in the Harbor in January, declining throughout the spring to few fish present in June (Figure C1). Striped bass were one of the most ubiquitous species collected, with low inter-annual variation (CV = 55%) in abundance (Table C1). Winter striped bass abundances were concentrated in channel stations of the Arthur Kill and Newark Bay and secondarily in Upper Bay (Figure C17). In the spring, abundances were lower and more localize at both channel and non-channel stations in Arthur Kill/Newark Bay and Upper Bay. One of the more common obligate estuarine-dependent species, very few striped bass were collected in the Lower Bay region.

Tautog

Tautog occur in shallow habitat where they feed on blue mussels in the intertidal zone and at depths ranging up to 18 meters. Tautog spawn inshore and at the mouths of estuaries and embayments. Juveniles occur in shallow habitat and move to deeper areas as they mature. Adults inhabit areas with structure, such as seagrass beds, rocks, shellfish beds, pilings, and jetties. Tautog were collected from all Harbor regions at channel and non-channel stations, however, mean CPUEs were low with the highest occurring in the Upper Bay during winter and spring (Figure C18). Tautog were collected during all months of sampling but peaked in abundance in April (Figure C2) and Tautog were collected in all years, which resulted in relatively low CVs for both monthly and inter-annual variation (Table C1).

White Perch

White perch inhabit fresh and brackish waters and feed on small fish, insects, fish eggs and larvae as adults and zooplankton as juveniles. Adults spawn in fresh water habitat and juveniles move downstream to estuarine habitat as they grow, overwintering in channels. One of the more common obligate estuarine-dependent species, white perch were the second most abundant species collected during the ABS but were primarily collected in the Arthur Kill and Newark Bay regions of the Harbor during winter and most were collected at channel stations (Figure C19). Few white perch were collected in the Arthur Kill and Newark Bay during spring.

Discussion

The species discussed in Part C are important primarily as forage species (alewife, Atlantic silverside, Atlantic tomcod, bay anchovy, and blueback herring), recreational fisheries (American shad, silver hake, spotted hake, striped bass, and tautog), or commercial fisheries (American shad, Atlantic menhaden and silver hake). Striped bass, American shad, alewife, and blueback herring are present primarily as YOY and yearlings during late summer through spring and use the Harbor as a nursery area for early juvenile development. Adults of these species are present during spawning migrations from coastal waters to freshwater during early spring and on their return to coastal waters in late spring. The adults of these species are infrequently collected in the bottom trawl due to their migrations primarily through pelagic waters. Two other herring species frequently encountered in bottom trawl collections include Atlantic menhaden and Atlantic herring.

The inter-annual and monthly variation in abundances, variation in mean monthly CPUE abundances of individual species indicate that some fish species occurred in the Harbor for short durations, with distinct monthly peaks, for example in March (American shad), April and May (spotted hake), and May (Atlantic herring). Other fish exhibited less monthly variation in abundance patterns, with the lowest monthly variation in abundance for windowpane and winter flounder.

Annual fluctuations in total abundances include species with highly variable annual abundances include American sandlance (CV = 208%), red hake (CV = 170%), Atlantic silversides (CV = 145%), and Atlantic tomcod (CV = 131%), whereas annual abundances of winter flounder (CV = 35%) and striped bass (CV = 55%) were relatively consistent. There was no indication of long-term trends (either increasing or decreasing) in abundance for any species.

The majority of the demersal finfish species collected in the Harbor during the nine years of ABS sampling were also collected in either near-shore areas off the south shore of Long Island (USACE 2008a and 2008b) or in the surf zone of northern New Jersey (Wilber *et al.* 2003). Differences in average fish size between Harbor and near-shore samples are apparent for some species; the average sizes of blueback herring, alewife, black sea bass, striped bass, windowpane, and winter flounder are considerably smaller in the Harbor than in near-shore habitat because small juveniles of these species are more common in the estuary. Alternatively, larger adults of American shad, Atlantic menhaden, winter skate, red hake, and spotted hake were more common in the Harbor than in near-shore habitat.

There were sufficient numbers of both juvenile and adult white perch collected in Arthur Kill/Newark Bay, Atlantic silversides in Lower Bay, and alewife and bay anchovies throughout the Harbor to test whether use of channel locations differed by age classes. For these species and areas, the abundances of adults and juveniles did not differ between channel and non-channel locations.

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Tables (Part C)

Table C1. Inter-annual and monthly variation in CPUE for each species estimated by the coefficient of variation (CV).

Common Name	Scientific Name	Inter-annual CV (%)	Monthly CV (%)
Bay anchovy	*Anchoa mitchilli*	125	156
White perch	*Morone americana*	98	121
Spotted hake	*Urophycis regia*	87	88
Alewife**	*Alosa pseudoharengus*	101	77
Striped bass**	*Morone saxatilis*	55	85
Atlantic herring*	*Clupea harengus*	123	164
Blueback herring**	*Alosa aestivalis*	107	70
American sandlance	*Ammodytes americanus*	208	108
Winter flounder*	*Pseudopleuronectes americanus*	35	25
Red hake*	*Urophycis chuss*	170	83
Atlantic silverside	*Menidia menidia*	145	138
Windowpane*	*Scophthalmus aquosus*	97	22
Atlantic tomcod	*Microgadus tomcod*	131	154
American shad**	*Alosa sapidissima*	106	100
Silver hake*	*Merluccius bilinearis*	122	170
Atlantic menhaden**	*Brevoortia tyrannus*	120	91
American eel	*Anguilla rostrata*	121	91
Atlantic croaker	*Micropogonias undulatus*	154	231
Spiny dogfish	*Squalus acanthias*	184	195
Spot	*Leiostomus xanthurus*	286	233
Tautog	*Tautoga onitis*	66	49

* Federally managed (EFH) species
** State managed species of concern

Table C2. Monthly mean CPUE (# fish/10 minute trawl) collected in the Arthur Kill/Newark Bay area during bi-weekly bottom trawl sampling from 2002-2010.

	Jan	Feb	Mar	Apr	May	June
White perch	124.4	61.4	52.9	5.2	0.2	0.0
Striped bass**	27.2	16.0	14.9	7.6	2.0	1.2
Bay anchovy	1.1	0.1	0.0	0.1	49.5	53.7
Spotted hake	1.7	0.4	2.3	37.0	17.5	7.3
Atlantic herring*	0.1	0.0	0.1	2.2	70.0	0.0
Winter flounder*	3.8	4.1	4.5	3.3	1.2	2.9
Alewife**	1.1	0.8	2.6	7.9	1.2	0.0
Red hake*	3.2	1.2	1.9	4.7	0.1	0.0
Blueback herring**	1.2	1.1	2.0	2.1	4.2	0.0
Atlantic silverside	1.0	0.8	0.3	0.1	0.0	0.0
Atlantic tomcod	0.0	0.1	0.4	0.3	1.9	1.4
Windowpane*	0.3	0.3	0.2	0.9	0.3	0.3
Gizzard shad	1.1	0.1	0.1	0.0	0.0	0.0
American shad**	0.1	0.1	0.5	0.7	0.2	0.0
Grubby	0.1	0.4	0.2	0.3	0.0	0.1
Summer flounder*	0.0	0.0	0.0	0.4	0.7	0.7
Smallmouth flounder	0.1	0.1	0.0	0.6	0.1	0.3
Atlantic croaker**	0.5	0.1	0.0	0.0	0.0	0.0
Atlantic menhaden**	0.1	0.0	0.1	0.2	0.1	0.3
Northern pipefish	0.0	0.0	0.1	0.2	0.1	0.2
Silver hake*	0.2	0.1	0.1	0.0	0.0	0.0
American eel	0.0	0.0	0.0	0.1	0.2	0.1
Northern searobin	0.0	0.0	0.0	0.0	0.2	0.3
Cunner	0.1	0.0	0.1	0.1	0.0	0.1
Mean CPUE for all fish	**168.3**	**87.5**	**83.8**	**79.1**	**151.9**	**72.1**
Species richness	**20**	**19**	**19**	**21**	**19**	**15**

* Federally managed (EFH) species
** State managed species of concern

Table C3. Monthly mean CPUE (# fish/10 minute trawl) collected in the Upper Bay during bi-weekly bottom trawl sampling from 2002-2010.

	Jan	Feb	Mar	Apr	May	June
Bay anchovy	1.3	0.1	0.1	4.9	153.1	112.4
Spotted hake	2.7	2.5	5.5	28.0	13.8	4.1
Atlantic herring*	0.3	0.4	0.6	22.1	14.3	0.0
Striped bass**	9.1	3.5	2.5	5.6	1.4	0.0
Blueback herring**	3.3	7.7	1.8	2.8	4.3	0.2
Alewife**	4.0	4.8	2.4	2.4	2.0	0.0
Winter flounder*	3.7	2.7	2.5	4.7	1.7	2.2
Red hake*	3.6	3.5	1.7	6.1	0.5	0.0
Atlantic tomcod	0.1	0.1	0.1	0.2	8.0	11.2
Windowpane*	1.2	0.7	1.0	1.4	1.2	1.5
American shad	0.4	0.6	2.5	0.4	0.2	0.2
White perch	0.9	0.5	0.9	0.6	0.0	0.0
American sandlance	0.2	0.0	0.0	3.5	0.0	0.0
Atlantic silverside	0.3	1.1	0.5	0.0	0.0	0.6
Scup*	0.0	0.0	0.0	0.0	1.1	3.4
Atlantic croaker**	1.7	0.0	0.0	0.0	0.0	0.0
Spot	1.4	0.1	0.0	0.0	0.0	0.0
Summer flounder*	0.1	0.0	0.0	0.3	0.9	1.6
Smallmouth flounder	0.5	0.1	0.3	0.2	0.2	0.1
Little skate*	0.4	0.1	0.1	0.4	0.1	0.0
Silver hake*	0.4	0.2	0.1	0.2	0.0	0.0
Grubby	0.2	0.3	0.2	0.3	0.0	0.0
Weakfish**	0.8	0.0	0.0	0.0	0.0	0.1
Atlantic menhaden**	0.2	0.2	0.1	0.2	0.3	0.1
Cunner	0.1	0.4	0.1	0.2	0.1	0.1
Clearnose skate*	0.5	0.1	0.0	0.1	0.1	0.1
Northern pipefish	0.2	0.2	0.2	0.3	0.1	0.1
Tautog	0.1	0.1	0.1	0.2	0.2	0.2
Striped searobin	0.0	0.0	0.0	0.1	0.4	0.2
Northern searobin	0.0	0.0	0.1	0.3	0.1	0.1
Gizzard shad	0.2	0.0	0.0	0.0	0.0	0.0
Atlantic butterfish*	0.0	0.0	0.0	0.0	0.2	0.3
Silver perch	0.2	0.0	0.0	0.0	0.0	0.0
Mean CPUE for all fish	**38.9**	**30.3**	**23.9**	**86.5**	**206.8**	**141.3**
Species richness	**30**	**24**	**23**	**26**	**24**	**21**

* Federally managed (EFH) species
** State managed species of concern

Table C4. Monthly mean CPUE (# fish/10 minute trawl) collected in the Lower Bay during bi-weekly bottom trawl sampling from 2002-2010.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**
Bay anchovy	12.8	2.1	0.1	0.2	3.9	131.0
Alewife**	0.0	15.3	21.3	12.0	4.5	0.1
American sandlance	0.0	17.3	9.1	6.4	0.2	0.0
Spotted hake	0.8	7.4	2.8	5.5	5.5	12.0
Blueback herring**	0.1	10.1	8.3	3.0	1.6	0.0
Atlantic silverside	0.0	10.5	8.7	0.3	0.0	0.0
Winter flounder*	0.4	2.4	1.1	1.1	2.5	1.7
Atlantic herring*	6.2	1.6	0.3	0.3	0.7	4.5
Silver hake*	0.0	4.1	0.4	0.1	0.1	0.2
Atlantic menhaden**	0.0	1.9	2.3	0.2	0.1	0.1
Red hake*	0.0	2.5	0.4	0.7	0.7	0.3
Smallmouth flounder	0.0	2.1	1.1	0.3	0.2	0.3
Windowpane*	0.3	0.6	0.3	0.7	0.5	0.7
Little skate*	0.0	1.1	0.3	0.3	0.4	0.3
Scup*	1.6	0.0	0.0	0.0	0.0	3.3
American shad	0.0	0.5	0.3	0.6	0.2	0.0
Atlantic butterfish*	1.9	0.0	0.0	0.0	0.8	0.4
Clearnose skate*	0.1	0.8	0.1	0.1	0.1	0.2
Striped searobin	1.0	0.0	0.0	0.0	0.0	1.7
Summer flounder*	0.1	0.2	0.0	0.0	0.2	0.6
Striped bass**	0.0	0.3	0.0	0.0	0.2	0.0
Grubby	0.0	0.2	0.1	0.1	0.0	0.0
Northern pipefish	0.0	0.2	0.1	0.2	0.0	0.0
Mean CPUE of all fish	**25.3**	**81.4**	**57.1**	**32.2**	**22.7**	**157.3**
Species richness	**28**	**19**	**18**	**21**	**19**	**15**

* Federally managed (EFH) species
** State managed species of concern

Table C5. Fish taxa collected in New York / New Jersey Harbor during bottom trawl sampling from 2002-2010 as part of the ABS. Taxa also collected in near-shore (USACE 2008a and 2008b) and surf zone (Wilber *et al.* 2003) habitats are denoted with an x.

Common Name	Scientific Name	Rockaway Borrow Area	Shinnecock Borrow Area	Northern New Jersey surf zone
Shortnose sturgeon	*Acipenser brevirostrum*			
Atlantic sturgeon	*Acipenser oxyrinchus oxyrinchus*		x	
Blueback herring**	*Alosa aestivalis*	x	x	x
Hickory shad	*Alosa mediocris*		x	
Alewife**	*Alosa pseudoharengus*		x	x
American shad**	*Alosa sapidissima*		x	x
American sandlance	*Ammodytes americanus*		x	x
Striped anchovy	*Anchoa hepsetus*	x	x	x
Bay anchovy	*Anchoa mitchilli*	x	x	x
American eel	*Anguilla rostrata*		x	
Fourspine stickleback	*Apeltes quadracus*			x
Sheepshead	*Archosargus probatocephalus*			
Northern stargazer	*Astroscopus guttatus*			x
Atlantic menhaden**	*Brevoortia tyrannus*	x	x	x
Crevalle jack	*Caranx hippos*			x
Black sea bass*	*Centropristis striata*	x	x	
Striped burrfish	*Chilomycterus schoepfii*	x		
Atlantic herring*	*Clupea harengus*	x	x	x
Conger eel	*Conger oceanicus*		x	
Weakfish	*Cynoscion regalis*	x	x	x
Silver perch	*Diapterus rhombeus*			
Gizzard shad	*Dorosoma cepedianum*			x
Four beard rockling	*Enchelyopus cimbrius*			
Smallmouth flounder	*Etropus microstomus*	x	x	x
Mummichog	*Fundulus heteroclitus*			
Striped killifish	*Fundulus majalis*			
Atlantic cod	*Gadus morhua*		x	
Threespine stickleback	*Gasterosteus aculeatus*		x	
Naked goby	*Gobiosoma bosci*		x	
Seaboard goby	*Gobiosoma ginsburgi*			
Lined seahorse	*Hippocampus erectus*		x	x
Fourspot flounder	*Hippoglossina oblonga*	x		
Feather blenny	*Hypsoblennius hentzi*			
Spot	*Leiostomus xanthurus*	x	x	x
Atlantic silverside	*Menidia menidia*		x	x
Northern kingfish	*Menticirrhus saxatilis*	x	x	x
Silver hake*	*Merluccius bilinearis*	x	x	

Atlantic tomcod	*Microgadus tomcod*			
Atlantic croaker**	*Micropogonias undulatus*	x	x	x
White perch	*Morone americana*			x
Striped bass**	*Morone saxatilis*		x	x
Striped mullet	*Mugil cephalus*			
White mullet	*Mugil curema*			x
Smooth dogfish	*Mustelus canis*	x	x	
Grubby	*Myoxocephalus aenaeus*			
Longhorn sculpin	*Myoxocephalus octodecemspinosus*		x	
Striped cuskeel	*Ophidion marginatum*			
Oyster toadfish	*Opsanus tau*			
Rainbow smelt	*Osmerus mordax mordax*			
Summer flounder*	*Paralichthys dentatus*	x	x	x
Atlantic butterfish*	*Peprilus triacanthus*	x	x	x
Rock gunnel	*Pholis gunnellus*			
Winter flounder*	*Pleuronectes americanus*	x	x	x
Yellowtail flounder	*Pleuronectes ferrugineus*			
Black drum	*Pogonias cromis*			
Pollock	*Pollachius virens*		x	
Bluefish	*Pomatomus saltatrix*	x	x	x
Northern searobin	*Prionotus carolinus*	x	x	x
Striped searobin	*Prionotus evolans*	x	x	
Clearnose skate*	*Raja eglanteria*	x	x	
Little skate*	*Raja erinacea*	x	x	
Winter skate*	*Raja ocellata*	x	x	
Windowpane*	*Scophthalmus aquosus*	x	x	x
Atlantic moonfish	*Selene setapinnis*	x	x	
Northern puffer	*Sphoeroides maculatus*	x	x	x
Spiny dogfish	*Squalus acanthias*		x	
Scup*	*Stenotomus chrysops*	x	x	
Northern pipefish	*Syngnathus fuscus*		x	x
Tautog	*Tautoga onitis*	x		x
Cunner	*Tautogolabrus adspersus*	x	x	x
Hogchocker	*Trinectes maculatus*			
Red hake*	*Urophycis chuss*	x	x	
Spotted hake	*Urophycis regia*	x	x	x

* Federally managed (EFH) species
** State managed species of concern

Table C6. Fish total length (mm) listed as the mean and range in parentheses in the winter (January through March) and spring (April through June) for all species with a minimum sample size of five individuals in each season. Data were obtained from bottom trawl sampling in the Harbor (ABS) and near-shore habitat on the south shore of Long Island (Shinnecock Borrow Area).

Common Name	Scientific Name	Winter Harbor (ABS) Mean size (range)	Spring Harbor (ABS) Mean size (range)	Winter Shinnecock Mean size (range)	Spring Shinnecock Mean size (range)
Blueback herring**	*Alosa aestivalis*	95 (29-335)	109 (50-302)	198 (80-350)	
Alewife**	*Alosa pseudoharengus*	108 (11-288)	136 (66-435)		180 (76-364)
American shad**	*Alosa sapidissima*	121 (70-285)	154 (70-535)	113 (62-180)	
American sandlance	*Ammodytes americanus*	136 (38-206)	88 (47-140)		
Bay anchovy	*Anchoa mitchilli*	50 (21-104)	74 (25-169)		76 (60-95)
American eel	*Anguilla rostrata*	514 (175-790)	503 (200-750)		
Atlantic menhaden**	*Brevoortia tyrannus*	99 (38-377)	186 (34-377)	91 (70-114)	
Black sea bass*	*Centropristis striata*	89 (62-232)	104 (44-392)		249 (44-378)
Atlantic herring*	*Clupea harengus*	219 (25-338)	64 (38-323)	247 (76-340)	89 (48-320)
Weakfish	*Cynoscion regalis*	193 (51-318)	326 (209-722)		
Smallmouth flounder	*Etropus microstomus*	69 (31-197)	67 (38-157)	69 (32-130)	84 (40-162)
Atlantic cod	*Gadus morhua*	25 (23-29)			46 (36-62)
Spot	*Leiostomus xanthurus*	56 (21-276)			
Atlantic silverside	*Menidia menidia*	91 (51-187)	45 (28-106)	85 (54-182)	77 (60-100)
Silver hake	*Merluccius bilinearis*	110 (54-298)	115 (63-158)	96 (81-180)	109 (60-180)
Atlantic croaker**	*Micropogonias undulatus*	49 (15-176)			
Striped bass**	*Morone saxatilis*	192 (41-824)	197 (55-853)		320 (261-600)
Smooth dogfish	*Mustelus canis*	730 (285-815)	743 (600-850)		737 (125-1300)
Summer flounder*	*Paralichthys dentatus*	151 (17-350)	343 (59-648)		357 (68-320)
Atlantic butterfish*	*Peprilus triacanthus*	142 (55-180)	103 (26-242)		73 (12-239)
Winter flounder*	*Pleuronectes americanus*	148 (25-441)	177 (25-471)	256 (30-428)	
Northern searobin	*Prionotus carolinus*	60 (41-97)	116 (51-384)	198 (60-284)	152 (50-418)
Striped searobin	*Prionotus evolans*	84 (45-134)	300 (88-415)		253 (130-394)
Clearnose skate*	*Raja eglanteria*	438 (113-775)	491 (340-695)		671 (500-880)
Little skate*	*Raja erinacea*	437 (36-780)	440 (368-861)	418 (102-840)	400 (20-840)

Winter skate*	*Raja ocellata*	513 (405-830)	518 (142-810)	315 (99-750)	351 (122-826)
Windowpane*	*Scophthalmus aquosus*	157 (15-793)	188 (22-388)	223 (12 -346)	257 (36-400)
Northern puffer	*Sphoeroides maculatus*		162 (111-331)		
Spiny dogfish	*Squalus acanthias*	784 (230-940)		748 (674-878)	
Scup*	*Stenotomus chrysops*		120 (80-323)		136 (38-379)
Northern pipefish	*Syngnathus fuscus*	165 (60-230)	167 (68-290)	166 (80-222)	166 (134-190)
Cunner	*Tautogolabrus adspersus*	94 (38-216)	113 (51-197)		
Red hake*	*Urophycis chuss*	142 (39-485)	161 (47-337)	96 (42-163)	116 (74-492)
Spotted hake	*Urophycis regia*	97 (38-362)	113 (13-773)	97 (22-290)	121 (32-320)

* Federally managed (EFH) species
** State managed species of concern

Figures (Part C)

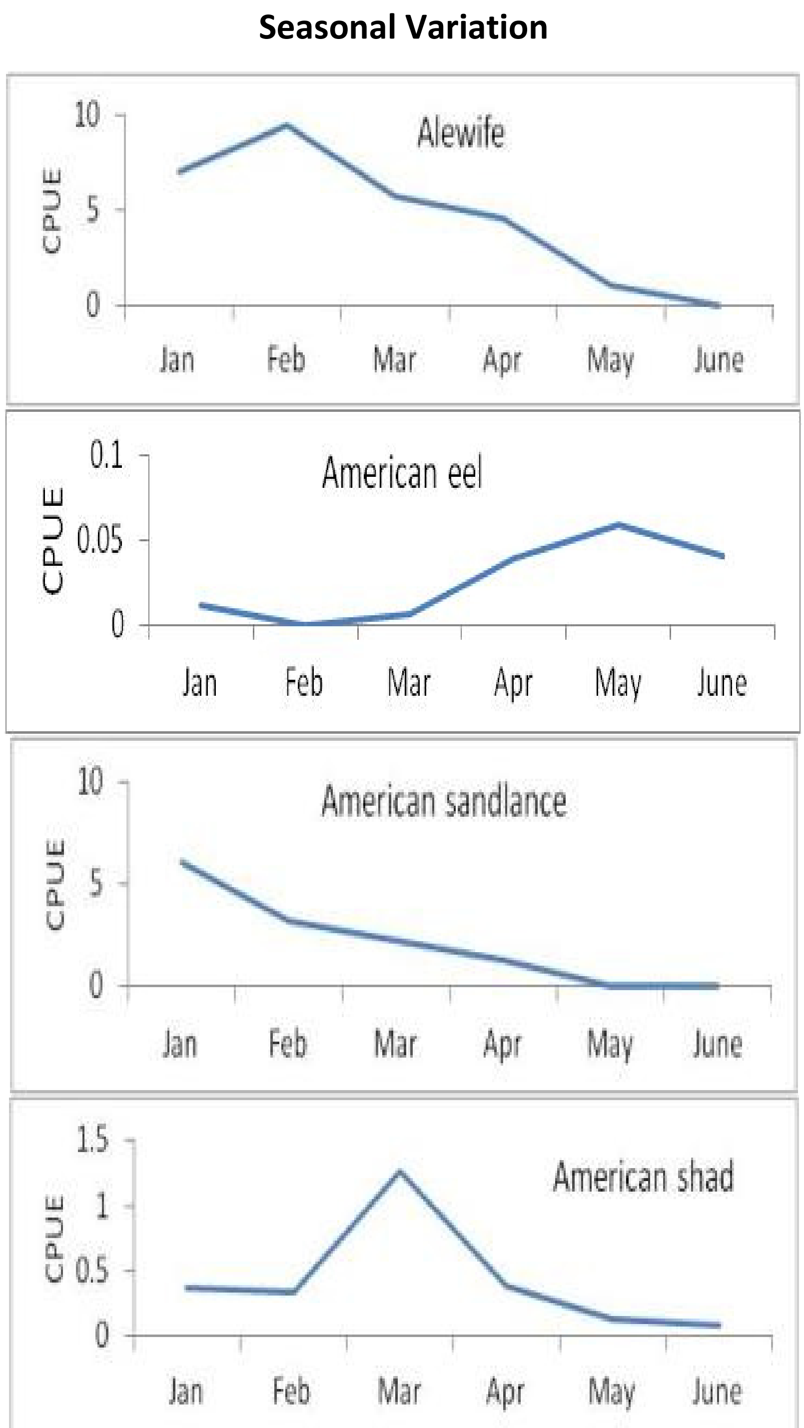

Figure C1. Average monthly CPUE for forage and state-managed species collected during ABS bottom trawl sampling from 2002-2010.

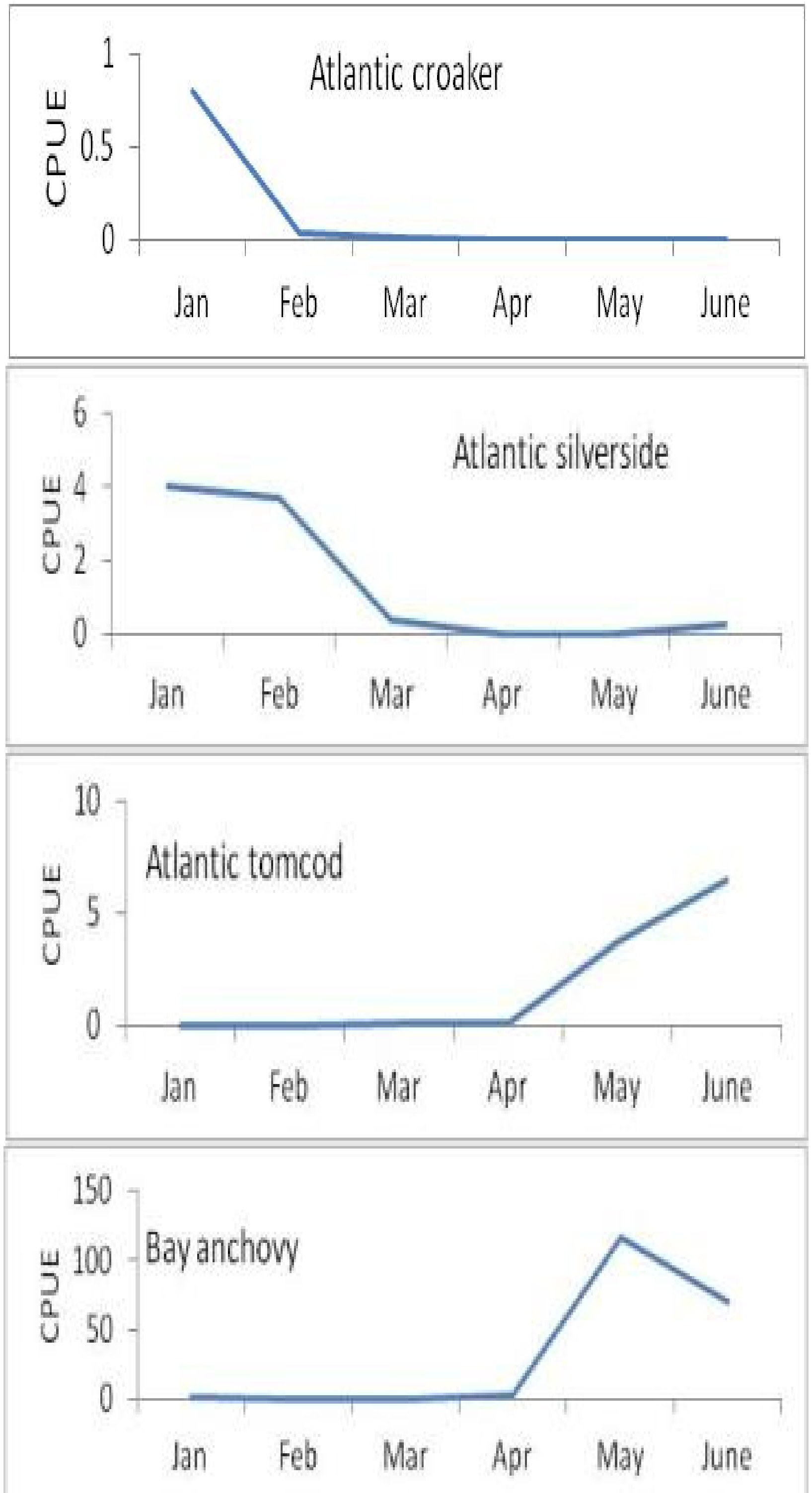

Figure C1 (cont.). Average monthly CPUE for forage and state-managed species collected during ABS bottom trawl sampling from 2002-2010.

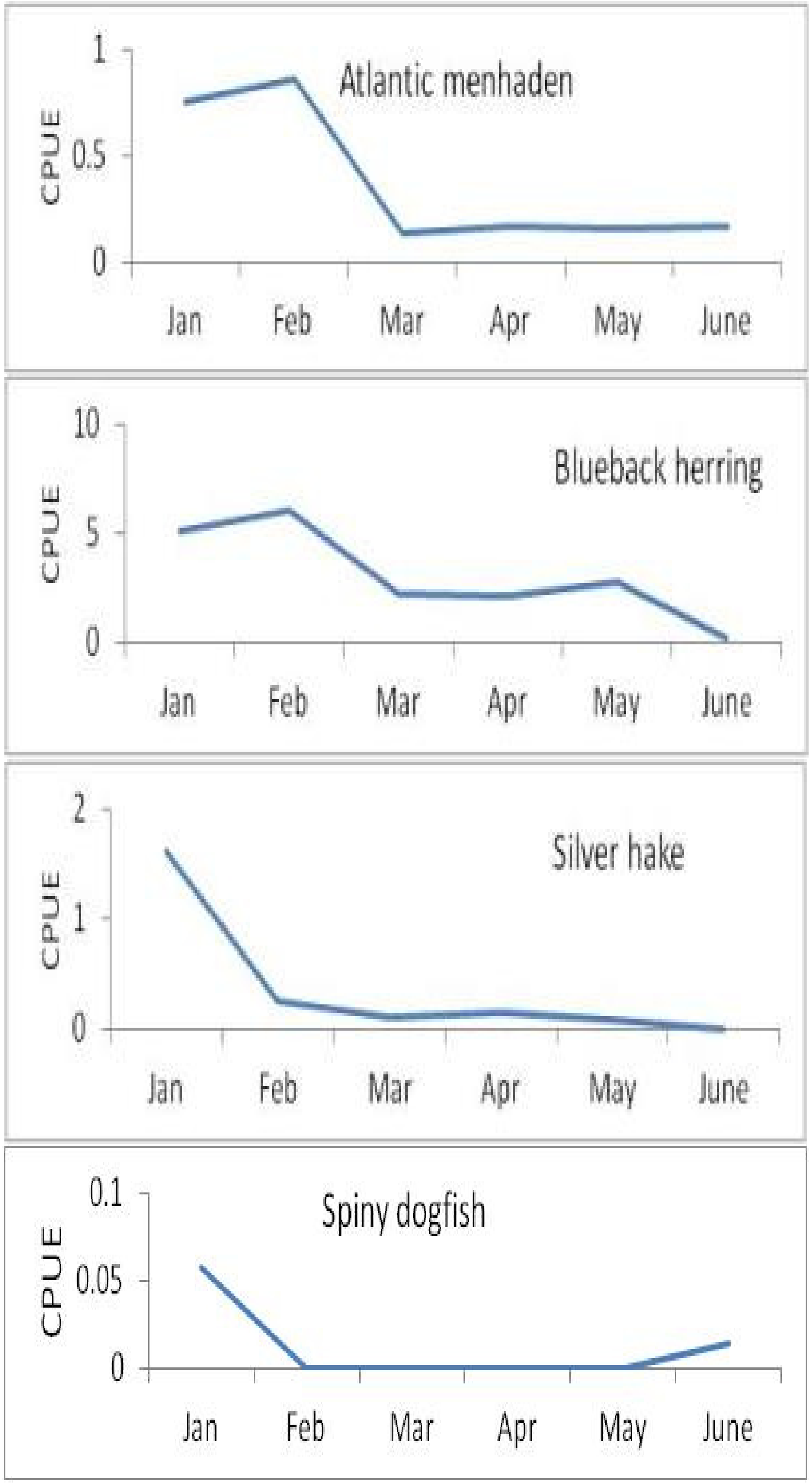

Figure C1 (cont.). Average monthly CPUE for forage and state-managed species collected during ABS bottom trawl sampling from 2002-2010.

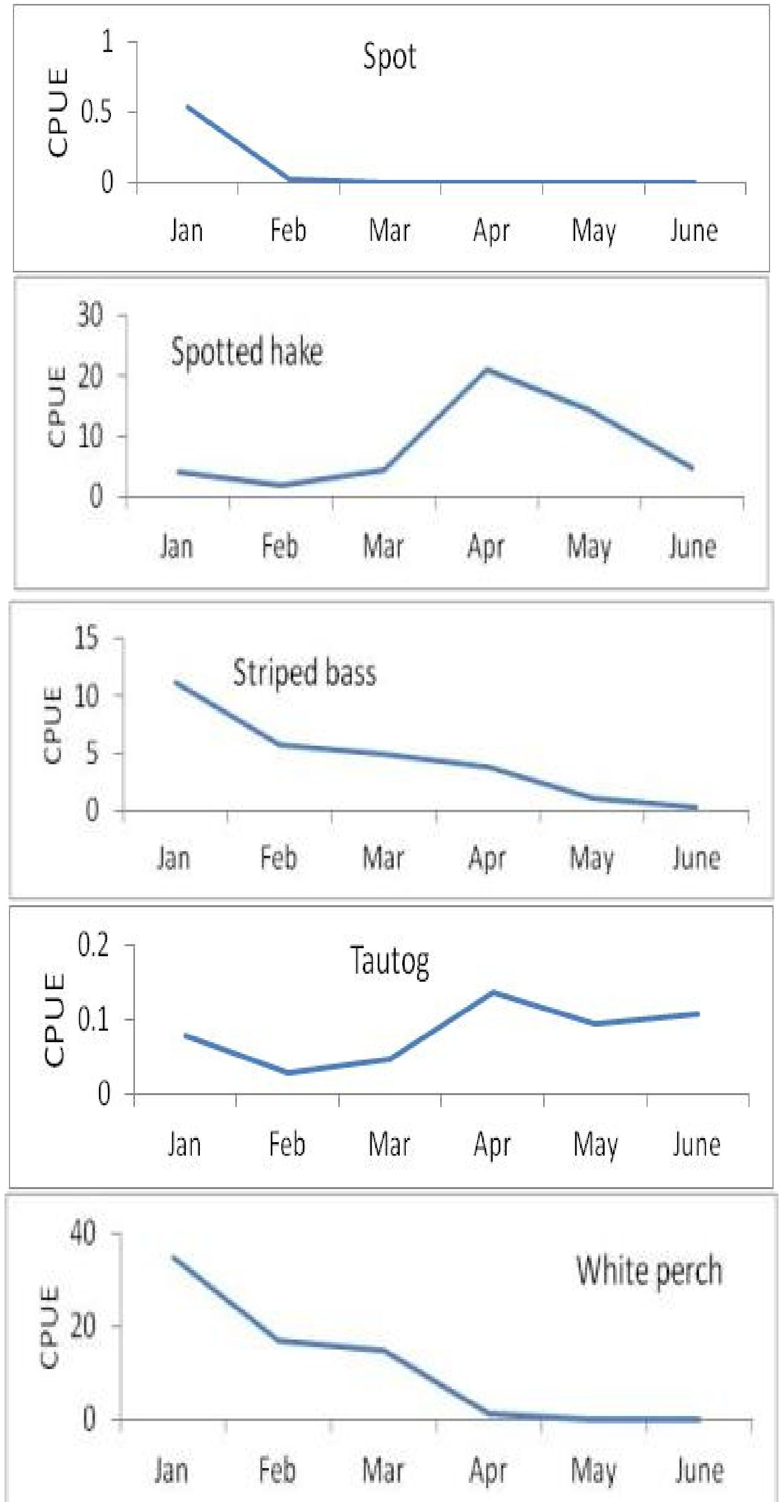

Figure C1 (cont.). Average monthly CPUE for forage and state-managed species collected during ABS bottom trawl sampling from 2002-2010.

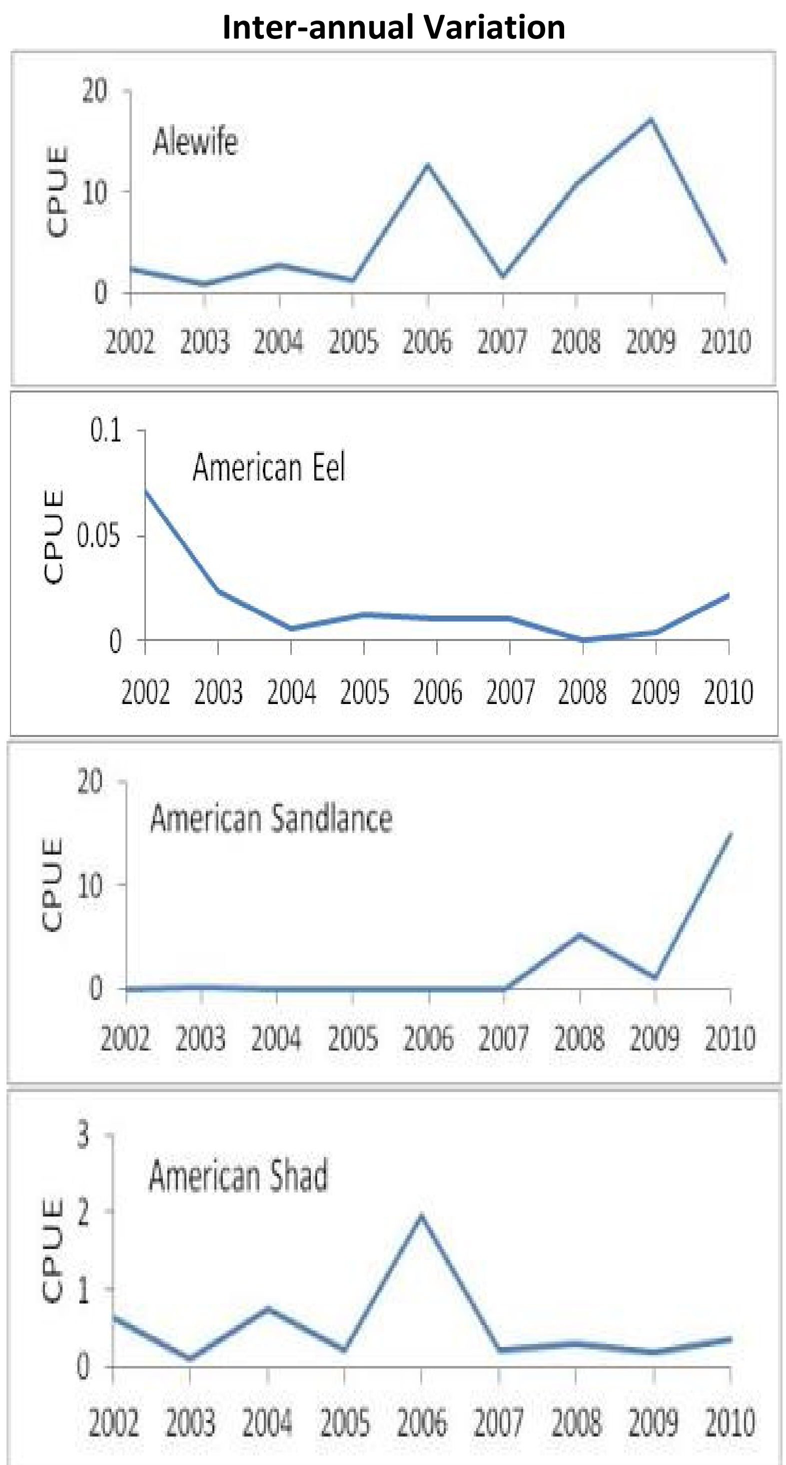

Figure C2. Average annual CPUE for forage and state-managed species collected during ABS bottom trawl sampling from 2002-2010.

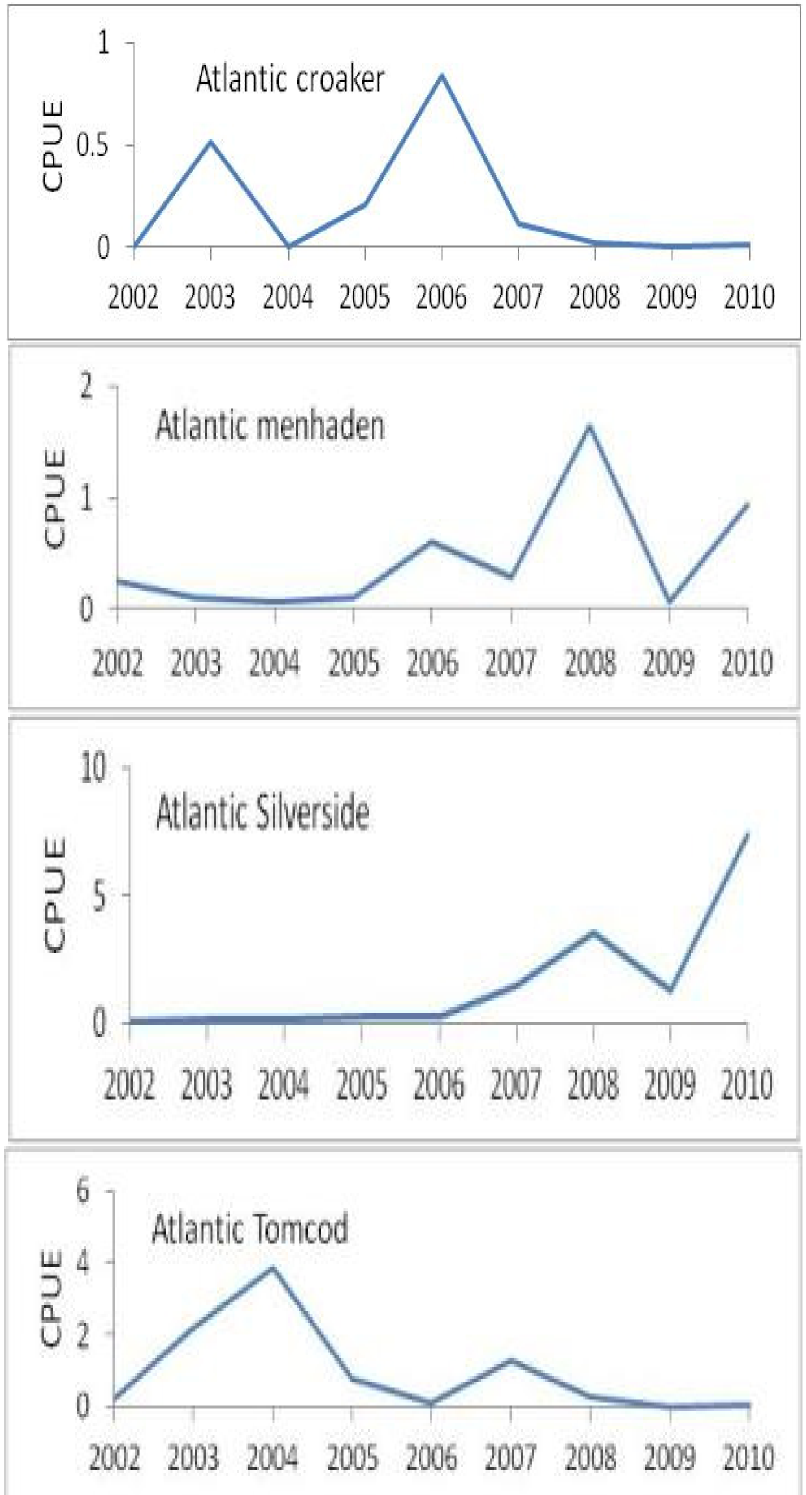

Figure C2 (cont.). Average annual CPUE for forage and state-managed species collected during ABS bottom trawl sampling from 2002-2010.

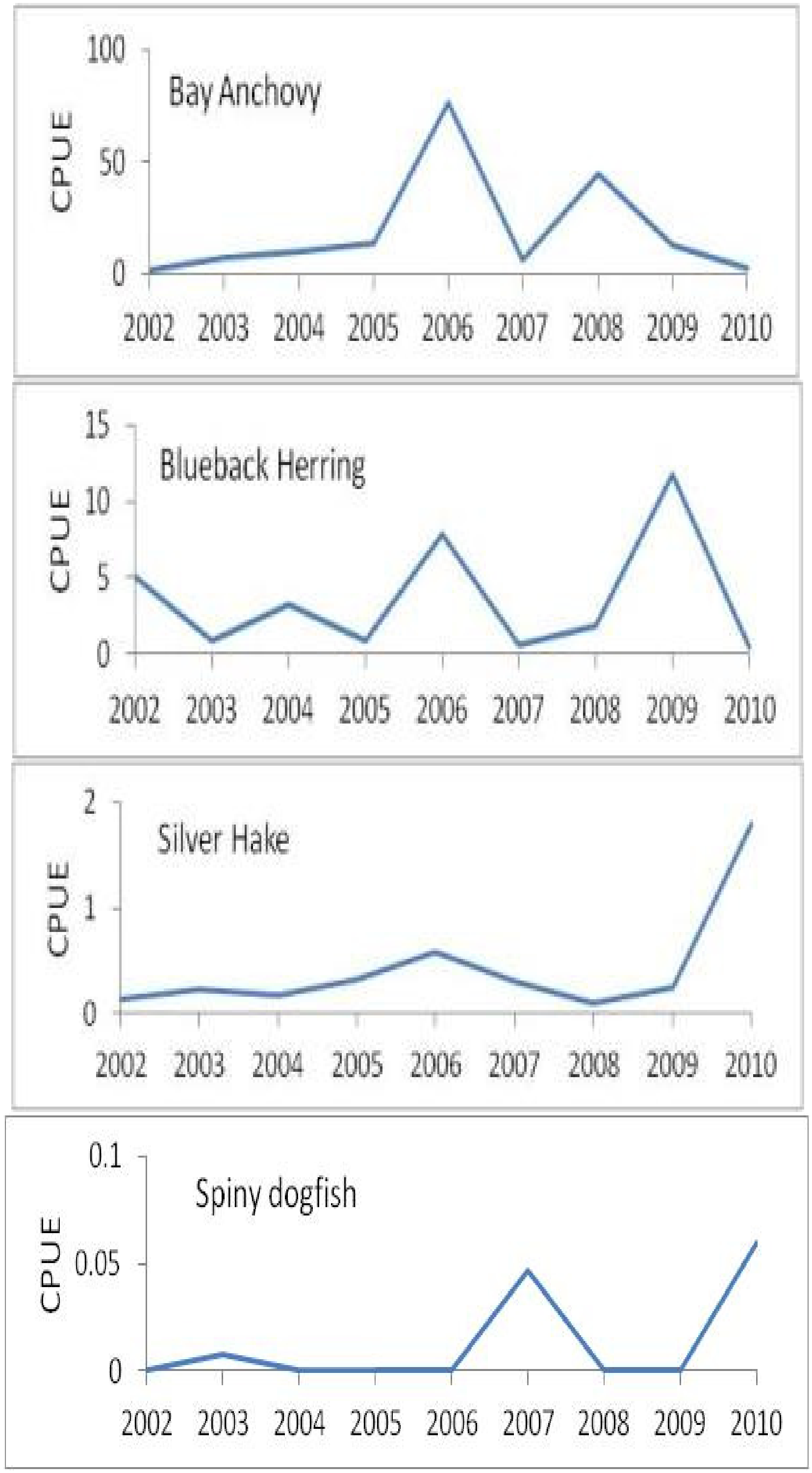

Figure C2 (cont.). Average annual CPUE for forage and state-managed species collected during ABS bottom trawl sampling from 2002-2010.

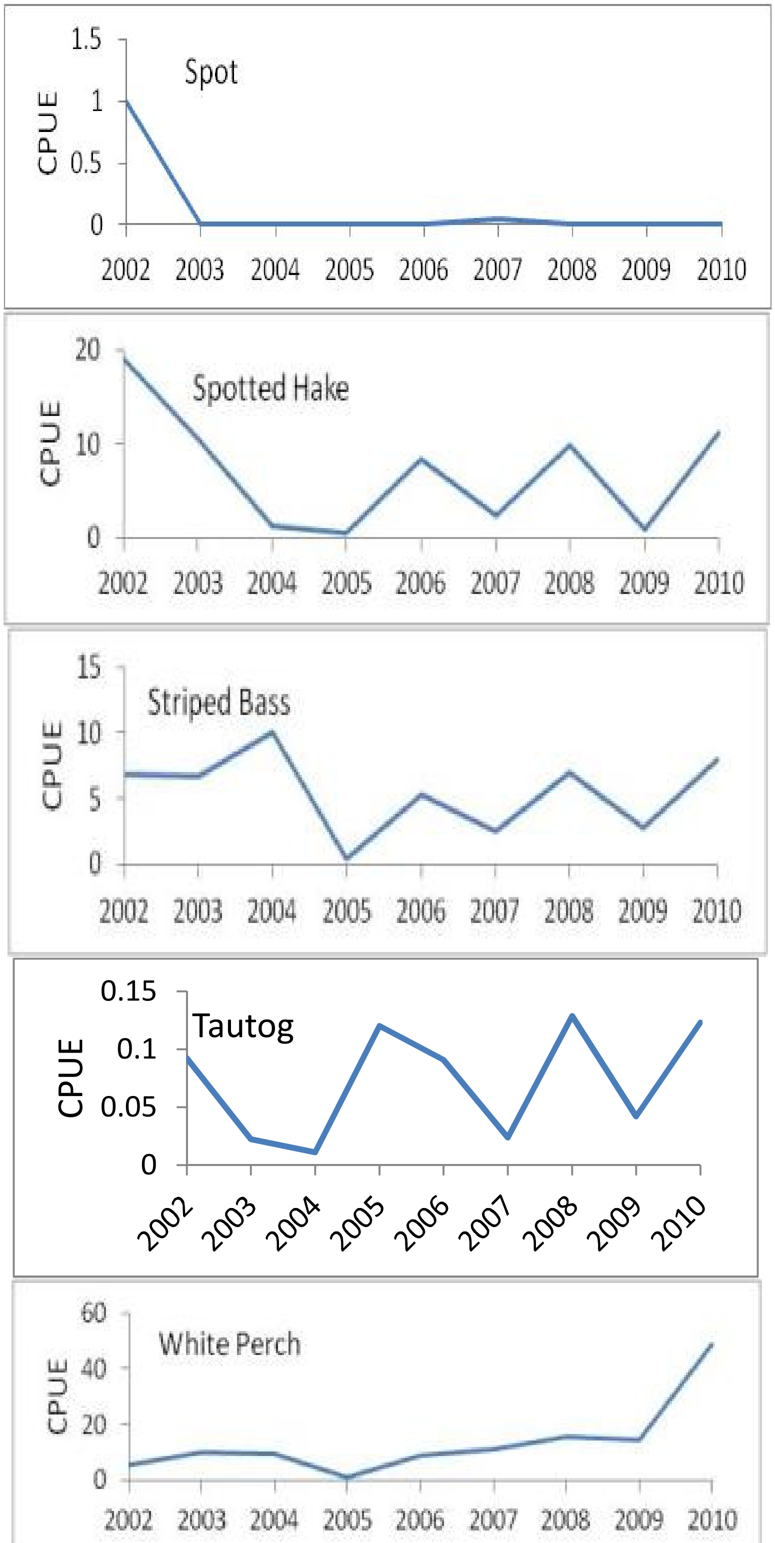

Figure C2 (cont.). Average annual CPUE for forage and state-managed species collected during ABS bottom trawl sampling from 2002-2010.

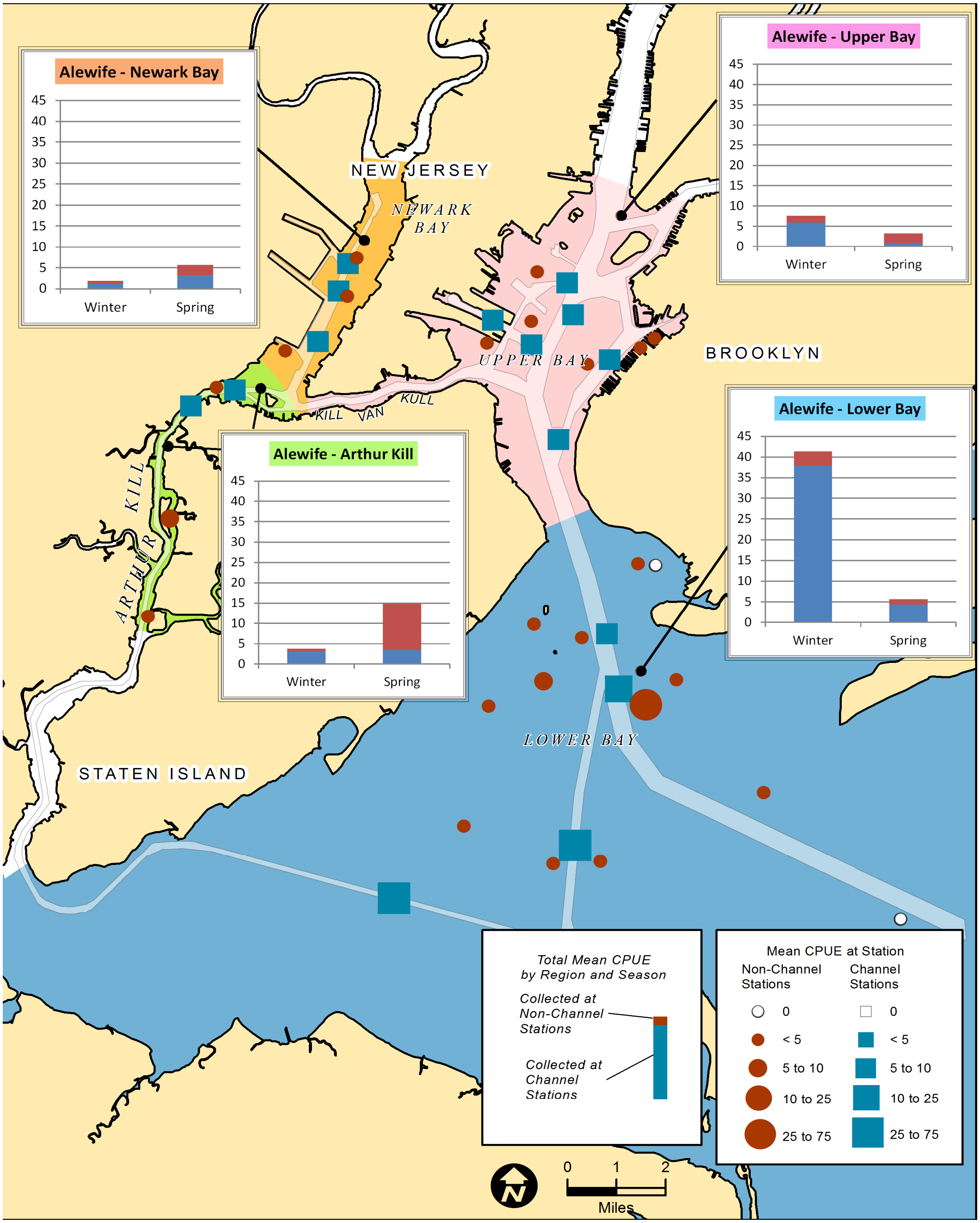

Figure C3. Alewife bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

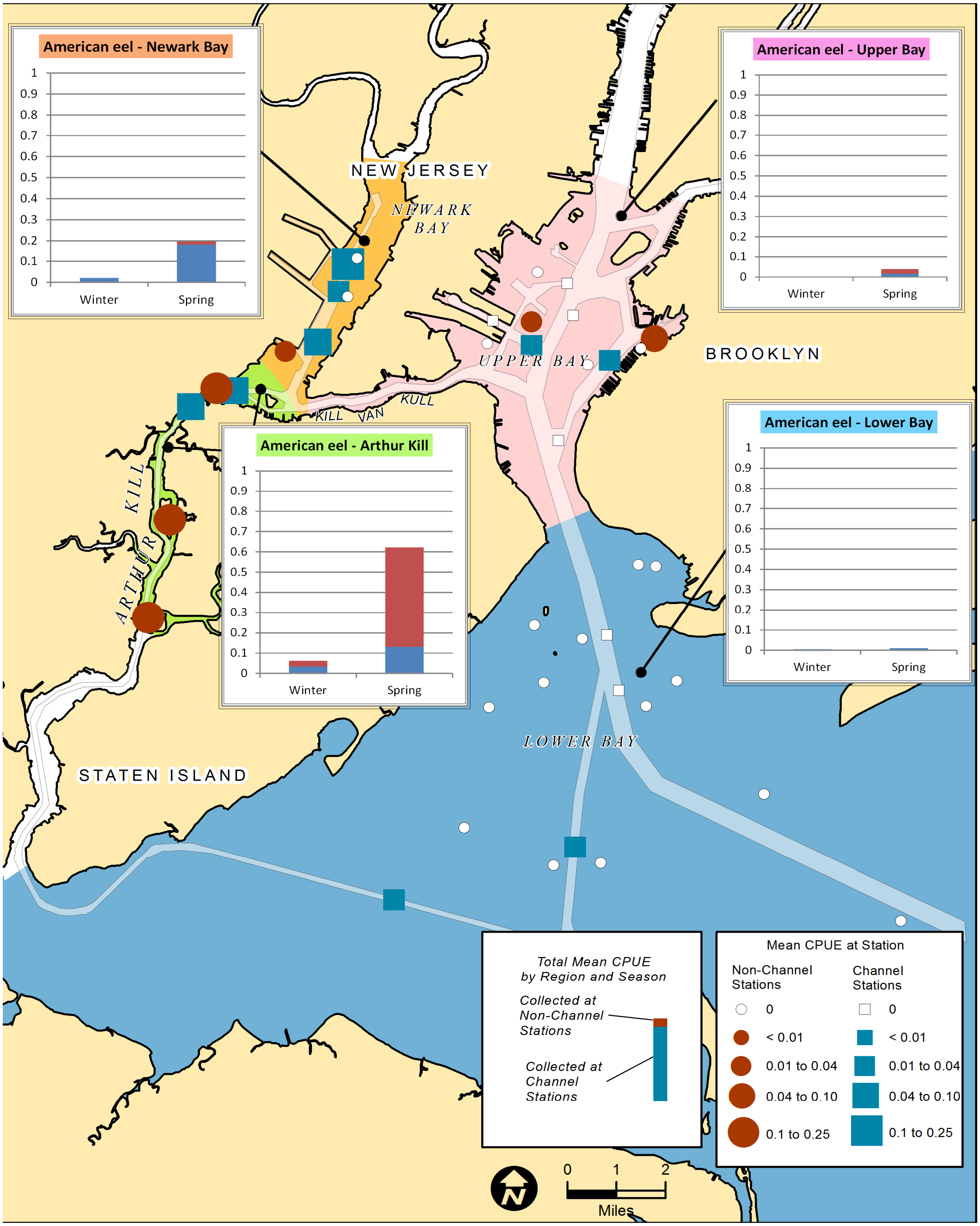

Figure C4. American eel bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

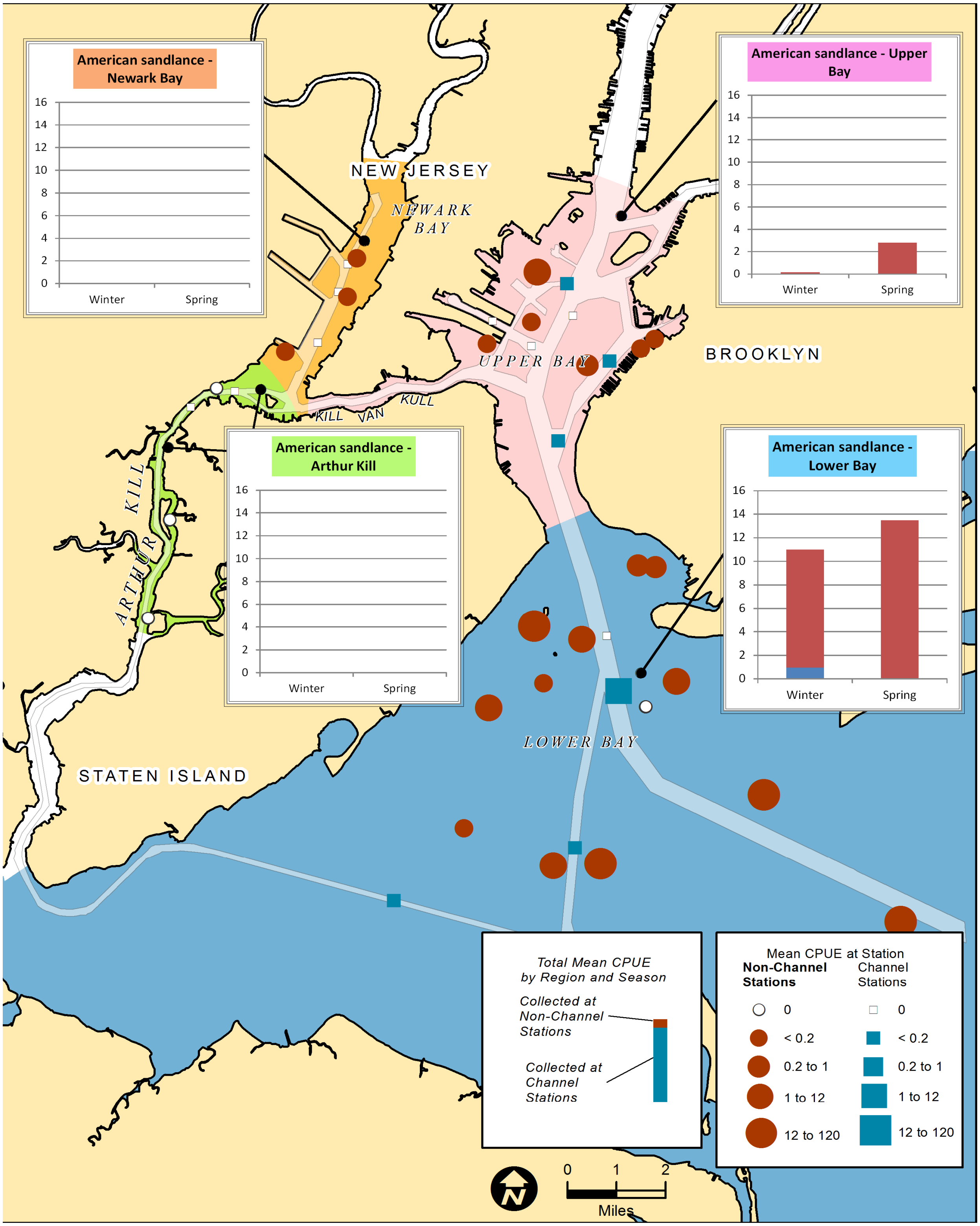

Figure C5. American sandlance bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

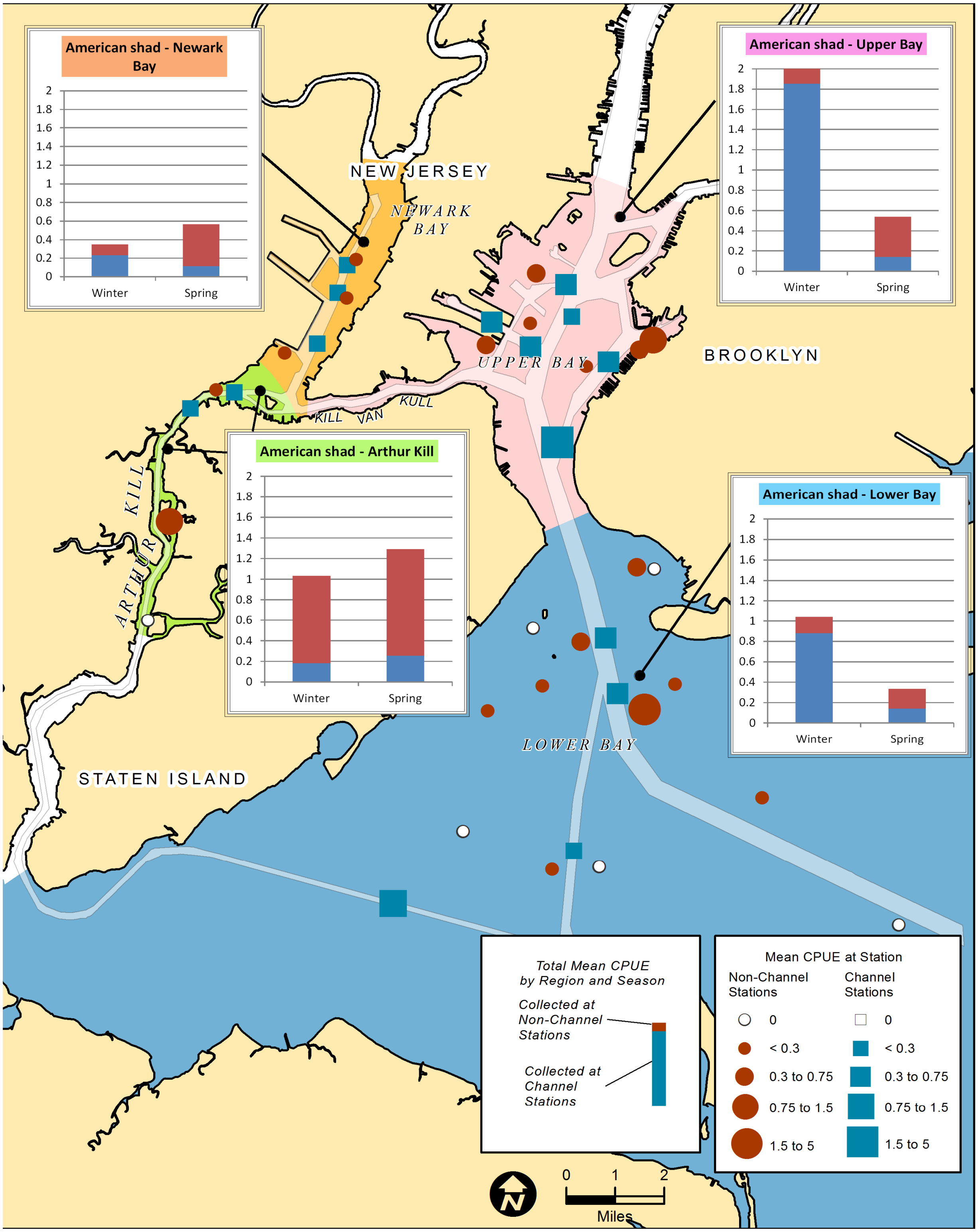

Figure C6. American shad bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

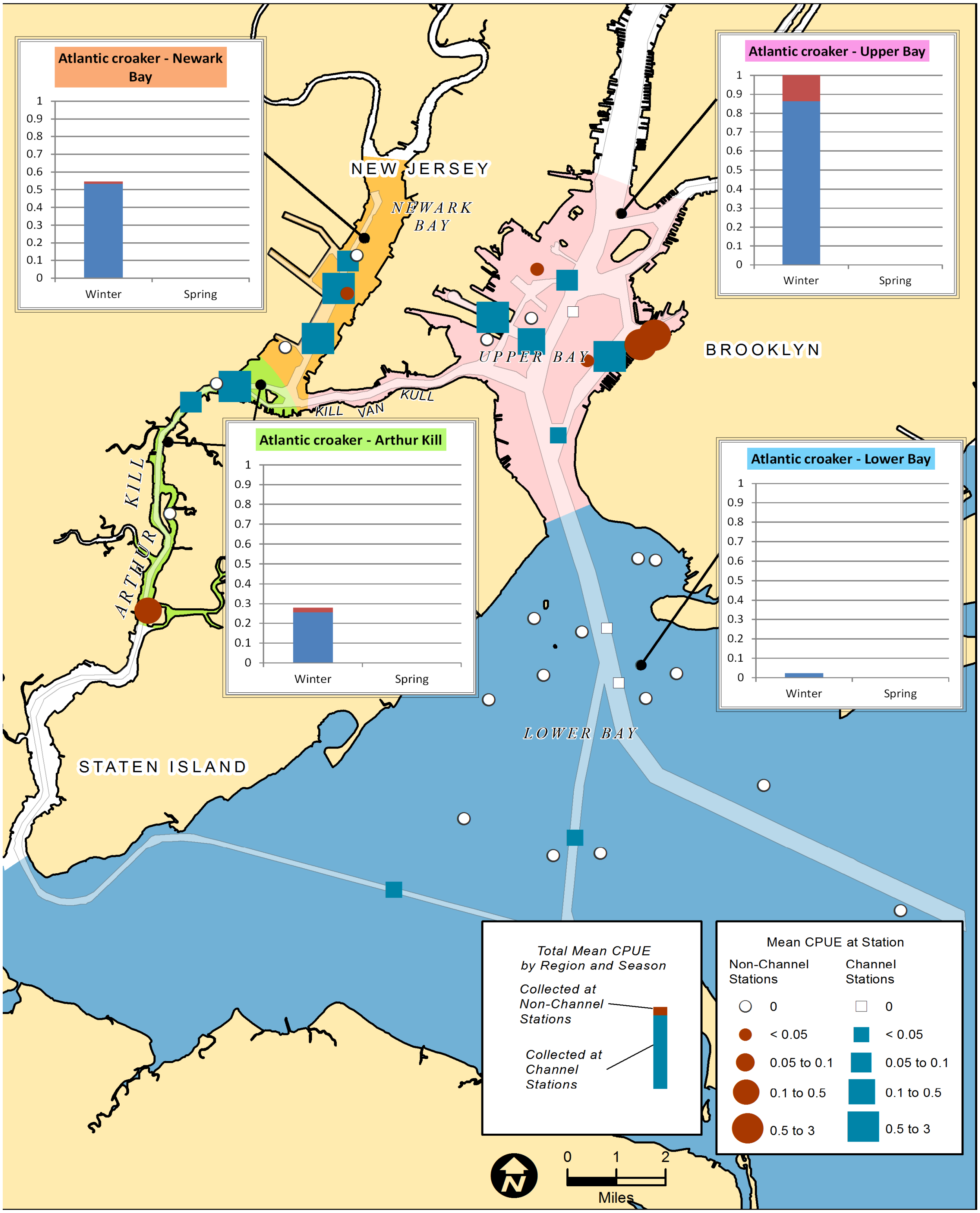

Figure C7. Atlantic croaker bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

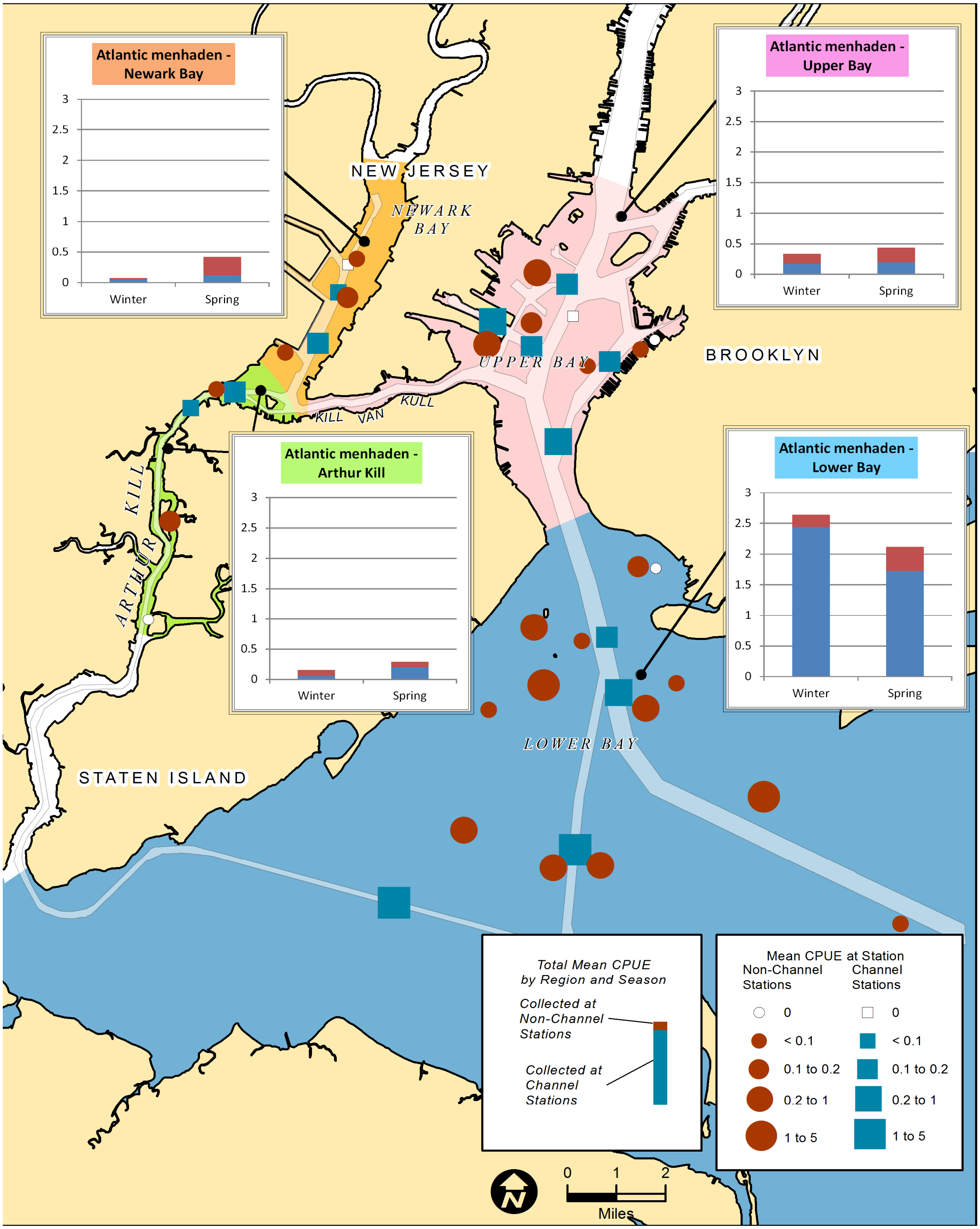

Figure C8. Atlantic Menhaden bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

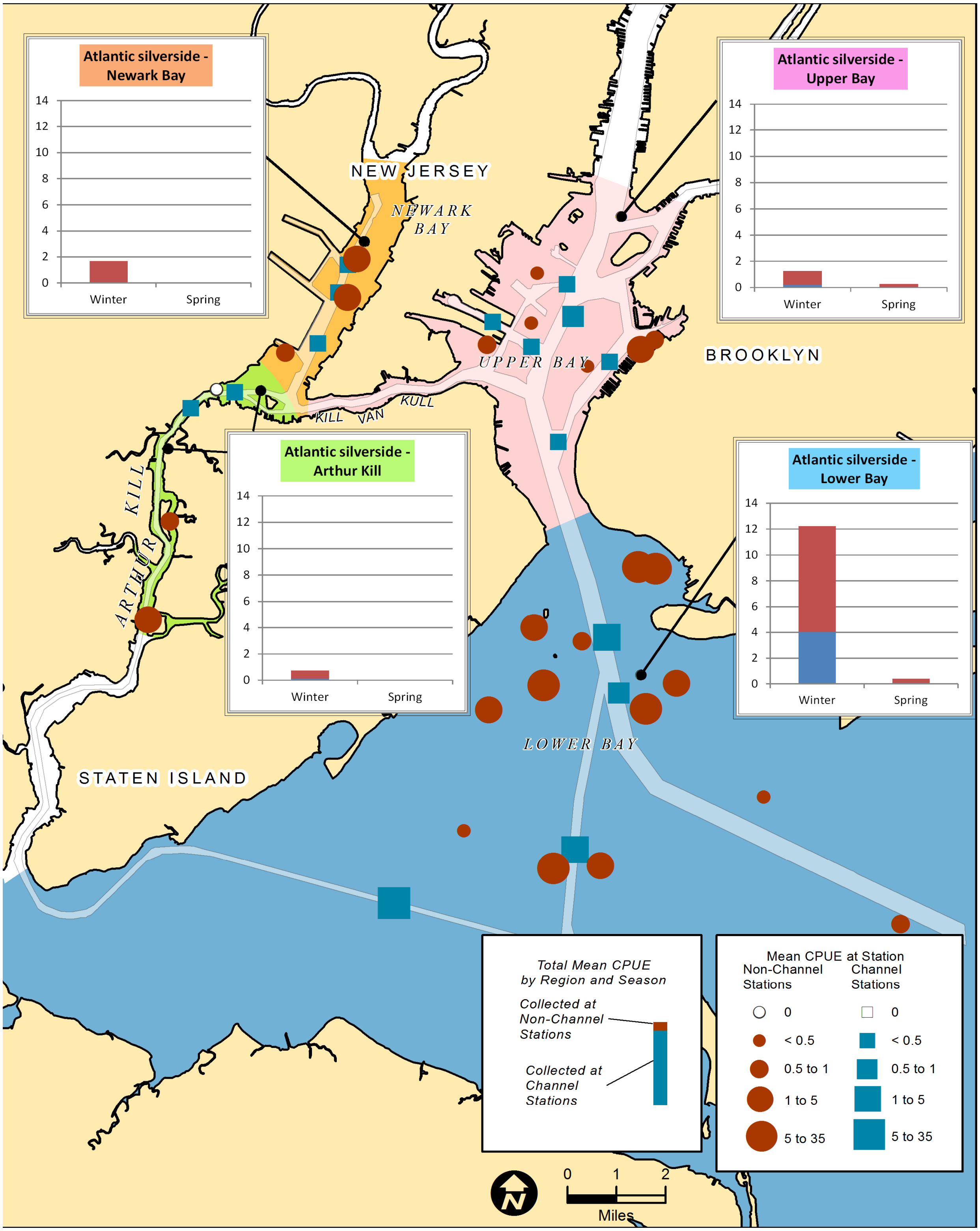

Figure C9. Atlantic silverside bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

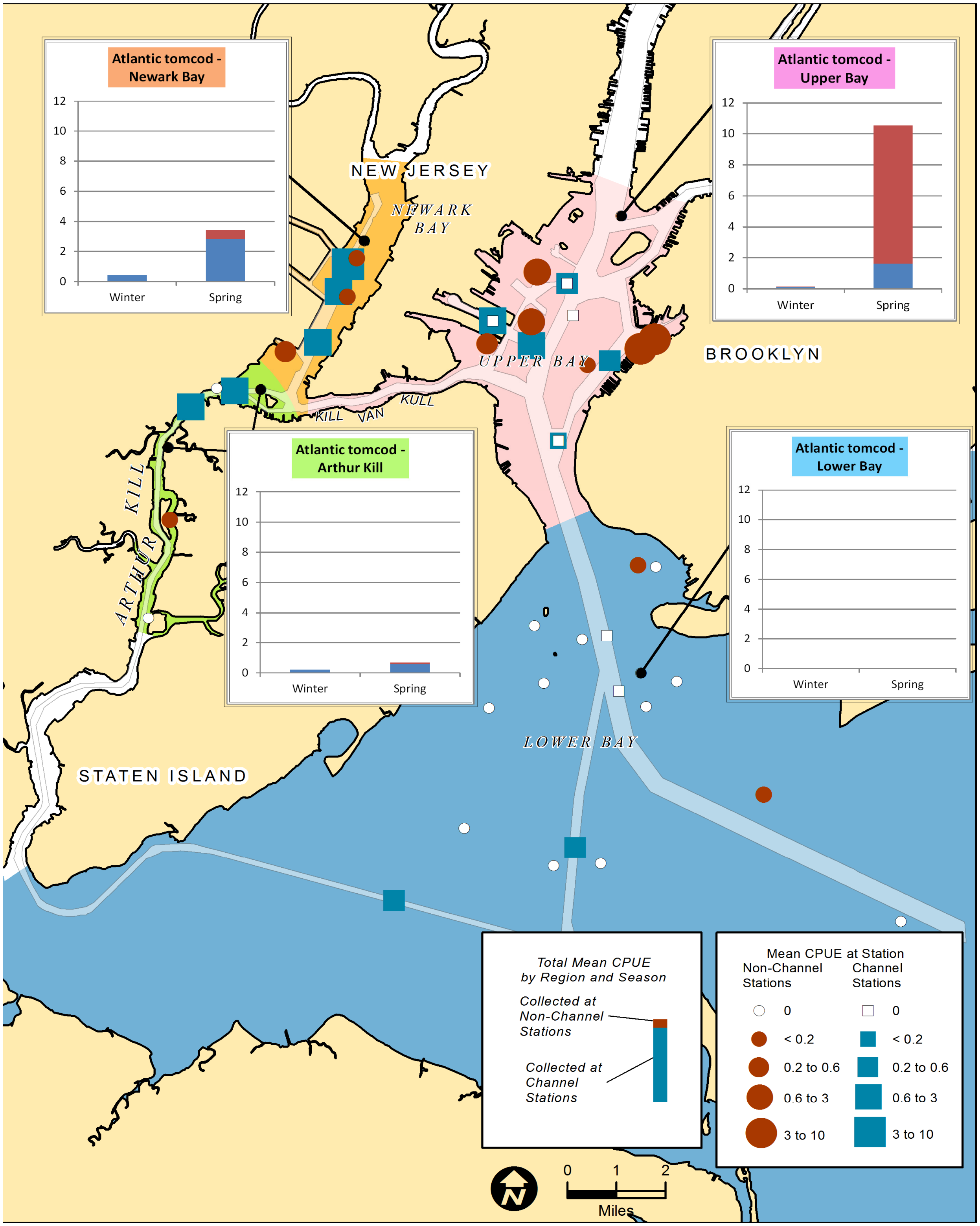

Figure C10. Atlantic tomcod bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

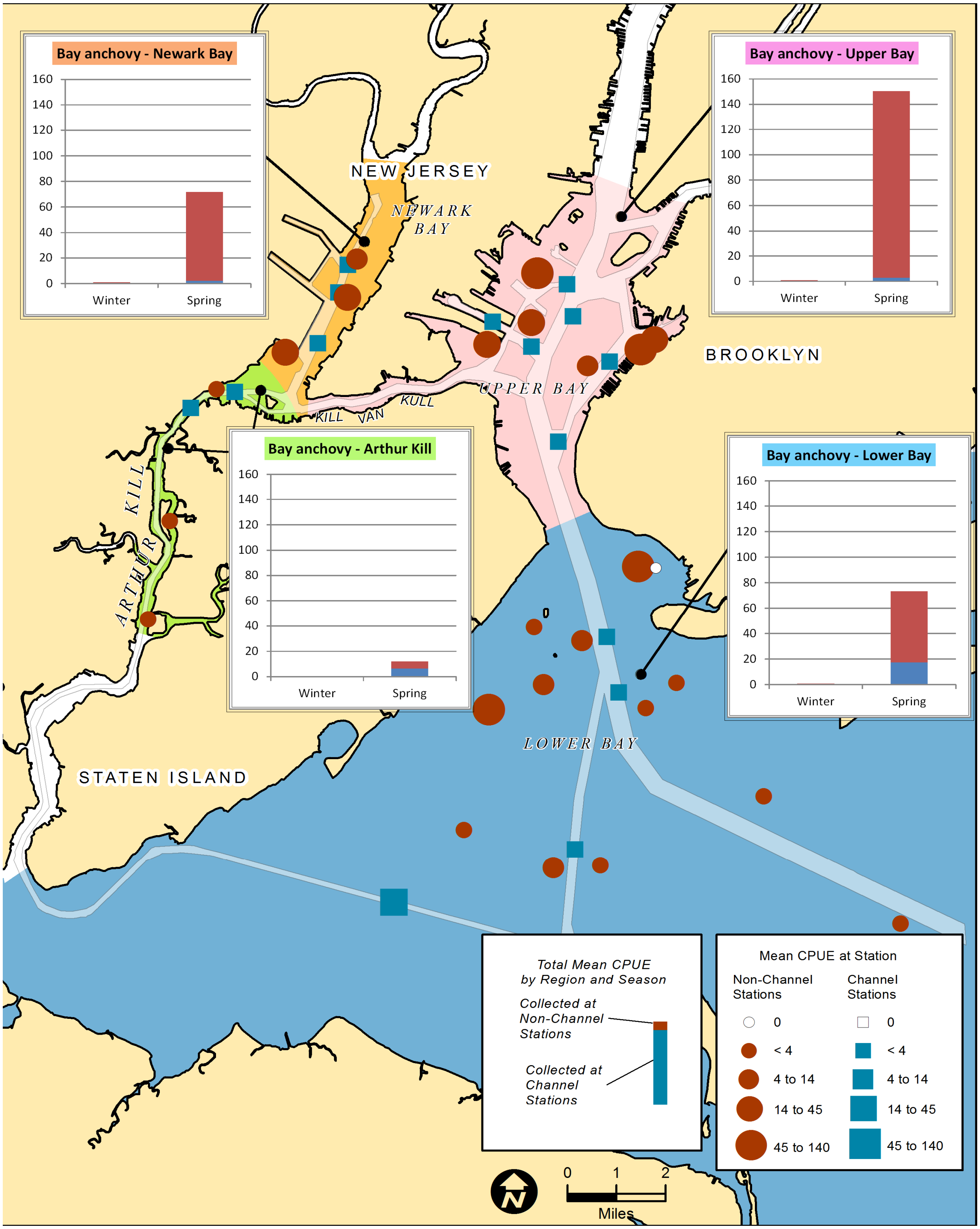

Figure C11. Bay Anchovy bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

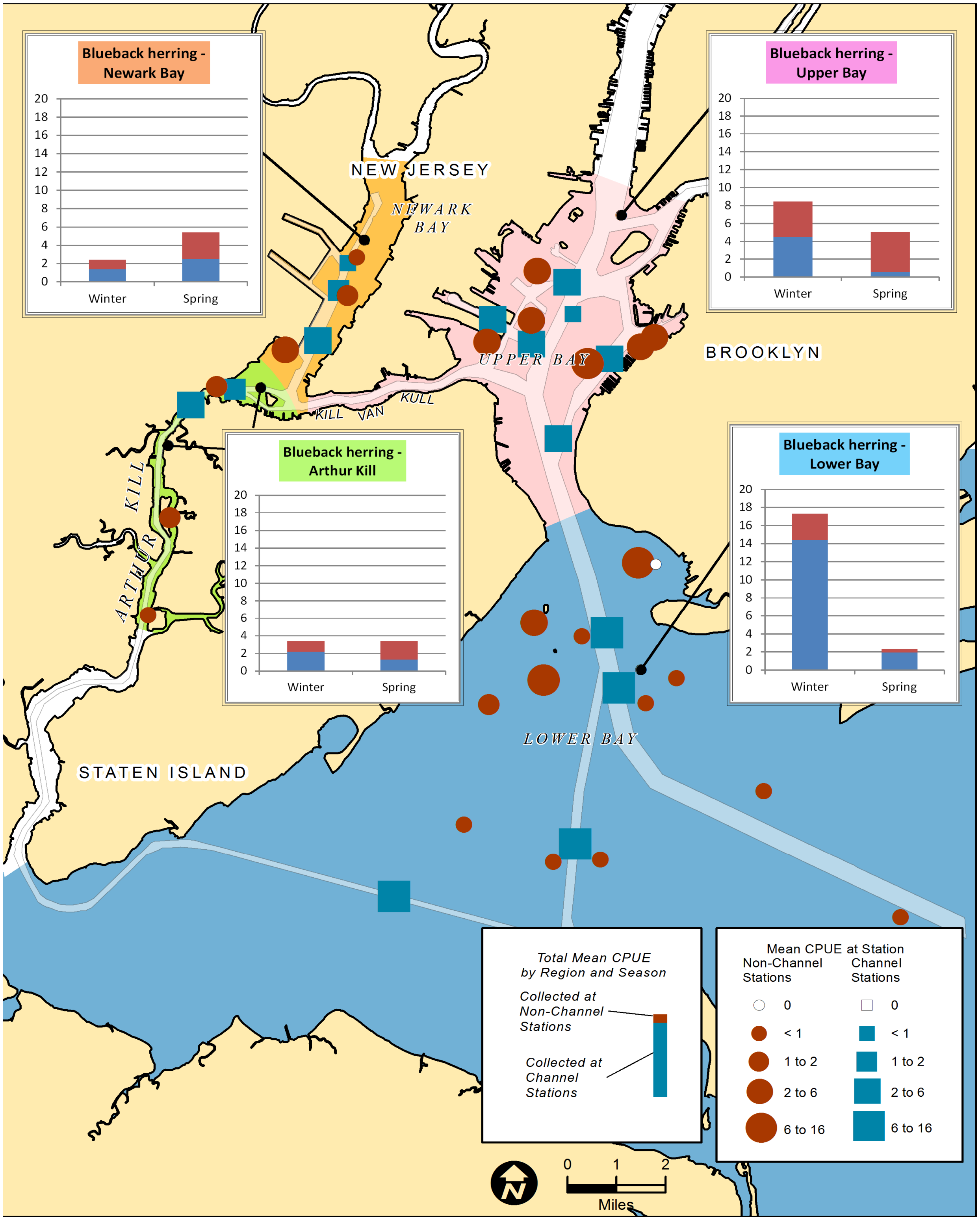

Figure C12. Blueback herring bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

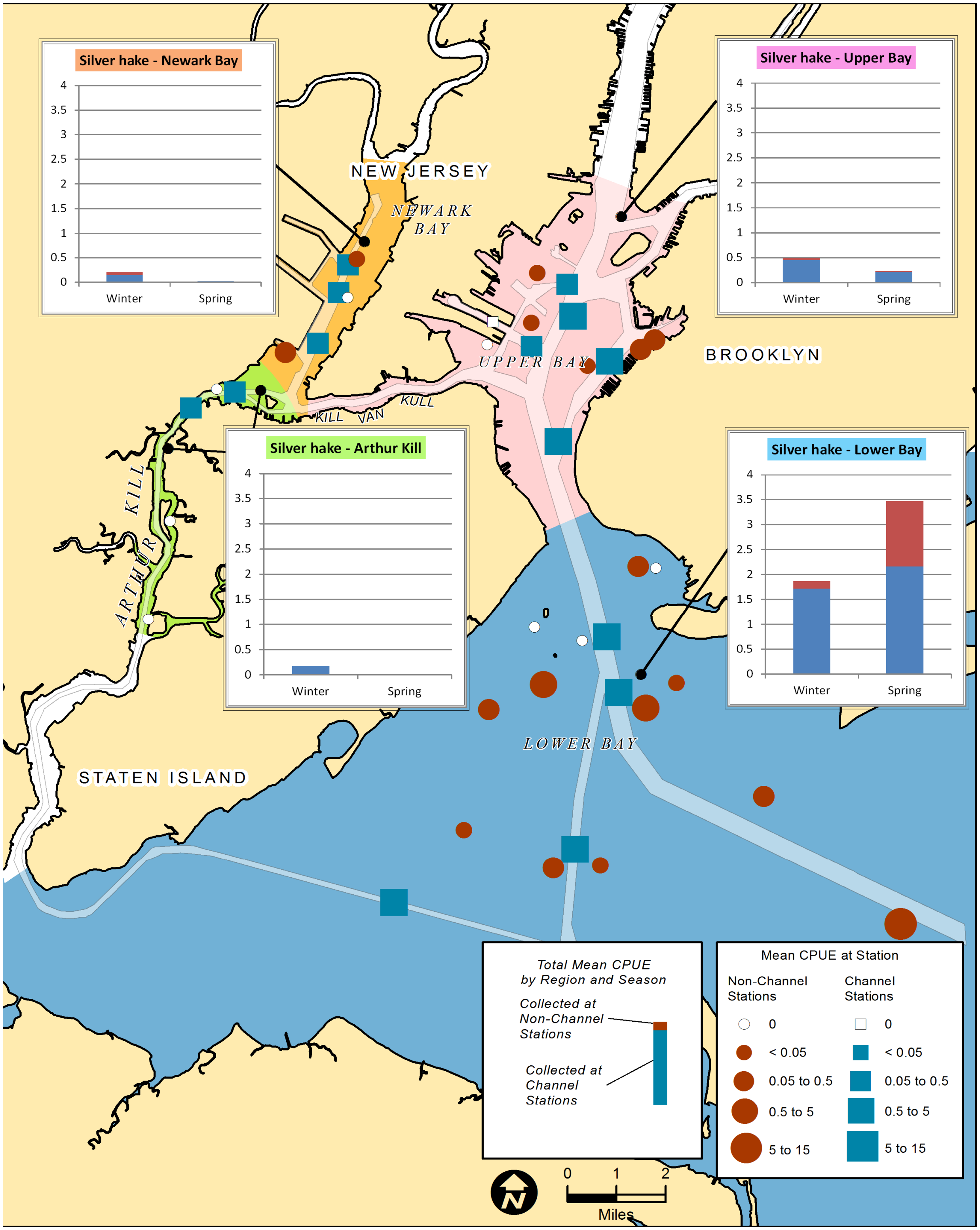

Figure C13. Silver hake bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

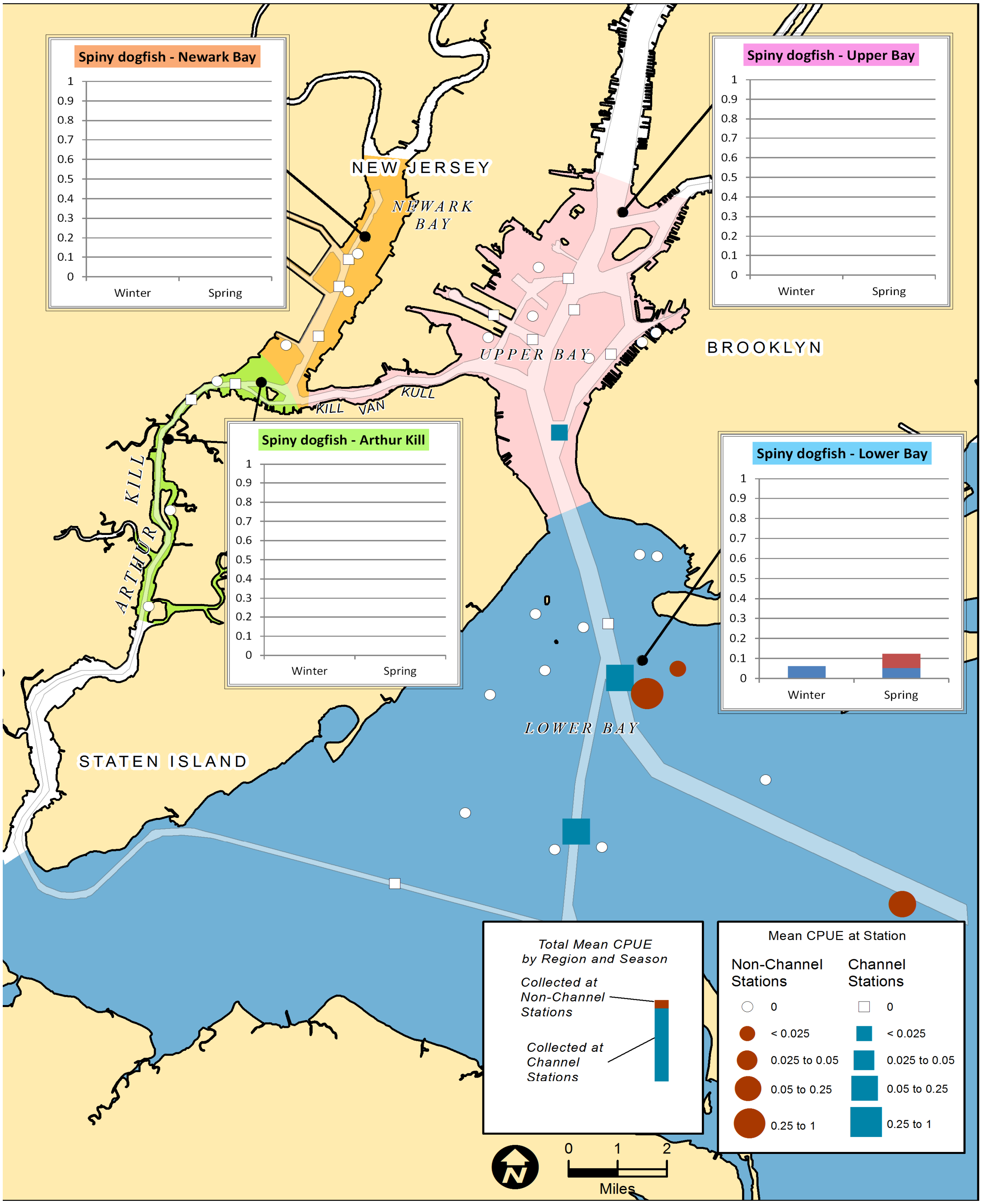

Figure C14. Spiny dogfish bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

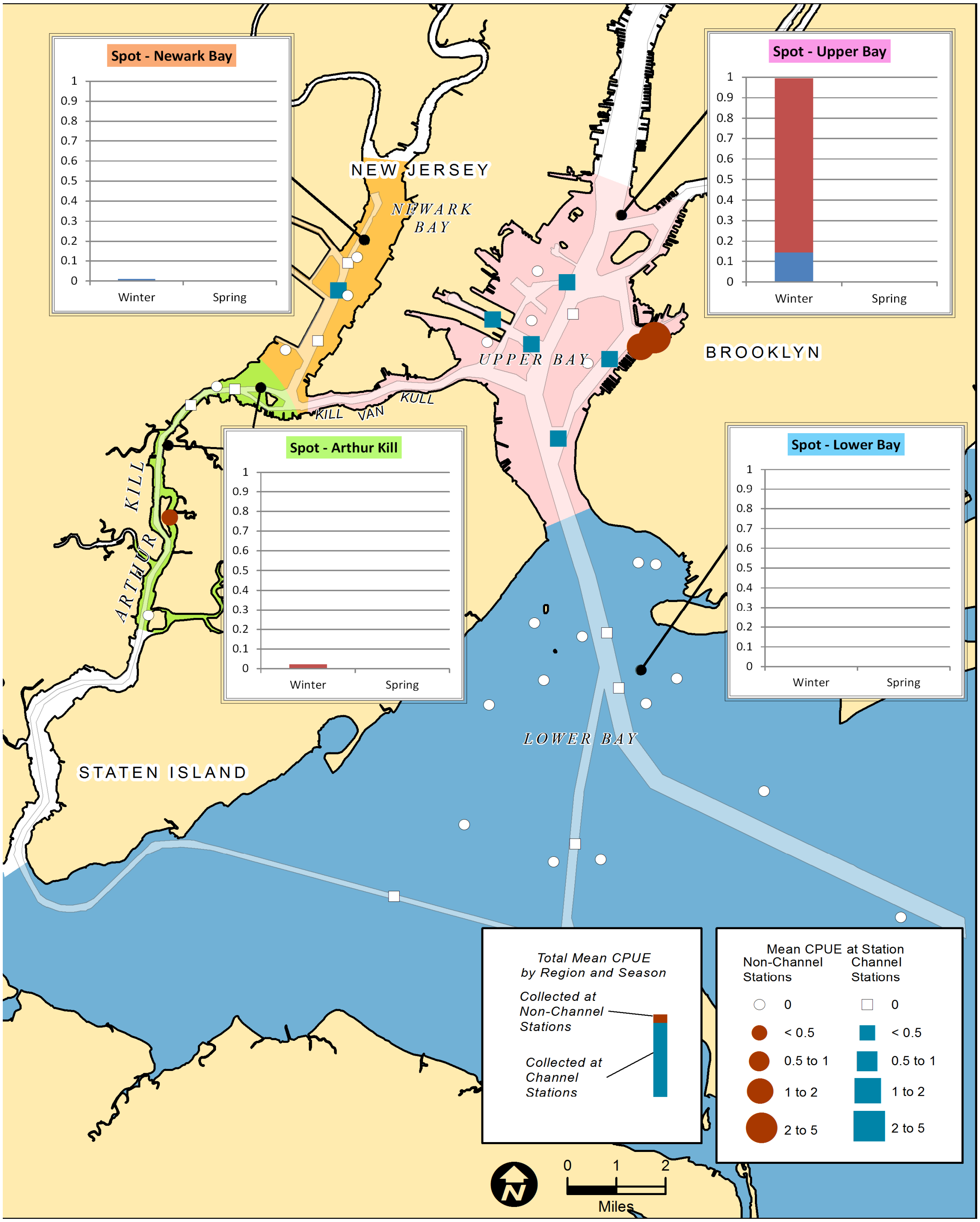

Figure C15. Spot bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

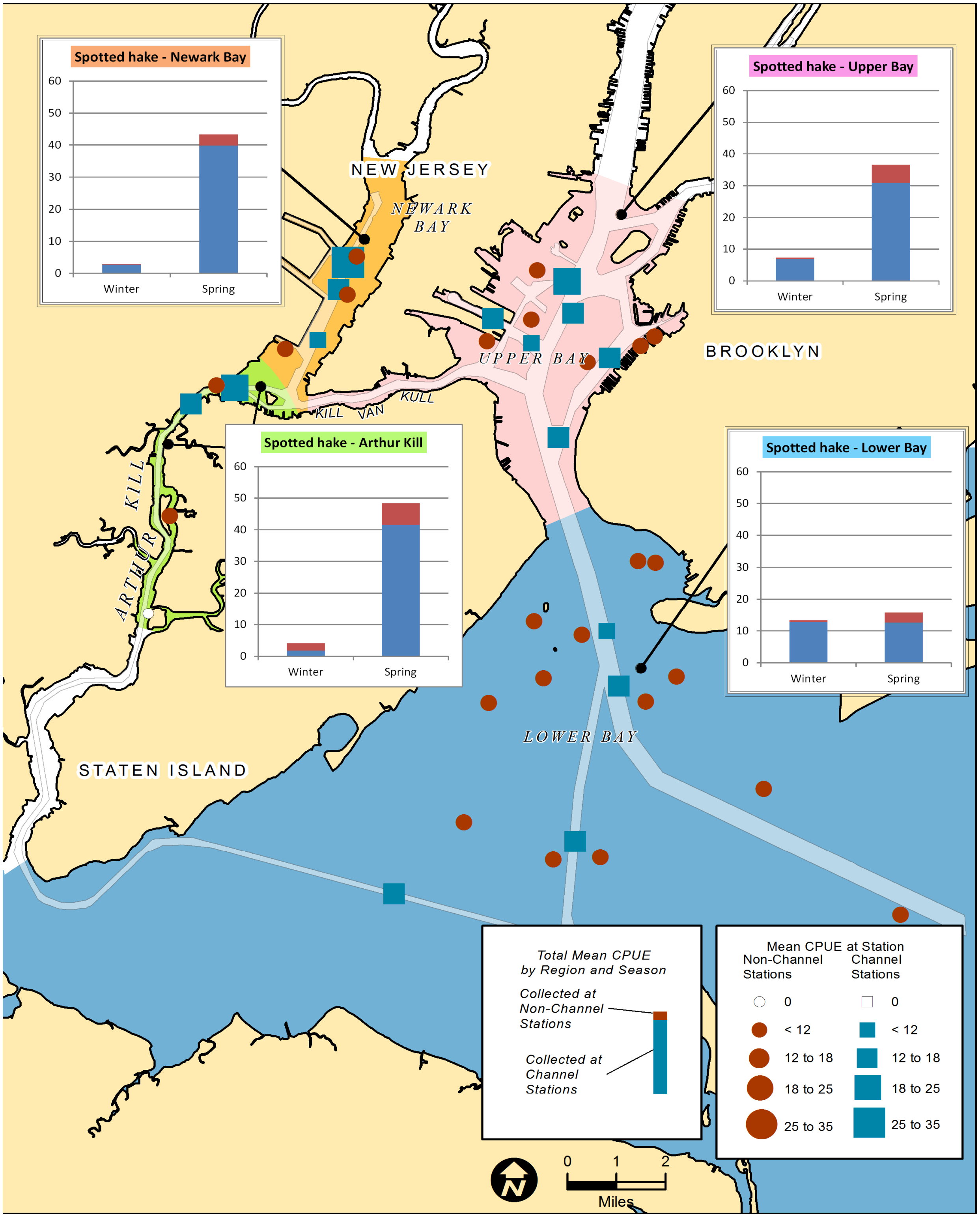

Figure C16. Spotted hake bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

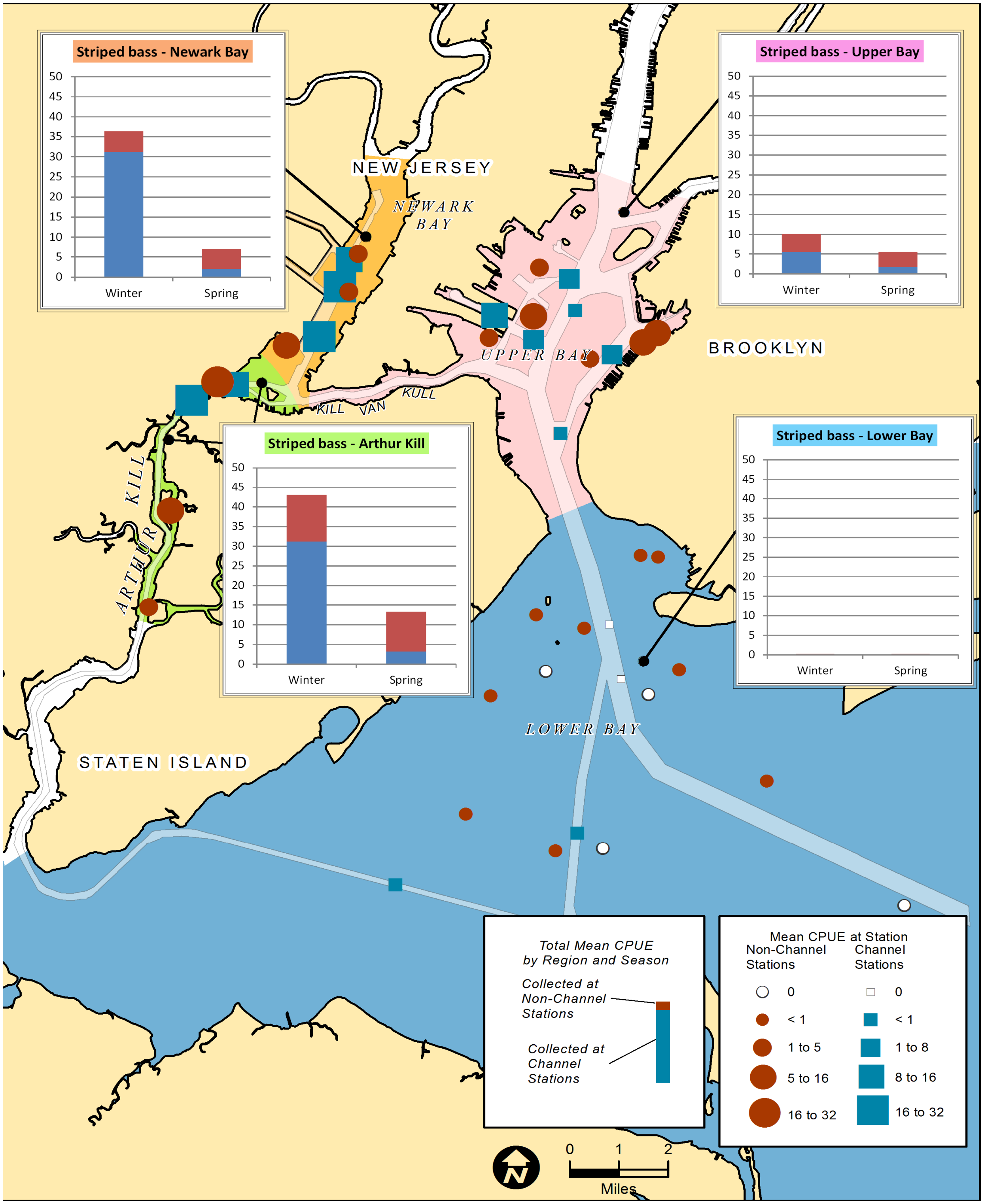

Figure C17. Striped bass bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

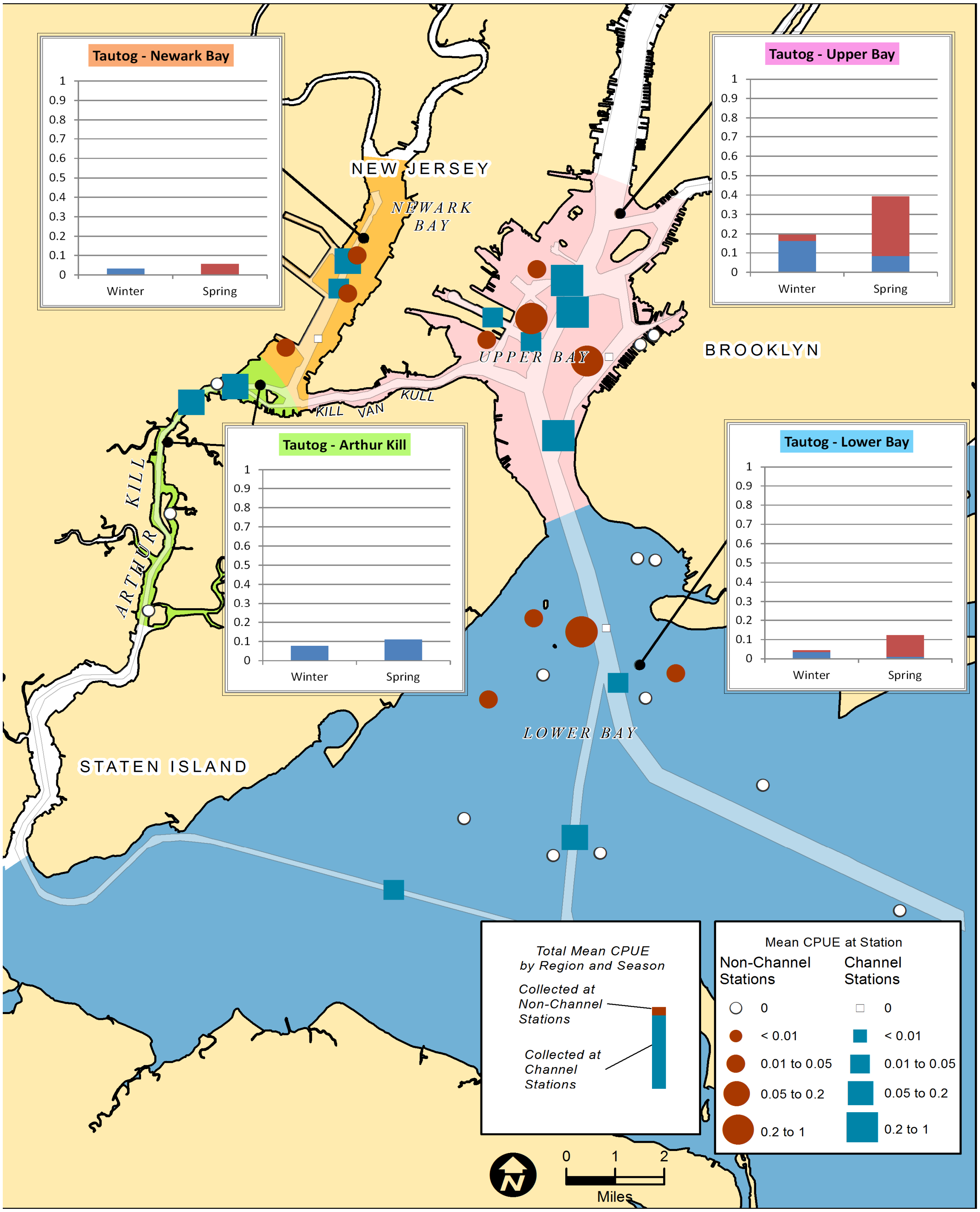

Figure C18. Tautog bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.

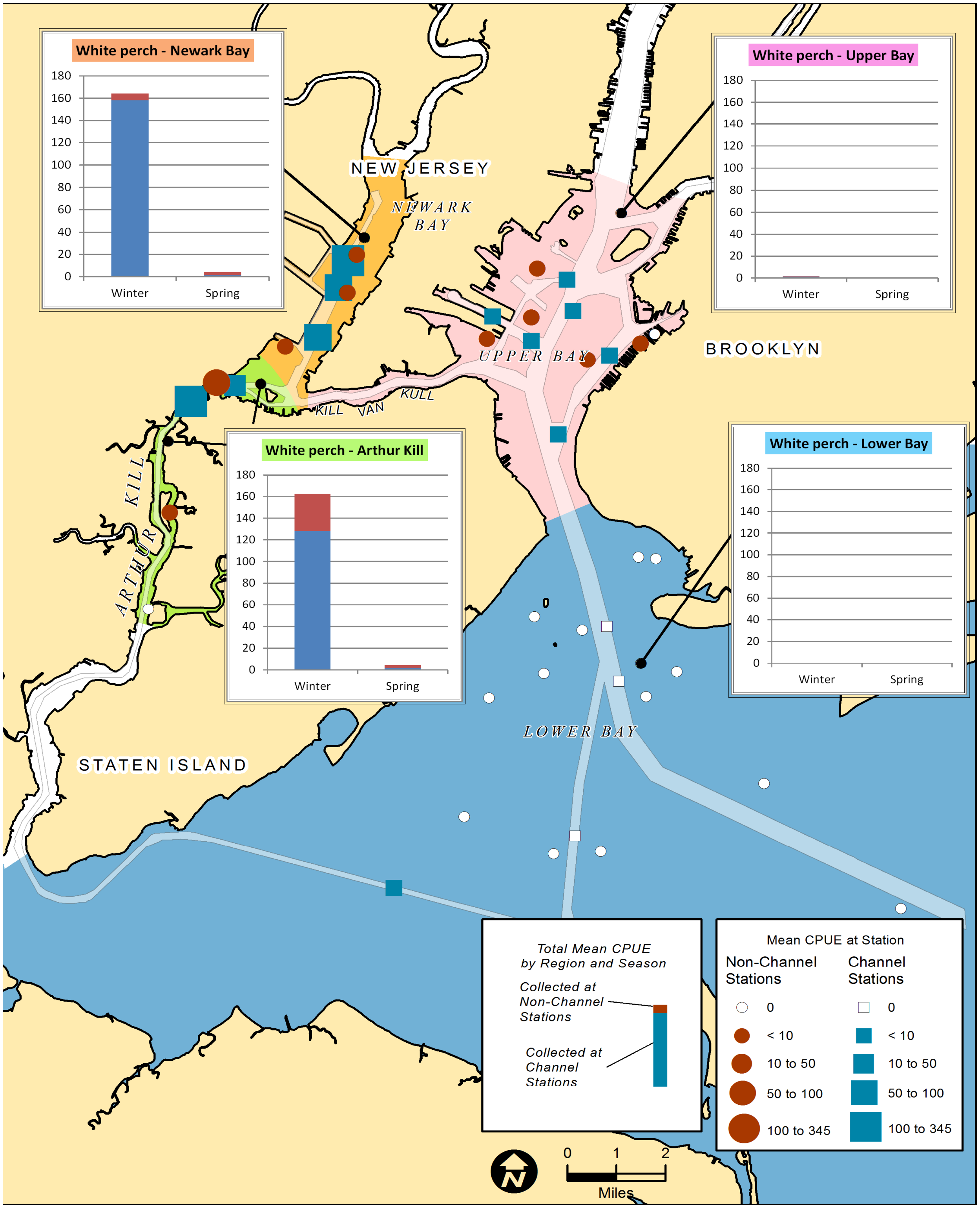

Figure C19. White perch bottom trawl abundance and distribution in the Harbor during winter (December – March) and spring (April – June) from 2002 to 2010.