Barnegat Bay— Year 3

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Executive Summary

While many estuaries in the northeastern U.S. are highly urbanized, such as Barnegat Bay, we do not understand the implications of urbanization on estuaries and especially for economically and ecologically important macrofauna such as fishes and crabs. The long term goal of this project is to determine how the macrofauna respond to urbanization by comparing the temporal (annual, seasonal) and spatial (among and within locations along the north-south gradient that vary in the extent of urbanization) variation in the Bay. During Years One, Two, and Three we sampled extensively at a variety of habitats (marsh creeks, submerged aquatic vegetation, open bay) with a variety of gears (plankton nets, otter trawls, gill nets) that allowed collection of most life-history stages (larvae, juveniles, adults) of representative fishes and crabs. In all 3 years the macrofauna was highly seasonal with abundance greatest in the summer across all habitats (submerged aquatic variation, marsh creeks, open bay). Variation in fish and juvenile blue crab abundance occurred across years with reduced numbers (but not species) during 2013 relative to 2012, but with highest values in 2014. These overall values were also correlated with macroalgae abundance. This variation might have been due to effects of Hurricane Sandy (Fall 2012) but the differences observed are difficult to separate from natural, year-to-year variation for lack of a longer time series that does not in which hurricanes did not make landafall here. Current work in the adjacent and connected estuary, the Mullica River/Great Bay estuary, by graduate student Katherine Nickerson examines a 24 year time series of juvenile fish collections to parse climate and event-related signals from other sources and, on completion, may be helpful in interpreting variation within Barnegat Bay. However, comparisons with similar sampling gear (otter trawl) from early (late 1970s/ early 1980s) and late (2012/2013) indicated that the fish fauna had changed. The fish faunal response over these decades suggest that some resident and cool-water migrant species (e.g. silver hake *Merluccius bilinearis*) are less abundant and have been replaced by warm-water migrants (e.g. northern kingfish *Menticirrhus saxatilis,* black drum *Pogonias cromis*). A prime example of a warm water migrant that is now so abundant that it is harvested in commercial and recreational fisheries is Atlantic croaker (*Micropogonias undulatus*).

There were no obvious, consistent differences among different locations of the same habitat type along the urbanization gradient. This finding may be confounded because this gradient co-varies with a salinity gradient and other variables such as tributary length. There was also no evident response at the small scale of urbanized vs. non-urbanized marsh creeks. The lack of obvious response to urbanization in Barnegat Bay may be accounted for in several ways. First, several factors external to the bay may be disproportionally contributing to the status of populations of fishes and crabs in the bay. For example, fishing pressure

elsewhere in the Mid-Atlantic Bight could contribute to the status of fishes at several life history stages by reducing adult fish populations and thus larval supply and subsequent recruitment to Barnegat Bay. Also, blue crab larval stages occur in the ocean and events there could influence their recruitment through inlets into the bay. Second, there may be multiple potential impacts (e.g. shoreline hardening, eutrophication, habitat destruction) that may contribute locally but not along the general north – south urbanization gradient. In fact, the contribution of urbanization may be part of an urbanization mosaic that varies also from one side of the bay to the other and is not easily distinguished among clusters of habitats. Rather, further analysis should focus on the relative contribution of individual habitats while continuation of of the current design for a longer time series would provide greater statistical confidence to the gauging of normal variation and thus the detection of anomalies. Another possibility is that response to urbanization follows threshold, rather than gradual linear change dynamic. In that scenario fish populations are relative stable within certain bounds due to ecological feedback mechanisms or through local adaptive behavioral response that allow them to continue to exploit degrading habitat until the system changes drastically. One obvious local example of urbanization that is known to effect fish populations is lagoon development such as Beach Haven West. Lagoons are distributed throughout the bay, although they are most abundant in the northern portion. In the instance of lagoons, habitat degradation has passed a threshold that makes negative effects detectable. This may not be the case for other potential impacts. Third, the habitat inventory may be reduced even while habitas within that inventory remain healthy, and this confounds detection in a balanced sample design. For example we sampled a similar number of creeks from strata along the natural to urban gradient and found similar fish assemblages, but the number of creeks themselves may change as an impact of urbanization. Fourth, the impact of local changes due to urbanization may be distributed across the bay for several reasons. Water in the bay largely moves from south to north as a result of the larger volume of water coming through Little Egg Inlet (Defne and Ganju 2014). Most importantly, fish and crabs are capable of extensive movements. Fourth, it is, in general, often difficult to determine fish population responses even though they may be obvious at the organismal level, such as for the effects of the Macondo Oil Spill on estuarine fishes (Fodrie et al. 2014).

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Introduction/Problem Statement

Many of the temperate estuaries in the northeastern U.S. are influenced by their densely human-populated watersheds (Joo et al. 2011, Cunico et al. 2011) and Barnegat Bay is perhaps the epitome of this increasing urbanization. However, while some of the effects of this urbanization are well documented (Kennish 1992, 2010; Kennish et al. 2007) the effects on the fauna are poorly understood. Fishes and crabs make up a large component of the faunal biomass in Barnegat Bay. They are the components that people want to harvest, either in recreational or commercial fisheries, and maintain in order to conserve the basic ecological functions of this important ecosystem. Since the last comprehensive studies of the Bay in the 1970's (Kennish and Lutz 1984) there has been increasing human population density and urbanization of the bay. This has occurred primarily from the densely populated northern upper bay to the less populated southern (Little Egg Harbor) lower bay, although the degree of human alteration varies between watersheds and barrier islands as well. The uncertainty regarding the effects of human alteration have prompted numerous efforts to positively influence Barnegat Bay, but until 2012 there was no comprehensive faunal monitoring in place to determine if the bay is declining, stable, or improving.

The long term goal of this project is to determine how the major components of the fauna (fish and crabs) respond to urbanization of Barnegat Bay by comparing the temporal (annual, seasonal) and spatial (along the gradient of urbanization) variation in the Bay. Embedded in this is a secondary goal of providing a baseline abundance and variability measure from which to assess long-term stability, improvement, or decline in the bay's condition. This approach incorporates most life history stages of fishes (larvae, juveniles, adults) and most stages of blue crabs. During Year Two, we continued to: 1) determine seasonal variation in species composition and abundance for larval fishes at Barnegat Inlet, Point Pleasant Canal and at Little Egg Inlet, 2) determine juvenile fish and blue crab distribution and abundance in SAV, non-SAV and in sub-estuary/tidal creek tributary habitats, and 3) across the same spectrum of habitats, determine the distribution and abundance of adult fish and adult blue crabs. Throughout this sampling effort we continued to emphasize representative fish species of economical (e.g. striped bass *Morone saxatilis,* white perch *Morone americana,* black sea bass *Centropristis striata,* tautog *Tautoga onitis*) and ecological (e.g. Atlantic silverside, *Menidia menidia*; bay anchovy, *Anchoa mitchilli*; Atlantic menhaden, *Brevoortia tyrannus* [and other Clupeids]; sand lance, *Ammodytes sp*.) importance. This sampling also included species known to be in decline (e.g. winter flounder, *Pseudopleuronectes americanus;* various herrings, *Clupiedae* spp.; American eel, *Anguilla rostrata*; and weakfish, *Cynoscion regalis*).

The potential response of the fishes and crabs to urbanization was measured across multiple life history stages by using a variety of sampling techniques. First, we extended an ongoing (since 1988) otter trawl survey in the lower bay (Little Egg Harbor) for juvenile and adult fish and crabs (Jivoff and Able 2001, Able and Fahay 2010a) to include the entire bay. This additional sampling concentrates on submerged aquatic vegetation habitats (eelgrass, widgeon grass, macroalgae), unvegetated areas, and subestuaries/tidal creeks along the gradient of human alteration. We evaluated the responses to the pattern of human alteration by using species composition, abundance and size data of these major faunal groups. Second, we determined the fish larval supply from the ocean and in the bay by using plankton net sampling at major inlets: Little Egg Inlet (sampling ongoing since 1989), Barnegat Inlet, and the Point Pleasant Canal (connecting Barnegat Bay to Manasquan River). Third, we determine the pattern of adult fish distribution and abundance along the gradient of human alteration in the bay by gill net sampling at selected locations. During Year Two we have modified the gill net sampling program to sample at night in order to increase the number of fish collected. Fourth, we analyzed the historical (late 1970s and early 1980s) data sources available on fishes and crabs in order to place our observations in 2012 and 2013 into a longer term perspective.

Project Design and Methods

Study Sites

Barnegat Bay is a shallow (average depth < 2 m, range 1 – 6 m), lagoonal estuary with a surface area of 279 km^2 that extends along the coast of New Jersey, USA, for approximately 70 km (Kennish 2001) (Fig. 1). This estuary is connected to the Atlantic Ocean at Little Egg Inlet and Barnegat Inlet. The Intracoastal Waterway channel, which runs the length of the bay, ranges from 1.5 – 3.7 m at mean low water. Exchanges between Great Bay and southern Barnegat Bay (Little Egg Harbor) occur at several thoroughfares through the Sheepshead Meadows which divides these two estuaries (Fig. 1). On flood tides one source of exchange between these estuaries is the flow from southern Barnegat Bay into Great Bay through Little Sheepshead Creek (Chant et al. 2000, Charlesworth 1968). At other nearby thoroughfares (Jimmy's Creek, Little Thoroughfare), flood tides flow from Great Bay into southern Barnegat Bay. Another source of exchange is through the Pt. Pleasant Canal between the bay and the Manasquan River estuary. Under normal conditions the water column in Barnegat Bay is well mixed although two layer flow may be evident in the deeper waters near the inlets and in the larger river tributaries (Carpenter 1963, Chizmadia et al. 1984). The flushing time for this bay varies seasonally and is reported to range from 27 – 71 days with the longest times during the summer (Guo et al. 1997). The tides are semidiurnal with highest velocities at Barnegat (>1 m/s) and Little Egg (> 2 m/s) inlets (Kennish 2001). Aspects of the circulation for the bay are available from Carriker (1961), Chant et al. (1996) and Defne and Ganju (2014).

Freshwater flow into Barnegat Bay comes from tributaries along the western shore of the bay with the largest tributaries north of Barnegat Inlet (Kennish 2001). Total surface inflow of freshwater into the bay represents about 2 – 3% of the tidal prism with other substantial contributions from groundwater. Mean salinity in the bay ranges from 18 – 25 ppt (range 8 – 32 ppt) with the highest salinities near the two inlets (Kennish 2001). Salinity is lowest (<15 ppt) off Toms River and to the north until the vicinity of the Pt. Pleasant Canal where values are higher. Subtidal circulation in the bay is driven primarily by coastal pumping (Chant 2001). Water temperature ranges from -1.4 to nearly 30 C^o with highest temperatures at the mouth of Oyster Creek due to thermal discharges from the Oyster Creek Nuclear Generating Station (Kennish 2001).

The dominant structural habitat types in Barnegat Bay include beds of submerged aquatic vegetation (SAV) consisting of eelgrass (*Zostera marina*) and widgeon grass (*Ruppia maritima*) isolated or combined, or macroalgae of various types and marsh creeks. SAV habitats, within otter trawl sampling locations, are most evident in the eastern portion of the bay (Fig. 4). However, SAV was detected in otter trawl tows at almost all sampling stations in the bay with the possible exception of marsh creeks. Those detections outside known SAV beds probably reflect movements of the SAV blades away from the beds. Macroalgae was dominated by sea lettuce (*Ulva lactuca*) (Fig. 5). The highest and lowest values of macroalgae were disbursed throughout the bay in both years. Notably high values occurred in urbanized areas in Tuckerton Creek and in the upper bay in both years. Others include open bay habitats with no well-defined structural components. Some of these habitats have been urbanized, which is most evident for marsh creeks especially in the upper bay.

To evaluate the impacts of urbanization within the bay on juvenile and adult fishes and crabs, we selected five spatially discreet sample strata which we called "clusters" (Table 2) along the north-south axis of the bay. The location of each cluster (Fig. 2) was influenced by our knowledge of habitat distributions within each cluster and in some instances by prior studies (e.g. OCNGS and the Beach Haven West study [Sugihara et al. 1979]). Within each cluster we selected sampling locations at an upper marsh creek and at the mouth of the same creek. Based on Figure 1 and our own experience (e.g. Szedlmayer and Able 1996, Jivoff and Able 2001), sampling sites included those that were urbanized and those that are fairly natural. The natural sites were chosen to correspond with the location of samples from previous studies in the central bay (Kennish and Lutz 1984). As representative habitats within each cluster, we chose two submerged aquatic vegetation (SAV) sites and two open bay sites (Table 3). We further characterized each habitat type based on visual observation of the dominant emergent vegetation (if present) bordering each habitat and the dominant type of submerged vegetation based on otter trawl samples (Table 3).

Sampling for Larval Supply to and Within the Bay

In order to evaluate the potential impact of urbanization, we first needed to understand the sources of larval fishes to the bay. Thus sampling of larval fishes was an important part of the study design although they are primarily a reflection of oceanic conditions and the health and position of adult broodstock in the ocean. Larvae were thus sampled near the inlets and major connections between elements of the Barnegat Bay estuary complex (Table 1, 2, 3; Fig. 1). We synoptically determined spatial variation in their occurrence and abundance at two inlets and four thoroughfares (Fig. 1, Table 1). Sampling locations for supply to the bay occurred at inlets (Little Egg Inlet Bay, Barnegat Inlet) and thoroughfares (Pt. Pleasant Canal between Manasquan River and Barnegat Bay, Jimmy's Creek and Little Thoroughfare between Great Bay and Barnegat Bay). These sites, all of which connect southern Barnegat Bay (Little Egg Harbor) to Great Bay, were selected based on their flow rate. Little Sheepshead Creek is one of the first thoroughfares to receive ocean water from Little Egg Inlet. As a result, samples from this creek are considered to represent both ngress of larvae into Little Egg Inlet from the Atlantic Ocean (e.g. Able et al. 2011, Sullivan et al. 2009) and transport of the larvae of resident species through Little Sheepshead Creek from Little Egg Harbor to Great Bay (Witting et al. 1999) (Table 1). Little Sheepshead Creek (3.8 km from inlet mouth) has the fastest flow rate and the greatest depth (3-4 m) of any thoroughfare sampled with flood waters moving from Little Egg Harbor into Great Bay. Jimmy's Creek has the slowest flow rate and shallowest depth (~1 m), and Little Thoroughfare has an intermediate flow rate and depth (~2.5 m). The latter two flood from Great Bay into Little Egg Harbor and Barnegat Bay. Another thoroughfare, the Pt. Pleasant Canal, connects northern Barnegat Bay to the Manasquan River and from there to the ocean (Fig.1). Simultaneous sampling at each thoroughfare occurred during night flood tides. Three 30 minute tows per creek occurred in May, June, July, August, and October of 2010, and February and April of 2011 (Table 1).

In addition, to assess degree of dispersal within the bay, we sampled at three sites (Oyster Creek Nuclear Generating Station [OCNGS], at the inflow and outflow sites of the power plant for supply to the in the central portion of the bay) and bridges over Rts 37 and 72 away from the inlets at the northern and southern portions of the bay respectively (Fig. 1, Table 1). Identical plankton nets were also used to sample fish larvae at four locations within the bay, two on the eastern and two on the western sides of the Bay on night flood tides (Fig. 1). Near Ship Bottom, samples were collected from a portion of the Rt. 72 bridge nearest to Long Beach Island at a site approximately equidistant between Little Egg and Barnegat Inlet (Table 1, Fig. 1). Samples were also collected from a portion of the Rt. 37 bridge nearest to the barrier island near Seaside at a site approximately equidistant between Barnegat Inlet and the Pt. Pleasant Canal (Fig. 1). At flooding tide, the flow at these two sites was from the south to the north. Two other sites were located at the cooling water intake and discharge canals of OCNGS (Fig. 1). Both of these samples were collected from the bridges over Rt. 9. At these two sites, the flow was nearly continuously toward the OCNGS and away from the OCNGS in the respective canals due to the cooling water pumps at the plant, although water depth changed with the tides (Kennish and Lutz 1984).

At all these locations larvae were collected with a 1 m-diameter (1 mm mesh) circular plankton net. The net was deployed with a flow meter to a depth of approximately 1.5 m. Collections were during the night time flood tide for three consecutive 30 minute sets (see Witting et al. 1999 for more details). All fish collected were brought back to the laboratory, preserved in EtOH and measured for total length by either ocular micrometer or a caliper and staged as either preflexion, flexion, or postflexion (Kendall et al. 1984). Plankton nets in the vicinity of estuary inlets (Fig. 1) were used to determine exchanges of larvae between the ocean and Barnegat Bay. Collections of ingressing larvae at Little Egg Inlet followed a weekly, ongoing sampling program for early stage, estuarine-dependent fishes at the Little Sheepshead Creek bridge (3.8 km from inlet mouth) that has been in place since 1989 (Able and Fahay 1998, Witting et al. 1999). This site has been previously sampled to detect long-term trends in larval fishes timing and abundance up to 2006 (Able and Fahay 2010a). For the present study, an identical protocol, but bi-monthly, sampling occurred over three years (2012, 2013, 2014) during the major seasons of larval ingress as previously determined (Witting et al. 1999) at this and Barnegat Inlet simultaneously (Table 1).

Sampling Juvenile and Adult Fish and Crabs

To determine the temporal response of juvenile and adult fishes and blue crabs during 2014, each habitat/location was sampled seasonally (spring, summer and fall) during the daytime using otter trawl sampling techniques (Table 2, 3, 4). All of the priority fauna (fishes, crabs) were collected with three 2-minute tows at each station using an otter trawl (4.9 m headrope, 19 mm mesh wings and 6.3 mm mesh codend liner). From each trawl tow, all fishes and selected decapods crustaceans (portunid, cancrid and majid crabs) were identified and counted. For each otter trawl sample the water depth, surface and bottom water temperature, salinity, dissolved oxygen, and pH was recorded with a hand-held YSI meter. Vegetation (SAV = eelgrass [*Zostera marina*] and widgeon grass [*Ruppia maritima*]) and macroalgae (includes several species grouped by tow and volume), was determined for each sample.

In order to determine spatial and temporal distribution of larger juvenile and adult fishes, during 2012 and 2013 sampling was conducted using anchored multi-mesh gill nets (15 m x 2.4 m with 5 panels of 5 mesh sizes [2.5, 3.8, 5.1, 6.4, and 7.6 cm box]) (Table 5). In June 2013 we compared day and night fish and crab abundance at the same sites and based on those findings, decided to sample only at night. Gill nets were set (2 nets per site) for 60 minutes during each sampling event.

To determine temporal (among months) and spatial (by major estuarine habitat, regional and local scales of urbanization) variation in adult blue crab population characteristics, we also sampled using standard, commercial-style blue crab traps (Table 6). In 2014, trap sampling for blue crab (*Callinectes sapidus*) occurred over four successive days in each month (May-August). Trap sampling locations mirrored the trawl sampling locations (except for upper creek habitats). Crab traps (2 per habitat) were placed at the collecting sites 24 hours prior to sampling (to ensure equal soak times among the sites) and baited daily (e.g., Atlantic menhaden [*Brevoortia tyrannus*]). Traps were sampled either for 3 (2012 & 2013) or 4 (2014) consecutive days in each month, May-August. In addition to trap sampling, we also tagged and released adult crabs at each creek mouth in the upper, central and southern areas of the Bay along the urban gradient (clusters V, III, and I). At each location we released 275 crabs in 2012 and 198 crabs in 2013. In 2014, the relatively low abundance of crabs (particularly in May and June) limited our ability to perform monthly tagging as in 2012 and 2013. Therefore, rather than one tagging day per month, we tagged crabs over four successive days in August and fewer crabs were tagged in 2014 as compared to previous years (cluster I: high urbanization-86, low urbanization-94; cluster III: high urbanization-62, low urbanization-89; cluster V: high urbanization-85, low urbanization-92). Unlike mark-recapture protocols that are designed to quantify fishing effort, our mark-recapture study is designed to assess movement of crabs within and between areas and to test the hypothesis that increased human urbanization (e.g., via increased human population size and thus increased fishing pressure) impacts blue crabs. We hypothesize that fishing pressure, particularly recreational, may reflect increased human urbanization and therefore we predict that recapture rates will positively correlate with the extent of human urbanization.

Data Analysis

We used a progression of multivariate iterative regression ordination techniques to examine the strength of species turnover along the various natural and anthropogenic gradients (McGarigal et al. 2000). We first subjected the 2012, 2013, and 2014 data sets together to a Principle Components Analysis (PCA) to examine latent trends in the assemblage and the difference among years as a possible response to Superstorm Sandy. Based on the pattern elucidated in that PCA (see Results and Discussion sections), we proceeded with separate analysis for each year's data set using Canonical Correspondence Analysis (CCA). Because SAV habitats in the bay and creek habitats in the marsh may be expected to be affected by urbanization through different mechanisms, for example, eutrophically enhanced epiphytic algal smothering of SAV as compared to human shoreline engineering in creeks, we compared species composition for these habitats in separate, focused analyses. Environmental/explanatory variables that were included in the CCA were temperature, salinity, pH, and dissolved oxygen. An additional categorical explanatory variable was included in analyses involving creek habitat to test the effect of urban vs non-urban creeks within a given urbanization zone. The same methods were applied to an examination of assemblage overturn using the current data and a historical data set collected in the late 1970s /early 1980s (detailed further in the Results section).

In preparing for assemblage analysis, we divided some species into life history stages (Table 7). We examined the size distribution of several species that use estuaries during different stages of their life cycle (e.g. juveniles vs adult) for different reasons (e.g. nursery vs spawning), and thus might respond to changes based on evaluation of different needs, stimuli, and external forcing (e.g. entry via transport vs by migration). These are all species (e.g. Weakfish [*Cynoscion regalis*], Atlantic croaker [*Micropogonias undulatus*]) that could be commonly encountered and were possible to catch by otter trawl. For this partitioning we used the monthly position of antinodes for each of these four species extracted from length frequency distributions published in Able and Fahay (2010a) as shown in Table 7. Once all data to be used in a given analysis were pooled, any species collected twice or less were removed to limit the effects on the analysis of rare species not adequately or regularly targeted by the sampling gear (e.g. Bluntnose stingray [*Dasyatis say*]). For historical analysis, where temperature change is of concern, species were categorized as resident, warm-water migrants, and cool-water migrants according to Tatham et al. (1984), with the exception of Atlantic croaker (*M. undulatus*) which was reclassified as a warm-water migrant following Miller and Able (2002). These groups were then tested for differences in rank abundance among years. For all ordination analyses, catch-per-unit effort was log-transformed. Where principle components analysis was appropriate, data were also centered and standardized. Ordination was performed in Canoco for Windows version 5.03. R version 3.0.2 (2013) was used to test for statistically significant differences between categorical ordination values where appropriate.

Differences in gill net catches between day and night were apparent and are not analyzed formally.

Quality Assurance

Our program has a NJDEP approved QAPP for 2012-2014. There were no deviations from the approved QAPP.

Results and Discussion

Environmental Variation

The measured environmental factors down the long axis of the bay were generally similar across the cluster of stations and across years (Fig. 3). The exception was salinity in which the values were lower in Cluster IV and V presumably because of influences from local rivers into the western portion of the upper bay.

A combination of hydrodynamic and particle tracking models of circulation in Barnegat Bay postulate a pronounced northward subtidal flow from Little Egg Inlet in the lower bay to Point Pleasant canal in the upper bay (Defne and Ganju 2014) This pattern, based on springtime conditions, causes more flushing in the lower bay and particle retention distribution in the upper bay. Variation in these factors respond to meteorological and offshore forcing in the model more so than to river flow.

The distribution and abundance of the dominant vegetated habitats may respond to the dominant circulation but also many other variables. Submerged aquatic vegetation such as eelgrass, *Zostera marina,* and widgeon grass (*Ruppia maritima*) were collected in otter trawls throughout Barnegat Bay (Fig. 4), although the known beds are most abundant in the upper bay. In our sampling, SAV occurred in all years in all portions of the bay but less was collected in 2014. The occurrence of SAV in the lower bay (Fig. 4) is likely due to drifting from the upper bay even though the postulated prevailing Spring time flow is from the lower to the upper bay (Defne and Ganju 2014).

The distribution of macroalgae (dominant species included sea lettuce [*Ulva lactuca*] and graceful red weed [*Gracilaria tikvahiae*]) was generally similar during each of the years sampled between 2012 – 2014) (Fig. 5). In each year, macroalgae occurred at every sampling station. The highest abundances often occurred in the upper Bay (Cluster V) and in the lower bay at Tuckerton Creek (Cluster I).

Gear Influences

The sizes of fishes collected in this study varied greatly by sampling gear (Fig. 6). The smallest individuals were larvae of a variety of stages (preflexion, flexion, postflexion) at small sizes collected by plankton net. Larger juveniles were collected by otter trawl. The largest individuals, representing both juveniles and adults, were collected by gill net.

The species composition and diversity (number of species) varied by gear as well, with 75 species of larvae collected by plankton net, 88 species of juveniles and adults collected by otter trawl, and the fewest number, 23, represented by juveniles and adults, collected by gill net (Table 8). Several species were represented in the collections of all gears including silver perch (*Bairdiella chrysoura*), Atlantic menhaden (*Brevoortia tyrannis*), weakfish (*Cynoscion regalis*), spot (*Leiostomus xanthurus*), southern kingfish (*Menticirrhus saxatilis*), Atlantic croaker (*Micropogonias undulatus*), black drum (*Pogonias cromis*), bluefish (*Pomatomus saltatrix*), Atlantic needlefish (*Stongylura marina*), hogchoker (*Trinectes maculatus*), and several crab species.

Larval Fish Supply

Supply to the bay. Sampling across inlets, thoroughfares, and within the bay varied markedly by larval stage (Fig. 7). Preflexion larvae constituted a small proportion at all of the above collecting sites; presumably as the result of the relatively large plankton net mesh size. Flexion larvae were consistently more abundant than preflexion larvae at all collecting sites. Postflexion larvae dominated all collections at inlets, thoroughfares, and within the bay. The lengths of larvae were similar at these three categories at all sampling sites (Fig. 8). The most abundant fish collected were 5-10 mm with declining proportions at larger sizes.

The geographical sources of larvae to Barnegat Bay vary seasonally and annually. Total larval fish density, across all sites and years, was fairly uniform across all seasons with inlets or thoroughfares or sites within the bay having peaks during different sampling months (Fig. 9). The most obvious peak was at thoroughfares in August. This was probably due to different species at different sites. In 2013, larval fishes collected at the inlets (Little Egg, Barnegat) and a thoroughfare between the Manasquan River and northern Barnegat Bay (Pt. Pleasant Canal) did not vary markedly in relation to flow (Fig. 10, 11).

The species collected included residents, i.e. those that remain in the bay or come back into the bay to spawn (e.g. bay anchovy [*Anchoa mitchilli*], naked goby [*Gobiosoma bosc*], Atlantic silverside [*Menidia menidia*], winter flounder [*Pseudopleuronectes americanus*], Northern pipefish [*Syngnathus fuscus]*) and transient species, i.e. those that spawned in the ocean and those which came into the bay from the ocean or adjacent estuaries (e.g. American eel [*Anguilla rostrata*], silver perch [*Bairdiella chrysoura*], Atlantic herring [*Clupea harengus*], summer flounder [*Paralichthys dentatus*]) (Table 9). The source of larval supply varied between years and locations for some representative species (Fig. 12, 13).

Among transient species spawned in the ocean, the pattern also varied within species (Fig. 12). For American eel (*A. rostrata*), peaks occurred in 2011 at Jimmy's Creek and in 2012 at the Pt. Pleasant Canal but this species was absent in 2013 at Barnegat Inlet (Table 10). For Atlantic menhaden (*Brevoortia tyrannus*) the prominent peak was at Little Egg Inlet (LSHCB) in 2013 but this species was not collected at Little Egg Inlet in 2011, Little Thoroughfare in 2011 and Pt. Pleasant Canal in 2012. For bay anchovy (*A. mitchilli*) which may spawn in the ocean and the bay (Able and Fahay 2010a), the largest peak was at Little Thoroughfare in 2010 and it was also very abundant in Little Egg Inlet in 2012 and Barnegat Inlet in 2013, but not abundant in Little Egg Inlet in 2013 or Little Thoroughfare in 2011 (Table 10). Other species (windowpane [*Scophthalmus aquosus*], cunner [*Tautogolabrus adspersus*]) were infrequently collected at most sites, but abundant at a few sites during a single year. Some species are known to spawn in both the estuary and the ocean. The density for several species varied between years as for bay anchovy (*A. mitchilli*) (greater in 2013 at Barnegat Light, but greater in 2012 in remaining sites) and winter flounder (*P. americanus*) (greater in 2013 at all sites). For Atlantic menhaden (*B. tyrannus*) and American eel (*A. rostrata*), the year of greater abundance varied with each site. Some species were common at most sites (bay anchovy [*A. mitchilli*]).

The occurrence of some species varied between locations. Some species such as sand lance (*Ammodytes* sp.) and Atlantic herring (*C. harengus*) only occurred in inlets but not at Pt. Pleasant, or were markedly reduced at the latter. One species, conger eel (*Conger oceanicus*), was only collected at Pt. Pleasant. Many species were collected at both inlets and Pt. Pleasant, including species that spawn in the bay (naked goby [*G. bosc*], northern pipefish [*S. fuscus*], winter flounder [*P. americanus*], Atlantic silverside [*M. menidia*]), the ocean (Atlantic menhaden [*B. tyrannus*]), or both (seaboard goby [*Gobiosoma ginsburgi*], windowpane [*S. aquosus*]). For resident species which spawn in the bays or estuaries, there was also considerable variation (Fig. 13).

Prior studies of larval supply to Barnegat Bay through Little Egg Inlet have characterized the seasonal variation in species composition (Witting et al. 1999), including relative to the adjacent inner shelf (Able et al. 2011), evaluated different sources of American eel (*A. rostrata*) glass eel (Able et al. 2015), and larval summer flounder (*P. dentatus*) relative to changes in stock status (Able et al. 2011), and to climate change induced changes in water temperature (Able and Fahay 2010a). These studies have also determined that the ingress of Atlantic menhaden (*B. tyrannus*) from Little Egg and Beaufort Inlets are from different sources and times in the ocean based on backcalculation of hatch dates (Warlen et al. 2002), and compared speckled worm eel (*Myrophis punctatus*) ingress across these two inlets as well as North Inlet (Able et al. 2011).

We also characterized the variation in species assemblage for this study across seasons and years, as well as across the spatial extent of the bay. Larval supply to Barnegat Bay through inlets and thoroughfares was assessed using principal components analysis (PCA) and canonical correspondence analysis (CCA). Data from 2010 – 2013 (Table 11) and from five sampling locations (Fig. 1, Table 1) were included in the analyses. Larval species composition (Fig. 14) was similar between years (Fig. 15) and did not differ much between sampling locations (Fig. 16). Larval supply varied monthly (Fig. 17) showing strong seasonality driven by temperature (Fig. 18).

Supply Within the Bay. – Larval fish delivery to nursery areas (e.g. marsh creeks, shallow open waters) on the western shore of Barnegat Bay was monitored by sampling at the intake and discharge for the OCNGS (Fig. 1). While the flow rates at the OCNGS (In and Out) were high relative to other within-bay sampling sites (Fig. 19), due to the pumps that provided cooling water to the power plant, the larval fish densities had overlapping values relative to the inlets and thoroughfares (Fig. 20, 21, 22). Some species had peak abundance at the OCNGS (Atlantic menhaden [*B. tyrannus*]; American eel [*A. rostrata*], which spawn in the ocean) or the lowest (winter flounder [*P. americanus*], which spawns in the estuary) values (Table 11). Those species which consistently occurred at the OCNGS included residents (e.g. naked goby [*G. bosc*], northern pipefish [*S. fuscus*], Atlantic silverside [*M. menidia*]), which is not surprising (Fig. 21). It is interesting that a number of species originating from spawning in the ocean also occurred consistently at OCNGS (e.g. American eel [*A. rostrata*], Atlantic menhaden [*B. tyrannus*]). These could have come from the closest source (Barnegat Inlet) or the source with the greatest volume of exchange (Little Egg Inlet) or through thoroughfares from Great Bay to Barnegat Bay or from a thoroughfare from the Manasquan River into Barnegat Bay (Table 12).

On the eastern side of the bay, at collecting sites at bridges on Rt. 37 and 72, there was similar variability across sites in 2014. Naked goby (*G. bosc*) and Northern pipefish (*S. fuscus*) occurred at most sites while Atlantic silverside (*M. menidia*) was most abundant at the OCNGS discharge but did not occur at Rt. 37 bridge (Fig. 21).

Larval supply within Barnegat Bay was also assessed using ordination techniques. Data from 2014 (Table 13) and from four sampling locations (Fig. 1, Table 1) were included in the analyses. Larval assemblage in waters to the bay (Fig. 23) did not vary much between sampling locations (Fig. 24), but differed on a monthly basis (Fig.25) again showing strong seasonality driven by temperature (Fig. 26).

Spatial Variation in Winter Flounder Larval Distribution and Abundance. – In an attempt to resolve the data patterns with other aspects of the life history, we focus on winter flounder (*P. americanus*). Earlier estimates of juvenile and adult abundance in New Jersey estuaries (Scarlett 1991) clearly show differences along a north-south cline with high abundances in the Manasquan River (CPUE=4.5 per tow, a source of larvae to northern Barnegat Bay), lower estimates for Toms River subestuary (CPUE=1.2) and lower values for Double Creek Channel (CPUE=0.5) and Little Egg Harbor (CPUE=0.2) with virtually none collected in more southern areas of New Jersey. These patterns presumably reflect abundance of spawning adults in these estuaries. Spawning in New Jersey has been documented by the presence of eggs and larvae in the Manasquan River (Scarlett and Allen 1992) and the Metedeconk and Toms Rivers (Scarlett 1993).

Spawning in Barnegat Bay takes place on the western, landward side of the bay, as occurs in other estuaries (Crawford and Carey 1985, Pearcy 1962). This is based on the consistent occurrence of mature males and females in a fyke net fishery in the winter in western Barnegat Bay in the vicinity of South Harbor. During the winter of 2008/2009, many of the adult (n=208, 200-459 mm TL) males (66%) and females (44%) captured there were running ripe based on our observations. Fertilized eggs were observed in the nets on February 19 (T. Malatesta, pers. observ.).

In addition, acoustically tagged fish, many of which were tagged from the same fyke nets, were tracked during the spawning season (Pravatiner 2010). These fish remained in northern Barnegat Bay until after the spawning season; those that were detected were found leaving the bay, presumably as part of a post-spawning migration into the ocean. Spawning may also occur in other areas of southern Barnegat Bay based on the high numbers of larvae consistently in Little Sheepshead Creek (Witting et al. 1999, Able and Fahay 2010a). We also found them in Jimmy's Creek and Little Thoroughfare (Table 10), which implies that larvae may be moving from Great Bay into southern Barnegat Bay. It is unlikely that larvae from spawning near South Harbor reach the thoroughfare at Little Sheepshead Creek, because the prevailing Spring time net flow is mostl likely from the largest inlet in Barnegat Bay (Little Egg Inlet) to northern Barnegat Bay based on recent analysis (Defne and Ganju 2014).

The interpretation of winter flounder (*P. americanus*) larval dispersal in Barnegat Bay is further confounded by the possibility of larvae from Great Bay to the south and the Manasquan River to the north (Fig. 1) entering Barnegat Bay on flood tides (Table 10). While winter flounder larvae were captured on flood tides at Barnegat Inlet, it is likely that these larvae from the ocean were initially transported out of the inlet on ebb tide and then back into the estuary on the subsequent ebb tide as occurs at Little Egg Inlet (Chant et al. 2000). This same back and forth transport may occur at thoroughfares as well. The net movement of the larvae, especially those at advanced stages (postflexion) may be mediated by selective tidal stream transport. The similarities in size and stage of larvae across all sampling sites may be a function of the relatively large plankton net mesh (1 mm) which precludes the collection of the small, preflexion individuals while the postflexion individuals are likely less numerous due to natural mortality. The low density of larvae in the Forked River and Oyster Creek tributaries on the western side of Barnegat Bay (Table 12) may not be reflective of other tributaries because of the altered flow in both creeks due to the cooling water pumps that greatly influence the flow in these creeks to and from the Oyster Creek Nuclear Generating Station. The variation in larval abundance across inlets, thoroughfares, and tributaries does not seem to be in response to temperature and salinity because most of these sites share similar values in the spring, with the exception of the tributaries which have lower salinities (Able et al. 2014).

More specifically, larvae were collected from all locations sampled in Barnegat Bay during 2010-2014 including two inlets and four thoroughfares between Barnegat Bay and adjacent estuaries (Fig. 13, 21, 22; Table 10, 12). The inlets included the southernmost location at Little Egg Inlet and the northernmost at Barnegat Inlet. The inlet sites had lower estimates of abundance than all other sites except the tributaries at the Oyster Creek Nuclear Generating Station, which were an order of magnitude lower at both the intake and discharge canals (Table 10, 12). The thoroughfares had the highest larval densities with some annual variation evident at Little Sheepshead Creek (Table 1). This variation was similar in magnitude to the overall larval density observed across all sites. These flood tide samples indicate that larvae were being transported from southern Barnegat Bay into Great Bay through Little Sheepshead Creek, and the reverse direction from southern Barnegat Bay into Great Bay from Jimmy's Creek and Little Thoroughfare, where the highest densities were found. Other larvae were transported from the Manasquan River estuary into northern Barnegat Bay through the Point Pleasant Canal. Alternatively, values obtained at the inlets and thoroughfares are not the result of one-way flow into Barnegat Bay but are the result of larvae being transported back and forth between these estuaries with the tides. All of these larvae, regardless of whether they were collected in inlets, thoroughfares or tributaries, were similar in stage and size (Table 9).

This interpretation of larval dispersal of winter flounder is supported by a spring time particle transport model developed by the USGS (Defne and Ganju 2014). When the model was seeded by particles released at South Harbor (just south of the OCNGS and in proximity of large collections of mature adults in a fyke net fishery). Virtual larvae after 30 days of dispersal were most abundant on the western shore in front of the OCNGS and over time, to the north up to the Metedeconk River (Fig. 27). As importantly, some of these larvae were transported out of Barnegat Inlet. This likely accounts for our larval collection of this species on flooding waters coming into Barnegat Inlet. Virtual larval release at Little Sheepshead Creek, where larvae are consistently collected (Fig. 28, Witting et al. 1999) also suggests that dispersal in Little Egg Harbor and southern Barnegat Bay, up to Barnegat Inlet and into Great Bay, and into the adjacent ocean. These larvae in the ocean could account for the larvae collected in Barnegat Inlet (Fig. 12) and previously reported coming into the inlet (Chant et al. 2001).

Together, these data suggest that fish larval supply to Barnegat Bay, through inlets and thoroughfares, is ubiquitous. Further, the occurrence of larvae from spawning in the bay is likely the result of being flushed from the bay and then transported back in. This "sloshing" effect makes determining the source and delivery mechanisms to settlement areas difficult to ascertain but it may also ensure broad scale delivery patterns regardless of where the larvae are from resident or transient species. Alternatively, this "sloshing" effect provides for multiple redundancies in larval supply and links ocean and estuarine habitats across space and time in New Jersey estuaries, as occurs elsewhere (Sheaves and Johnston 2008).

Limitations of Study. – There are several limitations that should be considered when interpreting the data from this study. First, the plankton net mesh is relatively large and this precludes the collection of small, preflexion larvae for many species. This is less of an issue, however, because the emphasis in this study was on species that spawned in the ocean and entered the estuary at larger flexion and postflexion sizes and stages. Further, the collectors were capable of collecting the larger flexion and postflexion stages of estuarine resident species. Second, the sampling, although synoptic at all collections, was relatively infrequent with sampling typically only five times per year. A prior analysis at the Little Egg Inlet site, based on six years of data, indicated that weekly samples were necessary to determine the pattern of seasonality for most species (Witting et al. 1999). However, the same study identified five seasons (winter, spring, early summer, late summer, fall) and our sampling approximated those seasons over two to three years.

Characterization of Juvenile and Adult Fish and Crab Distribution

The fish species composition from otter trawl tows in April, June, August and October was diverse and crabs varied by habitat in 2013 (Table 14, 15). Fishes were most abundant in SAV (CPUE = 12.3) and open bay (CPUE = 10.2) with lower values in creek mouth (CPUE = 9.3) and upper creek (CPUE = 6.4) habitats. For crabs, the greatest abundance was in upper creek (CPUE = 4.2) and SAV (CPUE = 4.5) habitats with lower values in creek mouth (CPUE = 1.9) and lowest in open bay (CPUE = 1.1) habitats (Table 15). Particular attention is focused on marsh creek habitats along the urbanization gradient (Fig. 1).

The juvenile fishes and blue crabs (*Callinectes sapidus*) collected by otter trawl during 2014 (Table 15) exhibited several patterns including distribution throughout the bay and species that were most abundant on the western shore or in the northern part of the bay (Fig. 29-41). These general patterns, for these dominant species, also indicate that they occur across the major habitat types (Table 15). Species with higher abundances in the open bay, relative to other habitats, include bay anchovy (*Anchoa mitchilli*) and Atlantic silverside (*Menidia menidia*). Those with highest abundances in SAV include four-spine stickleback (*Apeltes quadracus,* winter flounder (*Pseudopleuronectes americanus*), northern pipefish (*Syngnathus fuscus*), and blue crab (*Callinectes sapidus*) (also marsh creek – upper). Species with high values in marsh creeks include silver perch (*Bairdiella chrysoura*) (upper and mouth), Atlantic menhaden (*Brevoortia tyrannus*) (upper), and naked goby (*Gobiosoma bosc*) (upper and mouth).

The abundance and distribution of summer flounder (*Paralichthys dentatus*) had a clear seasonal pattern during each year (Fig. 37-39). The earliest collections in April captured only a few individuals. These were located on the western portion of the bay. By June, they were more abundant and found scattered throughout the entire bay. By August, abundance was reduced across scattered locations and by October there were ever fewer captured.

Those fishes captured by gill nets in year one and two were dominated by Atlantic menhaden (*B. tyrannus*), smooth dogfish (*Mustelus canis*), and spot (*Leiostomus xanthurus*) and the blue crab (*C. sapidus*) (Table 16). The spatial pattern of distribution of juveniles and adults varied between species (Fig. 40, 41). Atlantic menhaden (*B. tyrannus*) were fairly evenly distributed across the clusters of sampling sites in the upper (Cluster 5), middle (Cluster 3), and lower (Cluster 1) bay. Weakfish (*Cynoscion regalis*) occurred most consistently in the lower (Cluster 1), and middle (Cluster 3) and was least abundant in the upper (Cluster 5) bay. Spot *(L. xanthurus*) was distributed across all sampled portions of the bay but was least abundant in the middle of the bay. Species with more restricted distributions were smooth dogfish (*M. canis*) which were found in proximity to the major inlets (Cluster 1 and 3) but not in the upper bay (Cluster 5). Common spider crab (*Libinia emarginata*) was found primarily near Little Egg Inlet, as was Atlantic horseshoe crab (*Limulus polyphemus*).

During sixteen days of trap sampling in 2014 (4 days per month May-August), 3,574 crabs were captured: 2,426 blue crabs (*C. sapidus*), 757 spider crabs (*Libinia emarginata*), 380 long-nosed spider crabs (*Libinia dubia*), 3 green crabs (*Carcinus maenas*), and 8 rock crabs (*Cancer irroratus*). These relative abundance levels were very consistent with 2012 and 2013 such that blue crabs and the two species of spider crabs were the most common crab species captured in traps. Crab distribution, both among clusters and among habitats, was also consistent across the years. Blue crabs were fairly evenly distributed among the clusters (observed range of percent representation among clusters; 11.1%-27.8% versus an even distribution of 20%) while both species of spider crabs predominated in cluster I (annual range of percent representation in cluster I: long-nosed spider crab [*L. dubia*]-41.9%-79.2%; common spider crab [*L. emarginata*] -54.0%-65.6%). These three species of crabs also showed relatively distinct distribution patterns among habitats. Blue crabs were more often captured at creek mouths (annual range of percent representation at creek mouth; 57.0%-61.5% versus an even distribution of 25%), although they were evenly distributed between low urbanized versus high urbanized creeks (no greater than a 5% difference between low and high urbanized creeks). Common spider crab (*L. emarginata*) were typically in the bay habitat (annual range of percent representation at bay; 46.24%-61.5% versus an even distribution of 25%) while long-nosed spider crab (*L. dubia*) varied annually in the habitat in which they were most common (2012-creek mouth; 2013-bay; 2014 SAV).

Response to Superstorm Sandy

Sampling from 2012 and 2013 corresponds to the periods before and after Superstorm Sandy. Number of species and overall abundance (number of individual fish) differed in their response. The number of fish species collected in April (n = 18), June (n = 27) and August (n = 35) 2013 is similar to the number collected with the same otter trawl techniques and locations in April (n = 23), June (n =25) and August (n= 31) 2012. However, overall abundance (catch per unit effort, CPUE) is lower with number of individuals collected in April (n=470), June (n=1117) and August (n=3274) 2013 less than that, prior to the hurricane, in April (n=1301), June (n=3103) and August (n=5175) 2012 when catches in each month were greater. This is reflected in the average CPUE by year from otter trawl with a lower CPUE in 2013 relative to 2012 (Fig. 42a). This pattern for fishes is very similar to that for macroalgae (Fig. 42b). This difference occurred across multiple species including both residents and estuarine dependent transient species and also across warm and cold water migrants. For example, nine species (striped anchovy [*Anchoa hepsetus*], bay anchovy [*Anchoa mitchilli*], four-spine stickleback [*Apeltes quadracus*], silver perch [*Bairdiella chrysoura*], Atlantic menhaden [*Brevoortia tyrannus*], lined seahorse [*Hippocampus erectus*], pinfish [*Lagodon rhomboids*], spot [*Leiostomus xanthurus*], and northern pipefish [*Syngnathus fuscus*]) were more abundant in 2012 than in 2013. Three other species (Atlantic herring [*Clupea harengus*], Atlantic silverside [*Menidia menidia*], and winter flounder [*Pseudopleuronectes americanus*]) were more abundant in 2013 than in 2012.

Sampling (either by trap or trawl) for blue crabs in 2012 occurred prior to Sandy whereas sampling in subsequent years (2013 & 2014) occurred after Sandy thus comparing “pre” versus “post” Sandy years represents one way of estimating the potential effects of the storm. However, the life history of blue crabs (*Callinectes sapidus*) creates temporal variation in the relative abundance of different size categories of crabs in the estuary, such that depending on the month, crabs of different size categories in 2013 (the first post Sandy year), may not have experienced Sandy. As such, a simple analysis of total crab abundance in post Sandy years versus pre Sandy may not accurately assess the impact of the storm on blue crabs. Our size-specific analyses of annual blue crab abundance suggest no obvious negative effect of hurricane Sandy on adults (>120mm) but, Sandy may have contributed to reductions in the abundance of recruits (<30mm), although the relative importance of Sandy versus other factors is not clear.

Adult crabs in any month of 2013 are likely to have experienced Sandy. On average, 90% of blue crabs captured by trap are adults. The number of adult blue crabs (for this analysis ≥120mm to be conservative) captured by trap in 2014 (1,688) and 2013 (1,637) was very similar to (in fact slightly larger than) the number captured by trap over the same time-period and sampling sites as 2012 (1,602) suggesting no obvious negative effects of hurricane Sandy on adult blue crab abundance. Trawls also capture blue crabs in the adult size category. Based on June, August and October samples, none of the habitats showed a significant decrease in the number of adults captured between 2012 and 2013 (Fig. 43). In fact, baywide, there was a 3% increase in the abundance of adults between 2012 and 2013. Thus neither the trap nor trawl data suggest an obvious negative effect of hurricane Sandy on adult blue crab abundance. On average, 90% of blue crabs captured by trawl are sub-adults (recruits, juveniles and pre-pubertal females). Juvenile crabs in any month of 2013 vary, depending on their size, in whether they actually experienced Sandy. Between 2012 and 2013, there was a considerable (53%) decrease in the number of juveniles (30mm-110mm) captured in SAV (which continued to a lesser degree in 2014), a moderate (27%) decrease captured in the bay habitat, a small (10%) decrease captured at creek mouths but a gain (20%) in juveniles captured in upper creek habitats (Fig. 43). Baywide there was a 24% decrease in the abundance of juveniles between 2012 and 2013. Due to the timing of Sandy (October, 2012) and the arrival of recruits (≤ 10mm) into the estuary (June-October), these crabs would not have experienced Sandy in either 2012 or 2013, although the females producing recruits in 2013 would have gone through the storm. Therefore, the abundance of recruits in any month of 2013 could have been influenced by Sandy via the storm's impact on spawning females. All habitats showed decreases, to a varying degree, in the number of recruits captured during 2013 as compared to 2012 (Fig. 43). As with juveniles, the decrease of recruits in SAV between 2012 and 2013 continued in 2014, although to a lesser degree. Indeed, SAV was the only habitat in which the abundance of any life history stage failed to recover beyond 2012 levels in 2014 (Fig. 43). Baywide there was a 52% decrease in the abundance of recruits between 2012 and 2013. It is not clear if these differences are due to Superstorm Sandy, or annual variation or some combination of both since we have very little information on size-specific annual patterns of blue crab abundance in this system.

Historical Comparison

In an attempt to provide an historical perspective for the response of fishes to the urbanization of the Bay, we are evaluating historical data sets for all fish life history stages (Appendix Table 1, 2, 3). The most prominent legacy data sets come from environmental impact evaluations relative to the Oyster Creek Nuclear Generating Station (OCNGS). The National Environmental policy Act (NEPA) of the US EPA requires and Environmental Impact Study (EIS) in order to site a nuclear generating station, and the compliance with this was the source of the data and the best baseline for studying change in the bay's ecology. Our general approach is to compare the species composition and abundance from sampling programs in the late 1970s and early 1980s (hereafter referred to as the Early data) to our recent sampling in 2012 and 2013 (Late data).

A general comparison of the major fish groups identified in the 1970s – early 1980s (early) were compared to our recent collections during 2012-2013 (late) and recent findings for a set of sampling sites common to both the historical and current data set (Table 17, Fig. 44). Species were examined individually but also classified into guilds on the basis of their natural history. Among resident species (those that spawn and spend their adult life in the estuary,) there were a similar number of species (20 early vs. 21 later). For Cool Water Migrants (those species with general northern sub-boreal cool water affinities that move into the Mid-Atlantic during fall and winter months), there were also a similar number of species (10 vs. 11) with some decidedly less abundant in late collections (silver hake [*Merluccius bilinearis*]) and others which may have been common previously but not frequently collected in late collections (pollock [*Pollachius virens*], grubby [*Myoxocephalus aenaeus*], and American sand lance [*Ammodytes americanus*]). Others may have become more abundant (striped bass [*Morone saxatilis*]*,* Atlantic herring [*Clupea harengus*]). The most striking change is in the occurrence of fishes that are Warm-Water Migrants (those that have warm-temperate sub-tropical affinities with centers of distribution to the south, but that may migrate along shore to occupy Mid-Atlantic-Bight waters during the warm summer months. These include a large number of species which may have been present but have not been documented while others may be the result of expanded occurrence with warmer temperatures in recent years (Able and Fahay 2010a).

In further analysis, the first and second principle components of a PCA comparing the early and recent samples explained 12% and 10% of the variation in the catch data, respectively (Fig. 45). Early and Late samples separated along the first and second component axes. Kruskal-Wallis analysis of variance revealed significant differences between Early and Late observations along principle components one ($P < 0.0001$) and two ($P = 0.0045$). Resident and cool-water migrant species (Table 17) loaded heavily on the first axis and warm-water migrants loaded heavily on the second axis (Fig. 46).

Given that species separated out along the eigen-axes according to temperature preference, canonical correspondence analysis was used to examine the relationship between environmental variables collected at the time of sampling, including temperature, salinity, dissolved oxygen, and pH, and species composition (Fig. 47). Only 12.1% of the variation in species composition was explained by the environmental variables. However, canonical correlation coefficients were 0.77 and 0.62, respectively, for the first and second canonical axes and these two axes accounted for 89% of total variation explained by the environmental variables. Cool and warm-water migrants (Table 17) separated out along the first canonical axis, which was defined by temperature and to a lesser extent dissolved oxygen (Fig. 47). Cool and warm water migrants can both enter and use Mid Atlantic estuaries but, as here, separate seasonally or spatially to occur in samples of different month or temperature. Interestingly, early and late observations were better separated along the northwest diagonal in canonical space, which was most prominently defined by salinity and to a lesser extent dissolved oxygen, but not temperature. A closer examination of the environmental conditions during late and early collections revealed that salinity, more than temperature, dissolved oxygen, or pH differed between the two decades (Fig. 48). Changes in species composition between the late 1970s/early 1980s and 2012/2013 therefore cannot be attributed to differences in temperature collected at the time of sampling. In fact, it appears as though salinity and dissolved oxygen played a larger role in defining differences in species composition from the two decades sampled. Salinity in the bay can be affected by both natural local watershed conditions (e.g. rainfall and inlet hydraulics) and local and telegraphed anthropogenic conditions, such as creek alteration or inlet alteration, catchment and channel construction, impervious surfacing, and others). Of course environmental conditions at the time of sampling are not necessarily representative of conditions for the entire year and the temperature, salinity, pH, and dissolved oxygen effects at other stages of life history for some or all species may play a larger role in defining their distribution in Barnegat Bay over time. These changes over time, from fewer northern species and more southern species have also been reported for larval and juvenile fishes in the same region (Able and Fahay 2010a).

For larval fishes, we examined the most coherent and complete summaries from the early time period to our recent data. There are several factors which limit the application of these comparisons. First, the taxonomic level of the identifications is relatively coarse in the early reports (Table 18). In the early reports the number of taxa range from 14 – 23 while in our most recent sampling these range from 34 – 47. This is most often the result of only identifying some taxa to the family level in the earlier reports. This is most obvious for silversides (*Atherinidae*), combtooth blennies (*Blenniidae*), and gobies (*Gobiidae*). Second, the difference in sampling gear between the early and later collections likely accounts for these and other differences (Table 18). The smaller mesh used in the early collections (0.5 mm) probably retained smaller individuals which were harder to identify than in the later collections with larger mesh (1.0 mm) thus the homogenization to the family level in some cases. Third, the difference in mesh sizes may also account for the differences in abundance between early and late collections (Table 18). In almost every instance where a taxon is represented in both years of both the early and late collections, abundance is greater in the early collections. This is true for bay anchovy (*Anchoa mitchilli*), silversides (Atherinidae) (if we include all species), northern pipefish (*Syngnathus fuscus*), tautog (*Tautoga onitis*), combtooth blennies (Blenniidae), gobies (Gobiidae), hogchoker (*Trinectes maculatus*) and Northern puffer (*Sphoeroides maculatus*). It is likely that the smaller mesh sizes in the early collections retained more individuals than the larger mesh sizes in the later collections. However, it is hard to verify this because we have not been able to locate any length data from the early collections.

Response to Urbanization

In order to evaluate the response of fishes to urbanization, we first evaluated the latent trends in distribution and abundance of fishes and crabs in terms of assemblage dynamics. Next, we analyzed trends in fish assemblage that correlated significantly to measured environmental variables that could themselves co-vary with or be a result of urbanization. Finally, we provided a focused analysis on assemblage dynamics within creeks, where we might expect to see effects of urbanization most directly as engineered alterations (rather than non-point source) to important sub habitats within the bay at the bay-land interface.

Species assemblage turnover among years

We examined the latent variation in assemblage of Barnegat Bay fishes and crabs from trawl samples through Principle Components Analysis (PCA). The specific abundance of fishes and crabs from all trawls (usually 3, but on rare occasions 2) of a site on quart-annual sampling event were transformed to catch-per-unit-effort and then log(y+1) transformed to mitigate heteroscedasticity. Individual trawls within a site are not independent and so were treated as pseudo replicates, but trawl impacts to a site among months are assumed to be negligible and therefore independent. PCA results were plotted as biplots with scaling focused on among-sample difference and centered on species. Sample symbols in the plot were coded (post-hoc) by year of collection and also by habitat type.

Of 102 nominal species documented in the total catch over all stations, all years, 57 were included in PCA. The first two eigenaxes accounted for the majority (58.8%) of the total variation (Table 19, Fig. 49). There was little discernable difference in sample scores among years, with the exception that that samples from many sites and (especially SAV) had somewhat more of the driver species in 2014 than in 2012 or 2013. The first axis was recognizable as a seasonal trend that held among years, with the greatest driver of variation being the abundance of bay anchovy (*Anchoa mitchilli*) and to a lesser extent a co-varying spring-time increase in silver perch (*Bairdiella chrysoura*), spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*), weakfish (*Cynoscion regalis*), and striped anchovy (*Anchoa hepsetus*) along Axis 1 and blue crab (*Callinectes sapidus*), four-spine stickleback (*Apeltes quadracus*), northern pipefish (*Syngnathus fuscus*), Atlantic silverside (*Menidia menidia*), and winter flounder (*Pseudopleuronectes americanus*) along Axis 2 (Fig. 50). This second mode was recognizable as an abundance trend principally of those species in SAV habitat (with some outstanding samples), followed by creek mouth habitats (Fig. 51).

Species assemblage turnover relative to environmental factors and urbanization

In order to relate the species assemblage turnover to environmental factors, including those related to urbanization, we used a direct analysis approach, Canonical Correspondence Analysis (CCA) to reduce variation to the most important dimensions that were significantly related to measured environmental variables. Species abundance was treated as for PCA (above) but all species were included. Environmental variables of salinity, temperature, water column depth, turbidity (Secchi disk light extinction coefficient), pH, and dissolved oxygen (mg/L), were included as environmental variables. Environmental variables were unit-variance standardized and centered. Results were plotted as a biplot of environmental gradients and samples with sample symbols representative (post-hoc) of the previously-designated Urbanization Cluster, and again with samples coded by habitat type, and species plotted separately (but in the same coenospace) for legibility.

Constrained eigenaxis (sum of all canonical eigenvalues = 0.734) accounted for only 5% of the unconstrained (latent) variation (Sum of all eigenvalues = 13.711) in assemblage among 571 site/month/year samples containing 102 species (Table 20). Of that 5%, 22% was explained by the first constrained eigenaxis, and 11.7 % to 9.4% by the next 3. Therefore the first eigen axis explained almost double the second and together with it explained nearly 605 of the constrained variance. This pattern was non-random based on significance testing (alpha = 0.05, F-ratio = 9.164, P = 0.0020, for test of significance of first canonical axis, and F-ratio = 3.524, P = 0.0020 for test of significance of all canonical axes).

The sample distribution from all clusters, all habitats overlapped especially during winter or early spring (Fig. 52,53) collections when the bay was generally depauperate but differentiated later in the season by both cluster and habitat because of both species and environmental differences. In particular, the most urban Cluster 5 and most natural cluster 1 differentiated along Eigenaxis 1 with higher salinity and dissolved oxygen in especially the SAV habitats of the natural cluster and lower dissolved oxygen and salinity but warmer temperature in the northern bay environment. Those bay environments were not characterized by unique species, but rather by slightly fewer individuals of species that were more common elsewhere. Upper creek habitats particularly of Cluster 2 had a slightly freshwater signature with pumpkin seed and a higher a tendency to hold white perch and white mullet, while bluntnose stingray (*Dasyatis say*), horse-eye jack (*Caranx latus*), scup (*Stenotomus chrysops*), smooth dogfish (*Mustelus canis*), striped anchovy (*Anchoa hepsetus)* and other species associated with the continental shelf were exclusively or more like to be found in creek mouth, SAV, or bay samples (i.e., non-creek samples) of cluster 3 (Fig. 54). Thus the trend was evident as one of salinity gradient and proximity to tidal influx from the ocean inlets. Urbanization stabilized the presence and location of these inlets.

Species assemblage turnover in urbanized and natural creeks

Species assemblage turnover among natural and urbanized creeks was also performed in isolation from all other samples to examine potential differences of samples closely associated with engineered (dredging, bulkheading, paving of adjacent upland) impacts. This analysis also utilized CCA, but only on upper creek sites. Specific monthly CPUE was averaged for each upper creek site across all sampling events (year, month) into a new single CPUE value for that site. This had the effect of smearing both seasonal and annual within-site differences, so that those replicates serve only to increase the confidence of which species a site holds over time. Environmental factors were likewise averaged over all sampling events within a site Scaling and CPUE were treated as before. Samples in the resulting triplot were post-hoc coded as “natural” and “urbanized.”

Sample amalgamation resulted in 10 samples (two creek types in each of five clusters) having 53 species in 170 occurrences. The sum of CCA eigenvalues (1.345) accounted for most (74.5%) of the sum of all unconstrained eigenvalues (1.803). Of this, 38% (thus 28.3% of total) was accounted for by the first eigenvalue, and a similar amount (30%) by the second (Table 21). Amalgamated samples did differentiate among urbanization class in post-hoc examination, but only along the second and weak Eigenaxis. Both natural and urban creeks were represented by examples of salty and fresh conditions, deep and shallow, low and Hi DO, and clear and turbid conditions. All factors covaried positively (Fig. 55). However, natural creeks on average were slightly warmer than urbanized creeks and differed in assemblage due to a few standouts in both types. One natural creek had a very “southern” assemblage which included unique (to it) species: bluntnose stingray (*Dasyatis say*), smallmouth flounder (*Etropus microstomus)*, grey snapper (*Lutjanus griseus*), lookdown (*Selene vomer*), rock crab (*Cancer irroratus*), and northern kingfish (*Menticirrhus americanus*), while an urbanized creek had a more “reef-typical” assemblage with unique (to it) species: tautog (*Tautoga onitis*), feather blenny (*Hypsoblennius hentz*), lined seahorse (*Hippocampus erectus*), common spider crab (*Libinia emarginata*), and also spotted hake (*Urophycis regia*) (Fig. 56). Bay anchovy (*Anchoa mitchilli*), spot (*Leiostomus xanthurus*), and blue crab (*Callinectes sapidus*) were ubiquitous. A freshwater assemblage including channel catfish (*Ictalurus punctatus*), pumpkinseed (*Lepomis gibbosus*), bluegill sunfish (*Lepomis macrochirus*), and yellow perch (*Perca flavescens*) was identified from one urbanized site despite a very similar salinity and temperature regime to a natural creek; this appears to be the result of a historical and persistent connection with a freshwater creek which was dredged to become a housing development creek at the lower (bayside) extremity, while the natural creek received only overland or interstitial freshwater flow.

The species-environment correlation was very strong, but the differentiation in these variables among sites was so weak that there was no confidence that it might not have sorted differently based on the included environmental variables; significance testing suggests that the scores of these samples along the axes could have been placed at random with similar results (Test of significance of first canonical axis: F-ratio = 0.803, P = 0.9940, Test of significance of all canonical axes : F-ratio = 1.469, P = 0.2480).Thus, at the amalgamated level, the samples could be expected to be the same on this basis, and their apparent difference owes to an unmeasured variable, or else to short-term differences among them.

Characteristics of Urbanization Clusters

The degree of urbanization of the five clusters along Barnegat Bay were determined from NJDEP 2007 data, the most recent available (Fig. 1, Table 1). This is based on six variables (Agricultural, Barren Land, Forest, Urban, Water, and Wetlands) for land use in each cluster. The degree of urbanization varies as a gradient from the most highly urbanized clusters in the northern part of the bay (IV, V) to the least urbanized in the southern part of the bay (I, II, III). The values for degree of urbanization correspond to the estimates of human population (Table 1) and generally, to the increased percent of wetlands in the southernmost clusters (I, II). The other variables have low values (percent Agricultural, Barren lands, Forests) or have fairly similar, but variable, values for percent water.

Within each cluster, we selected representative habitat types including beds of submerged aquatic vegetation, tidal creeks (upper and lower), and open bay for sampling fishes and crabs (Fig. 1, Table 2). Preliminary analyses of these habitats vary by cluster as well. The more urbanized clusters have fewer marsh creeks with borders of emergent vegetation (Table 2); instead the edge consisted of dredged canals with bulkheaded shorelines. This was most evident in Clusters IV and V while naturally vegetated shorelines were most evident in Clusters I and II. Average creek length is greater in Clusters I, II and III while the degree of urbanization is highest in Clusters III, IV and V (Fig. 1, Table 1).

During 2013 there was little variation in environmental factors across the clusters of study sites in Barnegat Bay (Fig. 3). The exception was salinity in which the values were lower in Cluster IV and V presumably because of influences from local rivers into the western portion of the upper bay.

Analysis Across the Urbanization Gradient

Because SAV habitats in the bay and creek habitats in the marsh may be expected to be affected by urbanization through different mechanisms, for example, epiphytic algal from eutrophication smothering of SAV as compared to shoreline engineering in creeks, and scars plowed by boat motors in shallow water, we compared species composition for these habitats in separate, focused analyses. In addition, because catch data from 2012 was significantly higher than in 2013 (see the *Response to Superstorm Sandy* section), we compared species composition across the urbanization gradient separately for both years. Environmental/explanatory variables that were included in the CCA were temperature, salinity, pH, and dissolved oxygen. An additional categorical explanatory variable was included in analyses involving creek habitat to test the effect of urban vs non-urban creeks within a given urbanization zone.

For samples collected in SAV beds in 2012, depth best explained variation of otter trawl collections along the first canonical axis (explained variance of 27%) while temperature and inversely covarying dissolved oxygen explained most of the variation along the second canonical axis (18% explained variance) (Fig. 56). Clusters did not separate from each other in gradients, but samples from Cluster 5 had a narrower and more centralized distribution on the first axis than did the other clusters, signifying a somewhat less dynamic assemblage. In general, this points to an assemblage that is available to all SAV sites within the estuarine complex but within which depth and secondarily temperature influences fish distribution of distribution. This pattern was very much emulated in 2013 with some moderate differences; salinity became an important co-variate of depth on the first axis, the first two eigenvalues were relatively stronger than the in 2012 (likely due to lesser overall abundance which results in lower inertia) at 31% and 22% explained variance respectively, and that the categorical clusters separated more strongly (Fig. 58). Blue crab (*Callinectes sapidus*) and four-spine stickleback (*Apeltes quadracus*) were more closely associated with the urban clusters while oyster toadfish (*Opsanus tau*), summer flounder (*Paralichthys dentatus*), and northern puffer (*Sphoeroides maculatus*) were more associated with the natural end of the gradient.

Abundance data (in the form of crabs per trap) were analyzed using a 4-way ANOVA with year, month, cluster, and habitat type as the independent variables. Blue crab abundance exhibited a significant amount of variation both temporally (month and year) and spatially (cluster and habitat type) (see Fig. 59). However, no independent variable or interaction between independent variables explained more than 7% of the variation in blue crab abundance. In addition, none of the habitat types showed a consistent effect of the regional urbanization gradient (i.e., among clusters), nor did any of the clusters show a consistent effect of local urbanization (i.e., low versus high urbanized creek) on blue crab abundance.

One characteristic of the adult blue crab population that varied consistently along the urbanization gradient was sex ratio, although the type of gear and the age class of females considered also contributed to variation in sex ratio (Table 22). In all years, the sex ratio of adult crabs captured in traps was consistently male-biased (Table 23). In 2012 and 2013, the clusters in lower urbanized areas (I, II, III) had lower sex ratios while the clusters in higher urbanized areas (IV and V) had considerably higher sex ratios (Table 22). This pattern was repeated in 2014, however with larger but more uniform sex ratios at all clusters, except for cluster V, which had the largest ratio (Table 22). This pattern continued when prepubertal females were also included in the sex ratio calculation, although the ratios and the change in ratios across the regional urbanization gradient were both reduced (Table 22). The adult crabs captured by trawl also exhibited male-biased sex ratios, albeit more spatially variable than traps, with the largest sex ratios at cluster V (Table 22). With prepubertal females included, in each year some ratios became female-biased and only 2013 exhibited a much higher ratio at cluster V (Table 22). Based on evidence from other estuaries in the mid-Atlantic and from our other blue crab population studies in Barnegat Bay, we suspect that higher sex ratios, particularly at cluster V, are more of a response to salinity than to urbanization per se. To separate these confounding effects, we used statistical techniques to remove the effect of salinity in order to focus on the potential urbanization effect. Briefly, using ANOVA we tested the effect of cluster on the fraction of males (# males/# total crabs) and sex ratio (# males/# females) using all data and data selected from a narrow salinity range (24-26ppt) shared by most clusters, thus eliminating the influence of salinity. Unfortunately, this also eliminated cluster 5 because salinities within the selected range did not occur there. With all data included, both the average fraction of males and sex ratio increased between clusters 3 and 4, with the highest values, particularly sex ratio, occurring at cluster 5 (Table 23). However, with data from a narrow salinity range, neither male fraction nor sex ratio differed among the clusters (Table 23) suggesting that salinity is a more important driver of sex ratio variation than urbanization.

The size frequency distribution of blue crabs captured in traps varied along the urbanization gradient. Clusters I and II were similar to one another (KS test, P=0.26) and clusters IV and V were similar to one another (KS test, P=0.50) but both differed from clusters I, II and III (KS tests, all P<0.001). Both clusters IV and V had relatively more crabs in each size category between 90-120mm than the other clusters and, unlike clusters I, II, and III, shared a distinct mode at 120mm (Fig. 60). In each cluster, the size frequency distribution of the high urbanized creek did not differ from that of the low urbanized creek (KS tests, all $P>0.05$). Overall the annual size frequency distribution of blue crabs captured in traps was similar both among years and among the habitats: the mode at the bay, SAV and high urbanized creek habitats was consistently 120mm and this was true for the low urbanized creek habitat in 2012 and 2014 (the mode was 130mm in 2013) (Fig. 61).

The size frequency distribution of crabs captured by trawl varied by cluster such that each cluster was statistically unique compared with all other clusters (KS tests, all $P<0.05$). All clusters contained the entire size range of crabs ($\leq$10mm-$\geq$150mm) but for some size categories, clusters IV and V (higher urbanized areas) were distinct from clusters I and II (lower urbanized areas). Clusters I and II exhibited single, indistinct modes at 20mm with similar abundances at most size categories, except 40mm where cluster I exceeded cluster II (Fig. 62). Cluster III exhibited a more distinct mode at 20mm, shared higher abundances of 50mm-70mm crabs than clusters I and II with clusters IV and V, and contained a second, although less distinct, mode at 80mm. Cluster III was the only cluster that showed evidence of bimodality and had greater abundances than all other clusters between 80-130mm (Fig. 62). Higher urbanized clusters exhibited modes at 10mm (although relatively weak at cluster IV this mode was very clear at cluster V) and these clusters contained more crabs between 50mm-70mm than the less urbanized clusters (I and II). Taken together, the size frequency distributions from the trap and trawl suggest that clusters IV and V contain relatively more crabs from the juvenile to small adult size classes (50mm-120mm) than clusters I and II, however it is not clear if this is a response to urbanization or to salinity, as suggested above for sex ratio variation, or to some combination of variables.

There is some evidence that blue crabs were influenced by variation in local urbanization and that this effect was somewhat consistent across the regional urbanization gradient. In each cluster (except cluster IV), the size frequency distribution of crabs captured in upper creek habitats differed significantly between low and high urbanized creeks (KS tests, all $P<0.001$). In clusters I, II, IV (although not statistically significant) and V, high urbanized upper creeks lacked small juveniles and recruits ($\leq$20mm) (Fig. 63) suggesting these areas are less attractive to small crabs (i.e., don't use them) or provide less refuge against predation (i.e., suffer greater mortality). Upper creek habitats, especially less urbanized ones, appear to be more important areas for small crabs in the less urbanized region of the estuary (clusters I and II), compared to more urbanized areas (clusters IV and V) (Fig. 62). The low urbanized upper creek in cluster III (Oyster Creek) exhibited a very different size frequency distribution than creeks of this type in all other clusters (KS tests, all $P<0.001$) (Fig. 63). The upper habitat of Oyster Creek contained almost no small crabs ($\leq$30mm) and had a much larger mode (80mm) than similar habitats in all other clusters (I=20mm, II=10mm, IV=50mm and V=40mm). It is not clear if this shift towards larger juveniles in Oyster Creek is the result of altered habitat use by those crabs or if smaller crabs exhibit different growth rates in this creek (as a result of warmer temperatures due to effluent from OCNGS).

In 2014, the relatively low abundance of crabs (particularly in May and June) limited our ability to perform monthly tagging as in 2012 and 2013. Therefore, rather than one tagging day per month, we tagged crabs over four successive days in August. Across all three years of the study, we tagged similar numbers of crabs in each cluster and creek type (Fig. 64). The tagging effort incorporated both regional (among clusters) and local (between creek types) variation in urbanization. The movement rate (distance per days at large) of recaptured crabs was not influenced by cluster ($F_{2,114}$= 0.65, P=0.52) or creek type ($F_{1,114}$= 0.08, P=0.78). On average, recaptured crabs moved one kilometer per day or less, except at cluster V where the average was about 2km/day, and movement was quite variable (Table 24). The majority (90%) of recapture crabs moved less than 1km per day. The movement data suggest that recaptured crabs rarely moved between clusters. The number of days recaptured crabs were at-large was not influenced by cluster ($F_{2,114}$= 0.80, P=0.45) or by creek type ($F_{1,114}$= 0.77, P=0.38). On average, recaptured crabs were at-large for 20 days or less and at-large durations were highly variable (Table 24). Most (60%) were recaptured in less than one week. Taken together the movement and days at-large data suggest that fishing pressure is intense enough so that tagged crabs were recaptured relatively quickly, and (2) recaptured crabs did not move far from their point of release before they were recaptured. Therefore, recapture rates are probably a good reflection of the extent of local fishing pressure near the release points.

Along the regional urbanization gradient, we expected the number of recaptured crabs to increase with the degree of urbanization. This was particularly true for crabs released at low urbanized creeks (χ^2, df=2, P<0.001) (Fig. 64). For crabs released at high urbanized creeks, there was less of a correlative effect, but more were also recaptured in the highly urbanized area (i.e., cluster V) of the estuary (χ^2, df=2, P<0.001) (Fig. 64). Within each cluster, a comparison of recapture rates between creek types (low versus high urbanization) tests the influence of local urbanization. We anticipated greater recapture rates near the high urbanized creeks in each cluster. However, recapture rate differences between the creek types were cluster-specific (Fig. 64). In the low urbanization area (Cluster I), the recapture rate was greater for crabs released at the high urbanized creek (χ^2, df=1, P<0.001); in the moderate urbanization area (Cluster III), the recapture rate was greater for crabs released at the low urbanized creek (χ^2, df=1, P<0.001); in the high urbanization area (Cluster V), recapture rates did not differ between the creek types (χ^2, df=1, P=0.15). One factor that may help explain the local differences in each cluster may be the type of fishermen that reported recaptured crabs (recreational versus commercial) and the relative extent of recreational versus commercial fishing in those locales. Recreational fishermen dominated the reported recaptures in both cluster I (χ^2, df=1, P<0.001) and III (χ^2, df=1, P<0.001) but reported recaptures were equally distributed between commercial and recreational fishermen in cluster V (χ^2, df=1, P=0.88). Based on our observations, there appears to be more recreational fishing at the high urbanized creek (Tuckerton Creek) in Cluster I, but more recreational fishing at the low urbanized creek (Oyster Creek) in cluster III. Thus, the local differences in the extent of (recreational) fishing may be as important as local variation in urbanization for explaining tagged crab recapture rates.

There were no obvious, consistent differences among different locations of the same habitat type along the urbanization gradient. This finding may be confounded because this gradient co-varies with a salinity gradient and other variables such as tributary length. There was also no evident response at the small scale of urbanized vs. non-urbanized marsh creeks. The lack of obvious response to urbanization in Barnegat Bay may be accounted for in several ways. First, several factors external to the bay may be disproportionally contributing to the status of populations of fishes and crabs in the bay. For example, fishing pressure elsewhere in the Mid-Atlantic Bight could contribute to the status of fishes at several life history stages by reducing adult fish populations and thus larval supply and subsequent recruitment to Barnegat Bay. Also, blue crab larval stages occur in the ocean and events there could influence their recruitment through inlets into the bay. Second, there may be multiple potential impacts (e.g. shoreline hardening, eutrophication, habitat destruction) that may contribute locally but not along the general north – south urbanization gradient. In fact, the contribution of urbanization may be part of an urbanization mosaic that varies also from one side of the bay to the other and is not easily distinguished among clusters of habitats. Rather, further analysis should focus on the relative contribution of individual habitats while continuation of of the current design for a longer time series would provide greater statistical confidence to the gauging of normal variation and thus the detection of anomalies. Another possibility is that response to urbanization follows threshold, rather than gradual linear change dynamic. In that scenario fish populations are relative stable within certain bounds due to ecological feedback mechanisms or through local adaptive behavioral response that allow them to continue to exploit degrading habitat until the system changes drastically. One obvious local example of urbanization that is known to effect fish populations is lagoon development such as Beach Haven West. Lagoons are distributed throughout the bay, although they are most abundant in the northern portion. In the instance of lagoons, habitat degradation has passed a threshold that makes negative effects detectable. This may not be the case for other potential impacts. Third, the habitat inventory may be reduced even while habitas within that inventory remain healthy, and this confounds detection in a balanced sample design. For example we sampled a similar number of creeks from strata along the natural to urban gradient and found similar fish assemblages, but the number of creeks themselves may change as an impact of urbanization. Fourth, the impact of local changes due to urbanization may be distributed across the bay for several reasons. Water in the bay largely moves from south to north as a result of the larger volume of water coming through Little Egg Inlet (Defne and Ganju 2014). Most importantly, fish and crabs are capable of extensive movements. Fourth, it is, in general, often difficult to determine fish population responses even though they may be obvious at the organismal level, such as for the effects of the Macondo Oil Spill on estuarine fishes (Fodrie et al. 2014).

<u>Responses to Selected Natural Resource Assessment and Management Charge Questions (Sustainable Fisheries)</u>

The responses to the following selected Charge Questions regarding Barnegat Bay are based on two sources: 1) three years of intensive data collection during the current project, and 2) the 25+ years of experience in this estuary by RUMFS personnel. The responses to similar questions are grouped together.

1. Has the increasing human population density and urbanization of the bay had an effect on the abundance and diversity of finfish and blue crabs? Can you distinguish between the effects of resource harvesting, incidental kills, habitat impacts, and water quality conditions?

3. Do the major components of the fauna (fish and crabs) in the bay respond to an urbanization gradient?

Response: There is a very weak spatial trend in assemblage constituency and abundance relative to indicators of urbanization. We cannot yet determine what the mechanism for the trend is; it could owe to other factors that are unrelated to urbanization but that act along the same spatial trend. For example flow and salinity differ along the urbanization gradient due to natural geographic causes. It could even happen randomly, because variation is so great as to encompass this probability. On the temporal scale, we see changes in the fish community and abundance but are not yet able to ascribe them to anthropogenic causes because of several steps that may decouple the source of the change (the stressor) from the result. An example is climate change, which has a root in urbanization, that translates into changes in rainfall and temperature at locations elsewhere or very broadly. Likewise, marsh loss and nutrient inputs at one location may be translated through trophic changes throughout the bay due to mobility of fishes and water.

For blue crabs, our mark-recapture study indicated that more tagged crabs were recaptured where levels of fishing were greatest. We hypothesized that along the regional urbanization gradient, recapture rates would be correlated with levels of urbanization because we assumed that fishing pressure, especially recreational fishing, would be positively associated with urbanization. Our results support the hypothesis, however, only loosely because we found local levels of fishing pressure that did not correlate with that of regional urbanization level. For example, Oyster Creek is one of our low urbanized creeks based on some urbanization metrics, e.g., bulkheaded shoreline, but it appeared to be a more popular recreational fishing spot than its corresponding high urbanized creek (Forked River). This produced variation in our recapture rates that superficially did not support our

hypothesis. It is very difficult to partition the impact of factors including resource harvesting, incidental kills, habitat impacts and water quality conditions on blue crabs. Certainly, it is more likely that variation in, for example, the abundance levels of adult crabs (e.g., between years) may be directly influenced by resource harvesting as compared to water quality conditions. However, impacts, such as habitat loss may indirectly influence the abundance levels of adult crabs via more direct impacts on juvenile crabs. Thus, in the context of this question, with the results of this study, it is not possible to distinguish the effects of these different metrics of urbanization on blue crabs.

For blue crabs, the sampling design allowed us to examine the potential impact of urbanization at two spatial scales: a regional scale encompassing an urbanization gradient (i.e., comparing clusters) and a local scale including marsh creeks containing different levels of urbanization along the regional urbanization gradient (i.e., comparing low urbanized versus high urbanized marsh creeks within each cluster). There were apparent differences in the abundance, size distribution and sex ratio of blue crabs particularly between the two extremes of the urbanization gradient (i.e., clusters I and II versus IV and V), however other potentially confounding factors, such as salinity, also vary consistently along that regional scale. Therefore, it is difficult to assign regional variation in blue crab population characteristics specifically as a response to urbanization. However, there were also apparent differences in the abundance and size distribution of blue crabs in the upper creek habitats between low urbanized and high urbanized creeks. In general, crabs were more abundant in low urbanized creeks, particularly recruits and small juveniles (≤ 20 mm). Furthermore, these local differences were relatively consistent across the regional urbanization gradient. Because of this consistency, it is more reasonable to attribute the differences in blue crab population characteristics in this habitat to urbanization. Indeed, these differences help stimulate more focused hypotheses for the specific impact urbanization may have on blue crabs in this habitat. For example, fewer small crabs may be present in high urbanized creeks due to increased predation rates (as a consequence of bulkheaded shorelines).

2. Are the finfish and crab species in the bay declining, stable, or improving?

Response: It is difficult to determine if fish and crab species are declining, stable or improving based on only three years' data. This is especially true when a highly unusual event, e.g. Superstorm Sandy, occurs in the middle of the three year sampling program. Where we have longer time series, as for larval fishes behind Little Egg Inlet, it is possible. See responses to Question 6.

In the context of this question, the initial response relative to blue crabs must be: "compared to when?". Thus, comments on the population status of crab species must be qualified by the temporal extent of the data. This is particularly true for species like blue crabs, that are economically important and therefore managers need to understand why populations are changing in order to respond appropriately. For blue crabs alone, the population in any given year is composed of overlapping cohorts of individuals, some of which entered the population at least two years previously. Therefore, to understand the population status in any one year, three years of information are necessary. Based solely on the three years of data from this study, overall the population of blue crabs, while temporally (among months and years) and spatially (among habitats and across the urbanization gradient) variable, appears to be relatively stable. This is quite remarkable, given that a highly unusual event (Sandy) occurred in the middle of this study. However, our ability to comment on the impact of a relatively isolated event, such as Sandy, or more long-term human-induced changes, such as shoreline development, on blue crabs is curtailed by the limited temporal perspective we have of the blue crab population in the estuary.

4. What is the status of species known to be in decline (e.g. *Pseudopleuronectes americanus*, *Clupiedae*, *Anguilla rostrat*a, and *Cynoscion regalis*)? Are there indications that this decline is due to urbanization, natural variation, food web compensations, or global changes (e.g., climate change, sea level rise, etc.)?

Response: A response to this related (to Question 2) question is only possible for longer time series for selected species. We suspect that climate change (as well as historical overfishing) is contributing to the decline of winter flounder in the Mid-Atlantic Bight based on our analysis of larval and settled juveniles (Able et al. 2014). Another historical analysis for the juveniles and adults of the same species on the continental shelf of the Mid-Atlantic Bight suggests that a decline has also occurred (Coleman 2015). The mechanism responsible for the apparent decline of weakfish is unresolved. The most recent analysis of larval and juvenile time series in the region does not indicate a clear pattern (Able and Fahay 2010a). We have a better understanding of seasonal and habitat use by adults in the region based on ultrasonic telemetry (Turnure et al. 2015 a, b). We have commented on the pattern of abundance of glass eels for American eel in response to Question 6.

We know that warmer winters, in general, are likely responsible for the increase in Atlantic croaker in the Mid-Atlantic Bight (Hare and Able 2007) and, as a result, in Barnegat Bay. Thus, this species is responding positively to climate change. The same may be true for summer flounder, in combination with successful reduction of fishing pressure (Able et al. 2011).

5. Is there a documented change or loss of preferred habitat in the bay that may have effects on fish and crab abundance and distributions? If so, are these in measurable decline?

Response: We suggest that habitat change has occurred, most prominently, in the upper bay where human development of shorelines has resulted in a decrease in natural edge and shallow intertidal habitat as the result of construction of bulkheads, rip-rap, and other structures. In addition, dredging for lagoon developments and resulting destruction of marshes has occurred, especially in the upper bay. This has resulted in destruction of marsh habitat critical to several small fish species (mummichog, Atlantic silversides) that are important to the diet of economically important fishes such as striped bass (Tupper and Able 2000, Nemerson and Able 2003).

Another habitat change that is occurring in the bay is the highly annual variation in the abundance of macroalgae such as sea lettuce as our trawl data clearly shows. We know that this macroalgae, at some level, is important habitat, such as for juvenile blue crabs (Wilson et al. 1990a, b). However, at greater abundance, perhaps due to eutrophication, it can contribute to hypoxia or anoxia. The apparent decline of eelgrass, perhaps due to eutrophication, is also of concern (Kennish et al. 2010).

6. What is the status of the fish larval supply from the ocean and in the bay? Is it sustainable? Changes?

Response: The response to Question 6 is facilitated by long-term (1989-2014), intensive (once per week) night-time sampling for larval fishes and temperature measurements behind Little Egg Inlet, the largest inlet to Barnegat Bay (Able and Fahay 2010a). This larval fish monitoring approach has included species composition and annual timing of ingress for larval fish assemblages (Witting et al. 1999), analysis of population dynamics and biology of economically important species such as summer flounder (Keefe and Able 1993, Able et al. 2011), winter flounder (Sogard et al. 2001; Chant et al. 2000), American eel (Sullivan et al. 2006, 2009), Atlantic menhaden (Warlen et al. 2002), and other ecologically important species such as Conger eels (Correia et al. 2004).

We suspect that many of the changes that are occurring are due to generally warming water temperatures over the last several decades. For example, preliminary analysis (Able and Fahay 2010b) indicates that long-term water temperatures have increased in the Mullica River – Great Bay estuary between 1976 and 2007 (Fig. A). In an overlapping time period, the larval species composition and abundance varied (Fig. B), apparently in response to warming temperatures. As average annual temperatures warmed during the late 1990's to 2006, the number of larvae represented by northern species (i.e. those spawned north of Cape Cod) declined and the number of southern species (i.e. those spawned south of Cape Hatteras) increased relative to the long-term average over that period. The pattern of decline of northern species and increase of southern species was also evident in terms of larval abundance for both of these groups (Fig. B).

A similar examination of data from long-term sampling for juveniles of northern and southern species indicated the juveniles of northern species were represented by fewer species and were less abundant since 2003, while those of southern origins were below or near the long-term average, but the trends were similar to that for larvae (Fig. C). A similar pattern of increasing numbers of southern species has been suggested for studies in Narragansett Bay and Long Island Sound (Collie et al., 2008, Wood et al., 2009). While the late summer transport of southern species to temperate waters of the east coast has been recognized for a long time (Able and Fahay 1998), the tempo appears to have increased over the last decade, presumably reflecting warmer estuarine temperatures. It remains to be seen whether these occurrences will be translated into a permanent change in the fauna, i.e. larvae and young-of-the-year surviving to reproduce and become incorporated into ecologically and economically important assemblages in Barnegat Bay and New Jersey. A good example of important change is the recent increase in survival, expansion of the range, and development of the fisheries for Atlantic croaker (Hare and Able 2007). For American eel larvae (glass eels) the apparent decline at the extremes of the range such as in Gulf of St. Lawrence tributaries are not apparent at Little Egg Inlet (Able and Fahay 2010a, Casselman et al. 2014). However, at this New Jersey site there is a decrease in average size and a delay in arrival in recent years (Casselman et al. 2014).

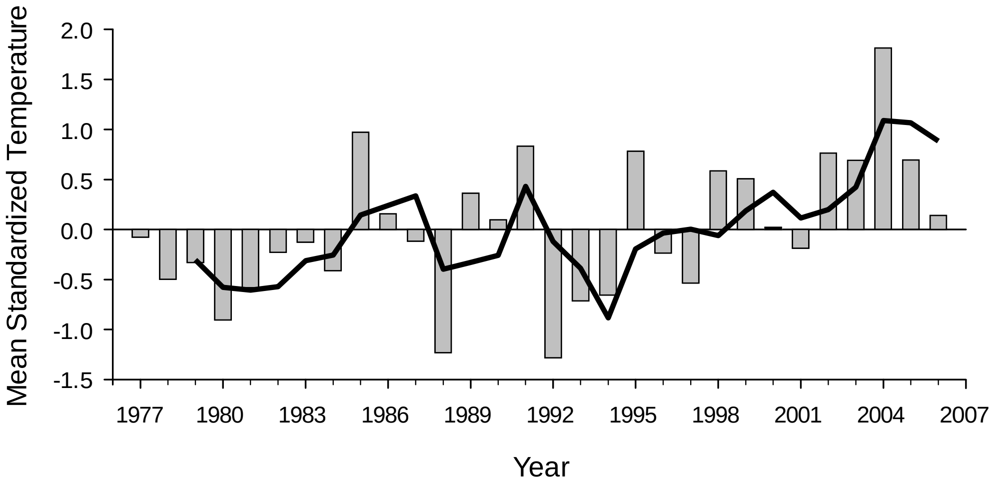

Figure A. Annual variation in monthly mean temperatures for spring, summer, and fall (weeks 12-47) during 1976-2007, in Great Bay, near the mouth of the RUMFS boat basin. The zero line indicates the long term averages. Modified from Able and Fahay (2010b).

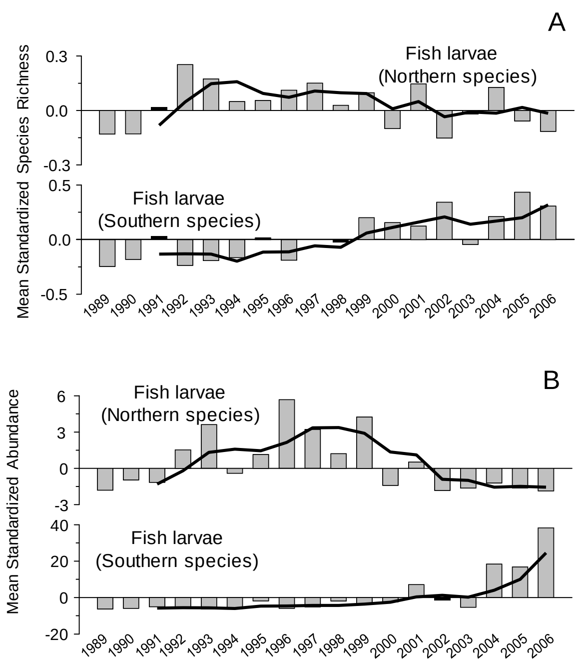

Figure B. Annual variation (1989-2006) in response of larval fish species richness (A) and abundance (B) based on ichthyoplankton collections at Little Egg Inlet. Modified from Able and Fahay (2010b).

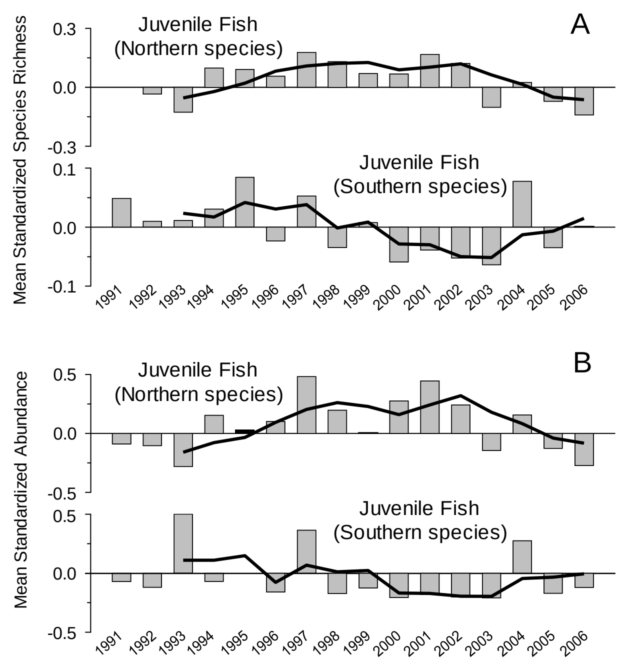

Figure C. Annual variation (1989-2006) in juvenile fish species richness (A) and abundance (B) based on wire mesh trap collections in Rutgers University Marine Field Station boat basin in Great Bay. Modified from Able and Fahay (2010b).

7. What is the long term perspective on sustainable commercial fisheries in the bay? Long term ecological perspective for a balanced food web, carbon cycling, habitat resilience, etc.?

Response: The marshes bordering the shores of Barnegat Bay are one of the major habitat features. They have experienced extensive loss, infilling and development resulting in the loss of marsh surface habitat such as marsh pools and intertidal creeks. These practices have been curtailed (Lathrop and Bognar 2001). One of the other major forms of marsh loss is lagoon development. Extensive collaborative studies at Beach Haven West (a large 2.2 miles^2 with 104 dead-end canals) between Rutgers University and NJ DEP is known to create less-than-optimal conditions because they cause hypoxia/anoxia in the summer (Sugihara et al. 1979). This may influence recruitment of American eels in the Mill Creek watershed, part of Beach Haven West (Able et al. 2015). In other estuaries, similar dead-end canals have produced similar low dissolved oxygen conditions as well as increased production of hydrogen sulfide (Luther et al. 2004, Ma et al. 2006), all of which can cause a negative response by many organisms (Bargarinao and Lantin-Olaguer 1999, Bagarinao and Vetter 1989, Seliger et al. 1985, Theede 1973). The proliferation of these dead-end, artificial waterways is increasing on all continents (Waltham and Connolly 2011), as has happened in Barnegat Bay, and may result in the decline in habitat quality.

These structural impacts on salt marshes also occur when *Phragmites,* late in the invasion, when marsh creeks are filled in, the marsh surfaces becomes elevated, drier and, as a results, lower quality habitat and reduced fish use and production (Able and Hagan 2003, Able et al. 2003, Hagan et al. 2007, Kimball et al. 2007).

Despite their destruction by human activities, salt marshes appear resilient to natural disturbances and storms, such as Superstorm Sandy. In our experience, there has been little alteration of natural marshes including the creeks and marsh surface pools based on observations of our specific study sites, especially in the vicinity of RUMFS. The marsh response is certainly different than that of human structures (Asbury Park Press 2012, Mazzella 2013). A possible exception is marsh edges that are exposed to wave fetch, as has occurred inside Little Egg Inlet near RUMFS (Able 2015). This response could be compounded by sea level rise as appears to be occurring on the Sheepshead Meadows marshes near RUMFS (K. W. Able, pers. observ.).

The continuing decline of eelgrass in Barnegat Bay, presumably due to eutrophication, has been well documented. (Kennish et al. 2010, Kennish and Fertig 2012, Fertig et al., 2013).

Collaborations

Otter Trawl Efficiency Efforts

Otter trawl efficiency evaluations were performed at estuarine creek sites during the 2014 sampling season with sites selected from ongoing Barnegat Bay trawl studies. The initial effort was conducted on July 1, 2014 at Jeremy's Creek (routinely sampled in 2012 and 2013, STA #51 upper creek location within Cluster I with natural marsh edge of *Spartina* and a depth ranging from 1.3 to 2.5 meters). On July 2, 2014, the effort was at Dinner Point Creek (STA # 64, an upper creek site routinely sampled in 2012-13 with a natural marsh edge of *Spartina* and a depth of 1 meter). On July 3, 2014 the creek adjacent to Jeremy's Creek (not part of regular sampling, but having a similar depth profile) was sampled. Another sample was initiated on August 25, 2014 at Dinner Point Creek (STA #64). On August 26, 2014 another sampling event occurred at the creek adjacent to Jeremy's Creek. On August 27, 2014, we sampled at Clamming Creek (STA #84 in Cluster IV, 1.5 meter deep, with *Spartina* marsh on one edge and hardened shoreline on the opposing edge).

For every sampling event, each creek was blocked, first at the upper end and then blocked at the lower end to close off the area of the creek to be trawled. The block net consisted of multi-paneled seine with a length sufficient to reach from one creek bank to the other (from 30-55 meters), a depth of 2 meters and a 6 mm bar mesh with 7.6 cm floats spaced 1 meter apart at the surface and leaded foot rope stepped into the mud to ensure minimal escapement of fishes from within the transect area. Additional PVC and wooden poles were driven vertically into the mud to give stability to the block net approximately every 2 meters across the length of the net with extra poles set near the middle. The trawl net used has a length of 4.9 m and 6 mm bar mesh at the cod end and was towed from a 20' Maritime skiff powered by an 115hp Honda being run at 1800 rpm. Tows (8-13 per site) were consistently 2 minutes long and hauled from the time access to the creek was tidally available during the flood tide and until the ebb tide had removed so much water that access was lost.

The catch for each tow was identified to species and measured (fish - TL or FL, crabs - BW, sex was also noted). Shrimp, hermit crabs and mud crabs were not counted. Once the trawl cod end was hauled up on deck, catch was immediately transferred to clean water to provide best possible conditions for continued survival of the fishes and crabs. Each fish or crab to be marked had its fin or appendage clipped with surgical scissors so that there was not a repeat in specific fin or appendage clip location within a site. These clipped fish and crabs were then released from the vessel and returned to the creek system at random locations along the trawl transect. If a fish or crab was collected with a fin or appendage clip it was considered a recapture, provided a second fin or appendage clip and re-returned to the trawl transect. At each location surface and bottom temperature, salinity, dissolved oxygen, and pH were recorded at all locations with a handheld YSI and water clarity as measured with Secchi disk (0.1 m diameter). Further analyses of these data are being conducted as part of the Barnegat Bay project by Olaf Jensen and Jim Vasslides.

In addition, Rutgers University student, Talia Young (PhD, Graduate Program in Evolution and Ecology) is examining seasonal abundance and distribution of gelatinous zooplankton within each habitat in each cluster with otter trawl and plankton net tows, focusing on sea nettles (*Chrysaora quinquecirrha*) and the most common ctenophore (*Mnemiopsis leidyi*). Abundance of sea nettles (*Chrysaora quinquecirrha*) and ctenophores (*Mnemiopsis leidyi*) was measured at all of the sampling locations in June, August and

October of 2012. The results confirmed that salinity is a determining factor for sea nettle distribution, as research on the species in the Chesapeake suggests; sea nettles were found in only one site with salinity greater than 20.3 ppt, and salinity was a significant covariate in a logistic regression model for presence/absence of nettles. The results also suggest that development may be a significant factor in determining sea nettle abundance; nettles were found in developed creeks, and not undeveloped ones. Ctenophores were found temporally and geographically in inverse abundance to sea nettles, suggesting (again, as supported by work in Chesapeake Bay) that sea nettles may be key predators on ctenophores.

In 2013, abundance of sea nettles (*Chrysaora quinquecirrha*) and ctenophore (*Mnemiopsis leidyi*) was measured for a second year at all of the sampling locations in June, August, and October. Additional sampling for sea nettles was conducted in July at two developed and two undeveloped creeks to further compare the effect of creek development on sea nettle abundance. Comparison of three gears (trawl, seine and plankton net) was also conducted in the hopes of combining trawl, seine and plankton net data on gelatinous zooplankton in the bay.

Gonad samples were collected from 95 sea nettles collected at 11 locations from northern Barnegat Bay in June, July and August and sliced onto slides for two purposes: first to conduct histological analysis ofreproductive biology of sea nettles, and to determine if historical techniques for determining sex of sea nettles (color of gonad) are accurate. Preliminary data analysis from June and July suggest that there were more females than males (6:4), and few of the males were sexually mature (demonstrated by ruptured sperm follicles). The histological analysis also suggest that while color is a more reliable way to identify male than female sea nettles (0% vs. 43% error, respectively).

In 2014, field data on sea nettles from 2012 and 2013 were incorporated into a two-stage general linear model (including NOAA ESI shoreline data) to predict sea nettle abundance in Barnegat Bay. That model was used to hindcast historical sea nettle abundance based on DEP environmental data and historical NOAA ESI shoreline data. The hindcast model results were validated against interviews with local experts. The results of this work are included in a manuscript in revision at *Marine Ecology Progress Series.*

Tissue samples (>200 total) from ctenophores, sea nettles, lion's mane jellyfish, zooplankton, ichthyoplankton, algae, and primary consumer baseline species were collected in northern and southern Barnegat Bay for stable isotope analysis. The goal of this work is to compare the trophic role and niche of ctenophores in the southern bay with that of sea nettles in the north.

In order to ascertain if the sea nettle sperm release period occurs at the very end of the sea nettles season, addition gonads from 25 sea nettles collected at three sites around the bay were collected and examined histologically. The analysis supports that gonad color is a useful way to identify male sea nettles in Barnegat Bay. Timing of the sea nettle sperm release remains unclear.

RUMFS personnel provided a day-long tutorial on larval fish identification for Monmouth University personnel including three students (May 24, 2013). We have also discussed (with Neil Ganju, USGS – Woods Hole) how the hydrodynamic model being developed could assist in enhancing our understanding of larval fish supply to different portions of and habitats within Barnegat Bay.

We have provided logistical support for several other bay projects. During 2013, we arranged for vessel support to the Barnegat Bay Partnership (Martha Maxwell-Doyle) for a project related to wetlands monitoring and assessment.

Complimentary Projects

A comprehensive chronology of research in Barnegat Bay, from the late 1880s to the present, is one of the major portions of a book (Able 2015). It reviews the major stanzas of activity from research on oysters in the earliest efforts, through an emphasis on power plants, salt marsh systems and fishes. Perhaps, most importantly, it documents the important and far-reaching changes, both human and natural, that have modified the bay to what it is now.

We are also taking advantage of the Rutgers University Marine Field Station long term data sites in Barnegat Bay by examining the apparent decline in the winter flounder (*Pseudopleuronectes americanus*) (Able et al. 2014) and predator-prey interactions between juvenile conger eel (*Conger oceanicus*) and American eel (*Anguilla rostrata*) (Musumeci et al. 2014). In addition, we are continuing to compile unpublished data on fishes (Appendix Table 1), including larvae (Appendix Table 2) as well as RUMFS published literature (Appendix Table 3) to evaluate their appropriateness for further analysis.

We have examined the entrance of larval *Anguilla rostrata* into Barnegat Bay. We expanded this effort during 2012 and 2013 inlet sampling. To date, it is clear that glass eels of this species enter all inlets to the Bay (including from Point Pleasant Canal) but their use of tributaries is variable (Able et al. 2015). Other analyses are evaluating the decline of this species throughout North America based in part, on the time series of data from Little Egg Inlet (Casselman et al. 2014, Chase 2014) and the patterns of *Brevoortia tyrannus* abundance (Miller et al. 2014). In addition, we compared larval winter flounder abundance at our Little Egg Inlet (Little Sheepshead Creek) over the period from 1989 to the present in order to evaluate the presumed decline of this species at the southern portion of its current range in New Jersey (Able et al. 2014). Other presentations have pointed out the advantages of the long time series of larval fish sampling at Little Egg Inlet (Able 2014).

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Table 1. Sampling location and effort for larval fishes into and within Barnegat Bay during 2010-2014 with identical plankton nets. See Fig. 1 for further details of location of sampling sites. Flow rates calculated from flowmeters in plankton nets at time of sampling.

Location	Sampling period	Sampling frequency	Number of samples	Temperature (Median and Range, °C)	Salinity (Median and Range, ppt)	Flow rates (range) m^3 per tow
Through Inlets						
Barnegat Inlet	2012 – 2013	Bi-Monthly	9	16.4, 5.6-25.7	29.9, 27.7-36.8	255-24166
Little Egg Inlet	2012 – 2014	Bi-Monthly	14	21.3, 6-25.8	25.3, 28-34.6	74-32277
Through Thoroughfares						
Point Pleasant Canal	2012 – 2013	Bi Monthly	9	16.6, 6.1-25.5	23.0, 14.8-34.6	38-31990
Jimmy's Creek	2010-2011	Bi-Monthly	8	14.5, 2.1-26	27.1, 23.4-31.9	21-33011
Little Thoroughfare	2010-2011	Bi-Monthly	8	16.7, 1.7-26.6	29.4, 25.12-30.3	18-56132
Within Bay						
Oyster Creek Nuclear Generating Station	2012-2014	Bi-Monthly	24	21.3, 6.6-32.9	25.3, 22-30.9	9825-63038
Route 37	2014	Bi-Monthly	5	16.1, 8.6-25.2	18.1, 15.1-20.5	205-36105
Route 72	2014	Bi-Monthly	5	16, 8.5-25.3	26.5, 24.2-27.6	398-46687

Table 2. General characteristics (based on NJDEP 2009 data) of each sample cluster (see Fig. 1) in Barnegat Bay relative to aspects of urbanization. Human population estimate is based on estimates of townships, or parts of them, from the Ocean County Planning Department for January 2011 as well as the 2010 US Census Bureau. See Fig. 1 for locations of clusters.

Cluster	Estimated Human Population	% Urbanized Land	% Agricultural Land	% Barren Land	% Forest	% Wetlands	% Water
I	6,017	10.6	0.1	0.4	2.3	22.4	64.2
II	6,257	12.6	0.2	0.5	3.0	32.4	51.4
III	7,387	13.5	0.1	0.8	7.1	16.3	62.3
IV	22,855	21.1	0.1	0.8	5.8	14.9	57.3
V	38,800	30.0	0.0	0.6	4.1	14.4	50.9

Table 3. Habitat characteristics by cluster and sampling site during 2012-2014. Habitat types are: Bay = open portion of bay; SAV= submerged aquatic vegetation; Creek Mouth and Upper Creek = locations in tidal marsh creeks. See Fig. 1 for locations of clusters. To be filled in as data are collected, entered and verified.

Cluster	Habitat Type	Station	Dominant Emergent Vegetation Along Shoreline	Dominant Submerged Vegetation	Volume of Submerged Vegetation in Trawl Tows (range, liters)	Salinity Range (ppt)	Temperature Range (°C)	Dissolved Oxygen Range (mg/L)
I	Bay	STA 5	Spartina, Phragmites	Macroalgae	0.01-41.0	28.5-31.1	6.4-25.8	5.3-10.2
		B110	Spartina, Phragmites	Macroalgae, Seagrass	0.01-20.0, 0.01-0.10	28.0-31.5	8.8-23.8	5.3-15.5
	SAV	STA 3	Spartina, Phragmites	Macroalgae, Seagrass	0.01-51.0, 0.01-36.0	26.7-30.8	9.7-26.4	5.9-9.9
		STA 52	Spartina, Phragmites	Macroalgae, Seagrass	0.01-50.0, 0.33-10.0	27.7-31.4	8.9-25.8	5.8-27.9
	Creek Mouth	STA 15	Spartina, Phragmites	Macroalgae	0.01-460.0	22.4-29.3	7.3-26.7	4.3-10.5
		STA 50	Spartina	Macroalgae	0.01-110.0	25.2-29.3	6.8-26.4	4.4-10.8
	Upper Creek	STA 14	Upland	Macroalgae	0.01-2.0	20.1-27.1	7.6-26.4	0.8-10.5
		STA 51	Spartina	Macroalgae	0.01-7.0	26.3-28.2	10.2-24.4	3.6-10.4
II	Bay	STA 60	-	Macroalgae, Seagrass	1.0-35.0, 0.01-5.0	22.8-28.3	7.3-26.3	5.1-10.4
		STA 61	-	Macroalgae	0.01-3.0	24.4-29.3	12.6-27.0	6.2-9.3
	SAV	STA 66	Spartina, Phragmites	Macroalgae, Seagrass	0.01-10.0, 3.0-12.0	21.3-29.8	10.0-27.1	6.1-9.4
		STA 67	Spartina, Phragmites	Macroalgae, Seagrass	0.01-30.0, 7.0-10.5	24.9-30.4	10.0-27.2	4.9-9.2
	Creek Mouth	STA 62	Spartina	Macroalgae	0.01-210.0	23.5-30.0	14.2-26.0	5.6-9.6
		STA 63	Spartina, Phragmites	Macroalgae, Seagrass	0.01-148.3, 0.01-2.5	22.4-28.3	12.6-26.5	6.0-9.0
	Creek	STA 64	Spartina	Seagrass	1.0-50.0	11.8-25.3	10.0-28.6	2.6-8.6

	Upper	STA 65	Upland	Macroalgae	0.01-0.01	9.7-22.2	13.9-27.1	1.2-8.5
III	Bay	STA 70	-	Macroalgae, Seagrass	0.01-12.5, 0.01-2.50	26.9-30.6	6.1-25.1	5.8-10.1
		STA 71	-	Macroalgae, Seagrass	0.01-42.5, 0.01-0.5	26.7-31.0	5.8-24.0	5.4-9.9
	SAV	STA 76	Spartina, Phragmites	Macroalgae, Seagrass	0.01-80.0, 0.01-142.0	27.2-31.4	4.7-25.0	3.7-10.9
		STA 77	Spartina, Phragmites	Macroalgae, Seagrass	0.01-176.0, 0.01-400.0	25.3-29.1	4.9-26.0	6.0-11.2
	Creek Mouth	STA 72	Spartina, Phragmites	Macroalgae, Seagrass	1.0-60.0, 0.01-0.01	22.0-29.3	6.9-30.0	5.5-10.5
		STA 73	Spartina, Phragmites	Macroalgae, Seagrass	0.01-70.0, 0.01-0.01	23.3-29.2	8.8-24.6	5.1-10.0
	Creek Upper	STA 74	Upland	Macroalgae, Seagrass	0.01-12.0, 0.01-0.01	22.1-27.2	11.3-30.6	4.9-10.5
		STA 75	Upland	Macroalgae	0.01-12.0	22.6-28.3	7.0-27.0	5.5-10.5
IV	Bay	STA 80	-	Macroalgae	0.01-13.0	9.5-26.0	13.1-26.5	3.9-8.6
		STA 81	-	Macroalgae, Seagrass	0.01-2.5, 0.01-0.01	17.7-24.3	13.2-25.8	6.1-9.0
	SAV	STA 86	Upland	Macroalgae, Seagrass	0.01-85.5, 0.01-10.7	19.4-24.9	12.9-26.8	5.2-9.0
		STA 87	-	Macroalgae, Seagrass	0.01-123.25, 0.01-7.25	17.4-24.7	13.9-27.4	5.9-9.5
	Creek Mouth	STA 82	Spartina, Phragmites	Macroalgae	0.01-9.0	17.8-24.9	14.0-27.1	5.4-8.7
		STA 83	Spartina, Phragmites	Macroalgae	3.0-46.0	16.8-22.6	13.9-26.3	4.9-9.2
	Creek Upper	STA 84	Spartina, Phragmites	Macroalgae, Seagrass	0.03-27.0	18.1-25.0	14.8-26.6	2.4-8.1
		STA 85	Upland	Macroalgae	0.01-2.5	16.2-22.2	14.8-27.5	0.2-7.9
V	Bay	STA 90	-	Macroalgae	0.01-8.0	14.4-26.4	5.3-24.6	0.16-20.5
		STA 91	-	Macroalgae	0.01-11.0	14.9-26.1	5.1-27.2	5.8-9.5
	SAV	STA 96	-	Macroalgae, Seagrass	0.01-1.5, 0.01-0.01	17.2-24.8	12.0-22.8	6.2-10.8

		STA 97	Spartina, Phragmites	Macroalgae, Seagrass	0.01-6.0, 0.01-0.01	17.5-26.8	14.1-22.6	6.2-9.7
	Creek Mouth	STA 92	upland, Spartina, Phragmites	Macroalgae	2.0-240.0	17.1-27.9	6.4-26.6	3.0-11.5
		STA 93	Spartina, Phragmites	Macroalgae, Seagrass	2.0-115.0, 0.01-0.01	16.8-28.9	6.4-27.0	1.1-11.3
	Creek Upper	STA 94	-	Macroalgae	0.01-3.0	19.1-27.1	13.9-25.0	0.8-11.3
		STA 95	Spartina, Phragmites, upland	Macroalgae	0.01-13.0	16.8-28.5	16.5-25.9	4.5-7.1

Table 4. Sampling effort with otter trawl in Barnegat Bay during 2012-2014. Habitat types are: Bay = open portion of bay; SAV= submerged aquatic vegetation; Creek Mouth and Upper Creek = locations in tidal marsh creeks. See Fig. 1 for locations of clusters.

Cluster	Habitat Type	Sampling Month	Number of Tows			Number of Fishes			Number of Crabs		
			2012	2013	2014	2012	2013	2014	2012	2013	2014
I	Bay	Feb	6	0	0	0	-	-	3	-	-
		April	6	6	6	5	3	4	6	36	7
		June	6	6	6	4	4	7	46	0	9
		Aug	6	6	6	173	279	48	1	7	12
		Oct	6	6	6	1,034	145	42	6	8	12
	SAV	Feb	9	0	0	4	-	-	3	-	-
		April	9	9	9	7	0	36	16	30	16
		June	9	9	9	45	21	27	82	14	12
		Aug	9	9	9	340	75	451	0	5	15
		Oct	9	9	9	97	12	359	18	1	7
	Creek Mouth	Feb	6	0	0	1	-	-	0	-	-
		April	6	6	6	81	27	10	8	4	5
		June	6	6	6	44	10	72	16	13	20
		Aug	6	6	6	122	150	110	40	7	30
		Oct	6	6	6	76	14	341	6	0	2
	Upper Creek	Feb	6	0	0	3	-	-	6	-	-
		April	6	6	6	166	0	7	43	9	29
		June	6	6	6	591	35	24	85	66	201
		Aug	6	6	6	15	100	110	8	8	30
		Oct	6	6	6	74	75	93	33	6	38
II	Bay	April	6	6	6	2	0	0	22	1	0
		June	6	6	6	2	20	62	0	8	14
		Aug	6	6	6	34	220	167	0	1	37
		Oct	6	6	6	185	12	176	1	8	23
	SAV	April	6	6	6	1	0	2	2	0	1
		June	6	6	6	13	95	19	16	36	1
		Aug	6	6	6	166	99	71	17	1	10
		Oct	6	6	6	17	1,059	836	1	1	10
	Creek Mouth	April	6	6	6	8	5	4	2	10	3
		June	6	6	6	253	25	7	3	22	5
		Aug	6	6	6	6	152	130	0	3	23
		Oct	6	6	6	14	42	234	2	5	79
	Creek Upper	April	6	6	6	4	0	10	20	21	30
		June	6	6	6	111	5	63	5	69	62

		Aug	6	6	6	40	53	353	8	28	92
		Oct	6	6	6	15	0	23	18	5	29
III	Bay	Feb	6	0	0	1	-	-	1	-	-
		April	6	6	6	2	2	0	9	1	0
		June	6	6	6	1	6	2	7	4	1
		Aug	6	6	6	848	202	92	1	22	8
		Oct	6	6	6	20	74	5	0	0	0
	SAV	Feb	6	0	0	9	-	-	1	-	-
		April	6	6	6	14	8	10	12	8	6
		June	6	6	6	635	40	388	412	73	6
		Aug	6	6	6	82	30	3,190	7	4	19
		Oct	6	6	6	67	7	1,990	87	1	24
	Creek Mouth	Feb	6	0	0	0	-	-	0	-	-
		April	6	6	6	126	6	7	12	2	11
		June	6	6	6	12	23	34	22	37	13
		Aug	6	6	6	76	149	161	57	13	11
		Oct	6	6	6	21	13	169	0	3	10
	Creek Upper	Feb	6	0	0	1	-	-	1	-	-
		April	6	6	6	1	6	8	2	9	48
		June	6	6	6	8	3	7	45	21	91
		Aug	6	6	6	23	5	14	70	92	25
		Oct	6	6	6	15	2	59	15	6	17
IV	Bay	April	6	6	6	8	0	5	0	1	5
		June	6	6	6	14	12	16	5	2	4
		Aug	6	6	6	468	1	188	19	0	10
		Oct	6	6	6	226	5	58	5	1	16
	SAV	April	6	6	6	28	0	6	365	89	14
		June	6	6	6	22	22	57	21	90	11
		Aug	6	6	6	148	63	66	5	4	11
		Oct	6	6	6	3	17	90	26	182	59
	Creek Mouth	April	6	6	6	18	0	8	11	6	31
		June	6	6	6	37	46	72	7	8	18
		Aug	6	6	6	220	272	534	26	14	55
		Oct	6	6	6	352	104	132	9	18	12
	Creek Upper	April	6	6	6	46	19	15	10	34	48
		June	6	6	6	156	21	222	36	12	56
		Aug	6	6	6	782	311	331	27	12	53
		Oct	6	6	6	159	36	375	15	13	40
V	Bay	Feb	6	0	0	6	-	-	1	-	-

		April	6	6	6	0	4	0	1	11	4
		June	6	6	6	18	22	120	6	5	27
		Aug	6	6	6	248	155	129	43	1	43
		Oct	6	6	6	32	54	646	11	9	18
	SAV	Feb	6	0	0	0	-	-	1	-	-
		April	6	6	6	49	2	5	29	4	28
		June	6	6	6	4	13	227	24	17	42
		Aug	6	6	6	40	57	38	84	21	45
		Oct	6	6	6	24	7	108	99	8	30
	Creek Mouth	Feb	6	0	0	6	-	-	1	-	-
		April	6	6	6	2	0	7	14	7	53
		June	6	6	6	9	37	36	117	49	61
		Aug	6	6	6	6	42	1,430	27	8	273
		Oct	9	6	6	11	0	851	33	4	147
	Creek Upper	Feb	6	0	0	23	-	-	3	-	-
		April	6	6	6	12	2	9	17	39	106
		June	6	6	6	32	3	161	19	10	69
		Aug	6	6	6	43	34	327	5	29	91
		Oct	9	6	6	26	53	25	6	20	45
Annual Total			573	492	492	8,993	4,727	16,328	2,432	1,457	2,679
Total			1,557			30,048			6,568		

Table 5. Sampling effort with gill nets in Barnegat Bay during 2012 and 2013. Set time was approximately 60 minutes. Habitat types are: Bay = open portion of bay; SAV= submerged aquatic vegetation; Creek Mouth and Upper Creek = locations in tidal marsh creeks. See Fig. 1 for locations of clusters. The day-night comparison occurred in Cluster I during June.

Cluster	Habitat Type	Number of Sets		Number of Fishes		Number of Crabs	
		2012	2013	2012	2013	2012	2013
I	Bay	April: 3	June Day: 4	3	0	7	2
		June: 2	June Night: 4	3	2	1	5
		Aug: 3	Aug: 4	9	8	3	3
		Oct: 4	Oct: 4	3	7	3	0
	Creek Mouth	April: 2	June Day: 4	3	8	5	2
		June: 2	June Night: 4	5	20	1	4
		Aug: 4	Aug: 4	15	30	4	3
		Oct: 4	Oct: 4	2	8	0	1
	Creek Upper	April: 2	June Day: 4	0	11	1	3
		June: 2	June Night: 4	5	39	0	1
		Aug: 4	Aug: 4	5	49	1	0
		Oct: 4	Oct: 4	11	1	4	0
	SAV	April: 0	June Day: 6	0	11	0	3
		June: 0	June Night: 4	0	17	0	5
		Aug: 0	Aug: 4	0	21	0	6
		Oct: 6	Oct: 4	4	5	31	3
III	Bay	April: 2	June: 2	0	0	0	2
		June: 2	Aug: 4	0	38	0	0
		Aug: 4	Oct: 4	1	2	0	0
		Oct: 4		0		0	
	Creek Mouth	April: 2	June: 2	0	1	4	0
		June: 2	Aug: 4	1	19	0	3
		Aug: 4	Oct: 4	17	15	2	0
		Oct: 4		6		0	
	Creek Upper	April: 2	June: 2	0	0	0	0
		June: 2	Aug: 4	0	1	0	0
		Aug: 4	Oct: 4	0	3	1	1
		Oct: 4		1		0	
	SAV	April: 0	June: 2	0	2	0	0
		June: 0	Aug: 4	0	30	0	3
		Aug: 2	Oct: 4	27	1	0	0
		Oct: 4		0		0	
V	Bay	April: 2	June: 2	0	1	0	4
		June: 2	Aug: 4	0	28	0	7
		Aug: 6	Oct: 4	19	1	4	2
		Oct: 4		5		0	
	Creek Mouth	April: 2	June: 2	1	1	0	3
		June: 3	Aug: 4	5	19	4	5
		Aug: 8	Oct: 4	17	0	5	0

		Oct: 6		8		0	
	Creek Upper	April: 1	June: 2	0	0	0	0
		June: 2	Aug: 4	1	7	0	1
		Aug: 4	Oct: 4	9	1	3	1
		Oct: 4		3		0	
	SAV	April: 0	June: 2	0	0	0	4
		June: 0	Aug: 4	0	24	0	3
		Aug: 2	Oct: 4	0	2	0	1
		Oct: 4		1		0	
Total		134	146	190	433	84	81

Table 6. Sampling effort with commercial crab pots in Barnegat Bay during 2012-2014. Habitat types are: Bay = open portion of bay; SAV= submerged aquatic vegetation; Creek Mouth = locations in tidal marsh creeks. See Fig. 1 for locations of clusters.

Cluster	Habitat Type	Sampling Month	Number of Traps			Number of Crabs		
			2012	2013	2014	2012	2013	2014
I	Bay	May	5	4	6	0	0	1
		Jun	6	3	8	3	20	10
		Jul	6	6	8	15	9	33
		Aug	6	6	8	13	41	21
	SAV	May	6	4	8	4	0	11
		Jun	6	4	8	20	13	12
		Jul	6	6	8	15	10	10
		Aug	6	6	8	14	36	27
	Creek Mouth (High Urbanization)	May	6	4	8	61	47	43
		Jun	6	4	8	22	44	61
		Jul	6	6	8	38	47	49
		Aug	6	6	8	35	30	38
	Creek Mouth (Low Urbanization)	May	6	4	8	19	16	12
		Jun	5	4	8	21	29	42
		Jul	6	6	8	25	22	33
		Aug	6	6	8	26	22	25
II	Bay	May	6	4	4	33	36	3
		Jun	6	4	8	21	33	6
		Jul	6	6	5	35	24	10
		Aug	6	6	8	26	25	14
	SAV	May	6	4	8	13	21	11
		Jun	6	4	8	18	15	7
		Jul	6	6	7	26	17	20
		Aug	6	6	8	26	21	30
	Creek Mouth (High Urbanization)	May	6	4	8	21	35	11
		Jun	5	3	5	15	35	11
		Jul	6	6	2	17	20	4
		Aug	6	6	8	28	33	25
	Creek Mouth (Low Urbanization)	May	6	4	8	33	30	34
		Jun	6	4	8	17	32	32
		Jul	6	6	8	31	24	18
		Aug	6	6	8	50	22	32
III	Bay	May	6	4	8	4	6	0
		Jun	6	4	8	16	7	4

		Jul	6	6	8	16	9	26
		Aug	6	5	8	11	11	22
	SAV	May	6	4	8	4	4	16
		Jun	6	4	8	13	11	20
		Jul	6	6	8	39	33	49
		Aug	6	6	8	36	25	30
	Creek Mouth (High Urbanization)	May	6	4	7	14	32	14
		Jun	6	4	8	20	24	42
		Jul	6	6	8	30	47	28
		Aug	6	6	8	27	33	46
	Creek Mouth (Low Urbanization)	May	6	4	7	106	29	10
		Jun	6	3	8	63	14	60
		Jul	6	6	8	31	53	39
		Aug	6	6	8	41	64	66
IV	Bay	May	6	6	8	13	10	8
		Jun	6	6	8	58	28	35
		Jul	3	6	8	17	56	84
		Aug	6	5	8	33	36	63
	SAV	May	6	6	8	26	6	4
		Jun	6	6	8	28	12	42
		Jul	6	6	8	17	63	33
		Aug	6	6	8	23	46	59
	Creek Mouth (High Urbanization)	May	6	6	8	26	10	19
		Jun	6	6	8	39	30	39
		Jul	6	6	8	37	31	73
		Aug	6	6	8	24	10	49
	Creek Mouth (Low Urbanization)	May	6	6	8	3	6	3
		Jun	6	6	8	43	20	46
		Jul	6	6	8	35	41	61
		Aug	6	6	8	29	41	56
IV	Bay	May	6	6	8	29	13	6
		Jun	6	6	8	59	34	11
		Jul	6	6	8	43	60	59
		Aug	6	6	8	28	49	55
	SAV	May	6	6	8	15	12	2
		Jun	6	6	8	14	24	12
		Jul	6	6	8	30	51	35
		Aug	6	6	8	23	32	33
	Creek Mouth (High Urbanization)	May	4	6	8	31	21	14
		Jun	6	6	8	56	40	53

		Jul	6	6	8	50	39	59
		Aug	6	6	8	37	55	69
	Creek Mouth (Low Urbanization)	May	6	6	8	17	12	8
		Jun	6	6	8	74	21	27
		Jul	6	6	8	56	56	95
		Aug	6	6	8	35	55	46
Annual Total			472	427	619	2,260	2,231	2,426
Total			1,518			6,917		

Table 7. Length (mm) of the size cutoff separating newly recruiting (young-of-the-year) fish from age 1 or older in a given year for the categorization by life history stage for PCA and CCA.

Month	*Pseudopleuronectes americanus*	*Paralichthys dentatus*	*Cynoscion regalis*	*Micropogonius undulatus*
Feb	20	20		120
April	50	30		170
May	70	50	50	200
June	100	170	100	200
Aug	140	300	210	200
Oct	160	20	210	

Table 8. Species composition in Barnegat bay by sampling gear during 2012-2014. X indicates present.

	Species	Plankton Net	Otter Trawl	Gill Net
Fishes				
	Alosa mediocris		x	x
	Alosa pseudoharengus		x	
	Alosa sp.		x	
	Ammodytes sp.	x		
	Anchoa hepsetus	x	x	
	Anchoa mitchilli	x	x	
	Anchoa sp.	x	x	
	Anguilla rostrata	x	x	
	Apeltes quadracus	x	x	
	Archosargus probatocephalus		x	
	Astroscopus guttatus		x	
	Bairdiella chrysoura	x	x	x
	Blenniidae sp.	x		
	Brevoortia tyrannus	x	x	x
	Caranx crysos		x	
	Caranx hippos		x	
	Carcharhinus plumbeus			x
	Centropristis striata	x	x	
	Chaetodon ocellatus		x	
	Chasmodes bosquianus	x	x	
	Chilomycterus schoepfi	x	x	
	Clupea harengus	x	x	
	Clupeidae sp.	x	x	
	Clupeiformes sp.	x	x	
	Conger oceanicus	x	x	
	Ctenogobius boleosoma	x		
	Cynoscion regalis	x	x	x
	Cyprinodon variegatus		x	
	Dactylopterus volitans		x	
	Dasyatis say		x	x
	Dorosoma cepedianum			x
	Elops saurus	x		
	Enchelyopus cimbrius	x		
	Engraulidae sp.	x		
	Engraulis eurystole	x		
	Etropus microstomus	x	x	
	Eucinostomus argenteus		x	
	Fundulus heteroclitus	x	x	
	Fundulus luciae	x	x	

Fundulus majalis	x	x	
Fundulus sp.	x	x	
Gadus morhua	x	x	
Gasterosteus aculeatus		x	
Gobiesox strumosus	x	x	
Gobiidae sp.	x		
Gobionellus oceanicus	x		
Gobiosoma bosc	x	x	
Gobiosoma ginsburgi	x	x	
Gobiosoma sp.	x	x	
Gracilaria sp.		x	
Hippocampus erectus	x	x	
Hyporhamphus meeki	x		
Hypsoblennius hentz	x	x	
Ictalurus punctatus		x	
Lagodon rhomboides	x	x	
Leiostomus xanthurus	x	x	x
Lepomis gibbosus		x	
Lepomis macrochirus		x	
Lucania parva	x	x	
Lutjanus griseus		x	
Menidia beryllina	x	x	
Menidia menidia	x	x	
Menidia sp.	x	x	
Menticirrhus saxatilis	x	x	x
Microgobius thalassinus	x	x	
Micropogonias undulatus	x	x	x
Morone americana		x	x
Morone saxatilis		x	x
Morone sp.		x	
Mugil cephalus	x	x	
Mugil curema	x	x	
Mugil sp.			x
Mustelus canis		x	x
Mycteroperca microlepis		x	
Myliobatis freminvillii			x
Myoxocephalus aenaeus	x		
Myrophis punctatus	x		
Ophichthus cruentifer	x		
Opisthonema oglinum	x		x
Opsanus tau	x	x	
Paralichthys dentatus	x	x	x
Peprilus sp.	x	x	

Peprilus triacanthus	x	x	
Perca flavescens		x	
Pholis gunnellus	x		
Pleuronectes sp.	x		
Pogonias cromis	x	x	x
Pollachius virens		x	
Pomatomus saltatrix	x	x	x
Portunus gibbesii		x	
Prionotus carolinus	x	x	
Prionotus evolans	x		
Pseudopleuronectes americanus	x	x	
Raja erinacea		x	
Rhinoptera bonasus			x
Sciaenidae sp.	x	x	
Scophthalmus aquosus	x	x	
Selene setapinnis		x	
Selene vomer		x	
Sphoeroides maculatus	x	x	
Stenotomus chrysops		x	
Strongylura marina	x	x	x
Symphurus plagiusa	x	x	
Syngnathus fuscus	x	x	
Synodus foetens		x	
Tautoga onitis	x	x	
Tautogolabrus adspersus	x	x	
Trinectes maculatus	x	x	x
Tylosurus acus	x		
Unidentified fish	x	x	x
Urophycis regia	x	x	
Crabs			
Callinectes sapidus	x	x	x
Callinectes similis	x	x	
Callinectes sp.	x		
Cancer irroratus	x	x	x
Carcinus maenas	x	x	
Libinia dubia		x	
Libinia emarginata	x	x	x
Libinia sp.	x	x	
Limulus polyphemus	x	x	x
Ovalipes ocellatus	x	x	

Table 9. Scientific and common names, origin (O=ocean, E=estuary), and stages for the larvae of each fish species collected at sites to and within Barnegat Bay during 2010-2014. See Figure 1 for sampling locations.

Family	Scientific Name	Common Name	Origin	Stages
Elopidae	Elops saurus	Ladyfish	O	POST
Anguillidae	Anguilla rostrata	American eel	O	FLEX/POST
Ophichthidae	Myrophis punctatus	Speckled worm eel	O	
	Ophichthus cruentifer	Margined snake eel	O	
Congridae	Conger oceanicus	Conger eel	O	
Clupeidae	Brevoortia tyrannus	Atlantic menhaden	O	FLEX/POST
	Clupea harengus	Atlantic herring	O	POST
	Clupeidae sp.	Herrings	O	PRE/FLEX/POST
	Clupeiformes sp.	Clupeid	-	PRE/FLEX/POST
	Opisthonema oglinum	Atlantic thread herring	O	PRE/POST
Engraulidae	Anchoa hepsetus	Striped anchovy	O	PRE/FLEX/POST
	Anchoa mitchilli	Bay anchovy	E/O	PRE/FLEX/POST
	Anchoa sp.	Anchovy	E/O	PRE/FLEX/POST
	Engraulidae sp.	Anchovies	-	PRE/FLEX/POST
	Engraulis eurystole	Silver anchovy	O	PRE/FLEX/POST
Gadidae	Enchelyopus cimbrius	Fourbeard rockling	O	FLEX/POST
	Gadus morhua	Atlantic cod	O	PRE/POST
	Urophycis regia	Spotted hake	O	POST
Ophidiidae	Ophidion marginatum	Striped cusk-eel	E/O	POST
Batrachoididae	Opsanus tau	Oyster toadfish	E	POST
Hemiramphidae	Hyporhamphus meeki	American halfbeak	?	POST
Belonidae	Strongylura marina	Atlantic needlefish	E	FLEX/POST
	Tylosurus acus	Agujon	?	POST
Cyprinodontidae	Cyprinodon variegatus	Sheepshead minnow	E	POST
	Fundulus heteroclitus	Mummichog	E	POST
	Fundulus luciae	Spotfin killifish	E	POST
	Fundulus majalis	Striped killifish	E	POST
	Fundulus sp.	Killifish	-	POST
	Lucania parva	Rainwater killifish	E	POST
Atherinidae	Menidia beryllina	Inland silverside	E	POST
	Menidia menidia	Atlantic silverside	E	PRE/FLEX/POST
	Menidia sp.	Silversides	-	PRE/FLEX/POST
Gasterosteidae	Apeltes quadracus	Fourspine stickleback	E	PRE/FLEX/POST
	Gasterosteus aculeatus	Threespine stickleback	E	POST
Syngnathidae	Hippocampus erectus	Lined seahorse	E	

	Syngnathus fuscus	Northern pipefish	E	
Triglidae	Prionotus carolinus	Northern searobin	O	FLEX/POST
	Prionotus evolans	Striped searobin	O	POST
Cottidae	Myoxocephalus aenaeus	Grubby	E/O	FLEX
Gerreidae	Gerreidae sp.	Mojarras	?	POST
Sciaenidae	Bairdiella chrysoura	Silver perch	E/O	PRE/FLEX/POST
	Cynoscion regalis	Weakfish	E/O	FLEX/POST
	Leiostomus xanthurus	Spot	O	FLEX/POST
	Menticirrhus americanus	Southern kingfish	O	FLEX
	Menticirrhus saxatilis	Northern kingfish	O	FLEX/POST
	Micropogonias undulatus	Atlantic croaker	O	FLEX/POST
	Pogonias cromis	Black drum	?	FLEX/POST
	Sciaenidae sp.	Drums	O	PRE/FLEX/POST
	Centropristis striata	Black sea bass	O	POST
Mugilidae	Mugil cephalus	Striped mullet	E	POST
	Mugil curema	white mullet	O	POST
Labridae	Tautoga onitis	Tautog	E/O	FLEX/POST
	Tautogolabrus adspersus	Cunner	O	FLEX/POST
Pholidae	Pholis gunnellus	Rock gunnel	?	FLEX/POST
Blenniidae	Blenniidae sp.	Combtooth blennies	-	POST
	Chasmodes bosquianus	Striped blenny	E	POST
	Hypsoblennius hentz	Feather blenny	E/O	FLEX/POST
Ammodytidae	Ammodytes americanus	American sand lance	?	FLEX/POST
	Ammodytes sp.	Sand lance	O	PRE/FLEX/POST
Gobiidae	Gobiidae sp.	Gobies	-	PRE/FLEX/POST
	Gobionellus oceanicus	Highfin goby	O	POST
	Gobiosoma bosc	Naked goby	E	FLEX/POST
	Gobiosoma ginsburgi	Seaboard goby	E/O	POST
	Gobiosoma sp.	Goby	E	PRE/FLEX/POST
	Microgobius thalassinus	Green goby	?	FLEX/POST
Stromateidae	Peprilus sp.	butterfish	-	FLEX
	Peprilus triacanthus	Butterfish	O	FLEX/POST
Bothidae	Etropus microstomus	Smallmouth flounder	O	POST
	Paralichthys dentatus	Summer flounder	O	POST
	Scophthalmus aquosus	Windowpane	E/O	PRE/FLEX/POST
Pleuronectidae	Pleuronectes sp.	flounder	-	FLEX
	Pseudopleuronectes americanus	winter flounder	E	PRE/FLEX/POST
	Pomatomus saltatrix	Bluefish	O	POST
Soleidae	Symphurus plagiusa	Blackcheek tonguefish	O	POST

	Trinectes maculatus	Hogchoker	E	POST
	Lagodon rhomboides	Pinfish	O	POST
Tetraodontidae	Chilomycterus schoepfi	Striped burrfish	?	POST
	Sphoeroides maculatus	Northern puffer	E	PRE/FLEX/POST
Gobiesocidae	Gobiesox strumosus	Skilletfish	E	FLEX/POST

Table 10. Larval fish supply to Barnegat Bay as estimated by larval fish density and total number of fish collected from Jimmy's Creek, Little Sheepshead Creek (a proxy for Little Egg Inlet), and Little Thoroughfare in May, June, July, August, October, and December of 2010 and in February and April of 2011, from Barnegat Inlet and Pt. Pleasant Canal in February, April, June, August, and October of 2012 and 2013, and from Little Sheepshead Creek in February, April, June, August, and October of 2012, 2013, and 2014. See Figure 1 for a map of each sampling location. For each year, total volume and numbers of fish were summed across all months sampled at each location and fish density was calculated as the number of fish per 1000m^3. Den=density, No=number.

Species	Inlets: Little Egg 2010 No	Den	Little Egg 2011 No	Den	Little Egg 2012 No	Den	Little Egg 2013 No	Den	Little Egg 2014 No	Den	Barnegat 2012 No	Den	Barnegat 2013 No	Den	Thoroughfares: Jimmys Creek 2010 No	Den	Jimmys Creek 2011 No	Den	Little Thoroughfare 2010 No	Den	Little Thoroughfare 2011 No	Den	Point Pleasant Canal 2012 No	Den	Point Pleasant Canal 2013 No	Den
Ammodytes americanus	1	0.1																								
Ammodytes sp.			40	9.9	1																					
						0.3	2	0.3	93	13	2	1.6	1	0.4			20	7			31	7.7	5	2.8		
Anchoa hepsetus	3	0.4			22	6.1	1	0.2			43	35			5	1.9					1	0.3	1	0.6		
Anchoa mitchilli	967	127			931	258	477	74	173	25	42	34	768	293	338	131			2800	384	4	1	20	11	23	4.3
Anchoa sp.	30	4			225	62	3	0.5	5	0.7	83	67	149	57	35	14	1	0.4	50	6.9			21	12	1	0.2
Anguilla rostrata	1	0.1	8	2	17	4.7	25	3.9	9	1.3	3	2.4			2	0.8	30	11			15	3.7	17	9.4	5	0.9
Apeltes quadracus	1	0.1									32	26	1	0.4			1	0.4	1	0.1			3	1.7		
Bairdiella chrysoura					2	0.6			32	4.6	7	5.7	3	1.1					3	0.4			1	0.6	4	0.8
Brevoortia tyrannus	40	5.3			60	17	378	59	32	4.6	3	2.4	20	7.6	25	9.7			129	18					6	1.1
Centropristis striata					4	1.1					43	35					1	0.4								
Chasmodes bosquianus															1	0.4										
Clupea harengus			17	4.2	5	1.4	11	1.7									28	9.8	1	0.1	48	12				
Clupeidae sp.	1	0.1					2	0.3			13	10	1	0.4												
Clupeiformes sp.	4	0.5	1	0.3	2	0.6	2	0.3	1	0.1	53	43	61	23												
Conger oceanicus	7	0.9			1	0.3			2	0.3					1	0.4			7	1					1	0.2
Ctenogobius boleosoma	1	0.1			1	0.3	1	0.2	15	2.2	5	4	2	0.8												
Cynoscion regalis					10	2.8	2	0.3			3	2.4	1	0.4												
Cyprinodon															2	0.8			2	0.3						
Elops saurus							1	0.2																		
Enchelyopus											2	1.6											5	2.8		

Engraulidae sp.					10	2.8	2	0.3					8	3.1												
Engraulis eurystole					3	0.8																				
Etropus microstomus	12	1.6							2	0.3	30	24											1	0.6		
Fundulus heteroclitus	11	1.5			2	0.6	2	0.3							47	18	1	0.4	9	1.2			1	0.6		
Fundulus luciae							1	0.2																		
Fundulus majalis	1	0.1													1	0.4			1	0.1						
Fundulus sp.									4	0.6																
Gadus morhua									2	0.3																
Gasterosteus aculeatus	1	0.1													6	2.3	2	0.7								
Gerreidae sp.	1	0.1													1	0.4			1	0.1						
Gobiesox strumosus													1	0.4											1	0.2
Gobiidae sp.							1	0.2			1	0.8	1	0.4									2	1.1		
Gobionellus oceanicus									4	0.6																
Gobiosoma bosc	206	27			200	55	3	0.5	2	0.3	2	1.6	1	0.4	240	93			170	23			17	9.4	12	2.3
Gobiosoma ginsburgi	246	32	1	0.3	58	16	5	0.8	10	1.5	35	28	54	21	1	0.4			131	18			1	0.6	13	2.5
Gobiosoma sp.	6	0.8			130	36	1	0.2	4	0.6			9	3.4	41	16			10	1.4					4	0.8
Hippocampus erectus	2	0.3			6	1.7	1	0.2	11	1.6	1	0.8			1	0.4			1	0.1			1	0.6	1	0.2
Hyporhamphus meeki	1	0.1																								
Hypsoblennius hentz													1	0.4	2	0.8										
Lagodon rhomboides					2	0.6	1	0.2			1	0.8														
Leiostomus xanthurus					10	2.8	1	0.2	1	0.1																
Menidia beryllina																			1	0.1						
Menidia menidia	257	34	3	0.7	10	2.8	18	2.8	657	95			2	0.8	208	81	1	0.4	8	1.1	1	0.3			2	0.4
Menidia sp.	177	23			5	1.4	13	2	160	23	1	0.8	1	0.4	202	78			15	2.1						
Menticirrhus americanus	1	0.1																								
Menticirrhus saxatilis	1	0.1			4	1.1							1	0.4												
Microgobius thalassinus	1	0.1											5	1.9	61	24			5	0.7					1	0.2
Micropogonias undulatus	64	8.4					2	0.3	121	18					6	2.3			25	3.4					1	0.2
Mugil curema							1	0.2							3	1.2			1	0.1						
Myoxocephalus aenaeus									1	0.1																

Myrophis punctatus					1	0.3			1	0.1					1	0.4			1	0.1						
Ophichthus cruentifer									2	0.3																
Ophidion marginatum			4	1																						
Opisthonema oglinum	20	2.6			2	0.6									18	7			9	1.2						
Opsanus tau							1	0.2															1	0.6	1	0.2
Paralichthys dentatus	12	1.6			15	4.2	4	0.6	9	1.3	2	1.6					2	0.7	2	0.3					2	0.4
Peprilus sp.							2	0.3																		
Peprilus triacanthus	1	0.1			7	1.9																				
Peprilus tricanthus	1	0.1																								
Pholis gunnellus			1	0.3					4	0.6																
Pleuronectes sp.																									1	0.2
Pogonias cromis																							1	0.6		
Pomatomus saltatrix																			1	0.1						
Prionotus carolinus			3	0.7	2	0.6					2	1.6	4	1.5			1	0.4					1	0.6	1	0.2
Prionotus evolans	1	0.1			1	0.3					3	2.4														
Pseudopleuronectes americanus	4	0.5	373	92	37	10	511	79	79	11	4	3.2	75	29			460	161			656	162	4	2.2	289	55
Sciaenidae sp.	5	0.7			75	21			3	0.4	5	4			1	0.4			2	0.3			2	1.1		
Scophthalmus aquosus	1	0.1			1	0.3	32	5	2	0.3			50	19					1	0.1					1	0.2
Sphoeroides maculatus									2	0.3					3	1.2									2	0.4
Strongylura marina	1	0.1													1	0.4										
Symphurus plagiusa											1	0.8														
Syngnathus fuscus	142	19			153	42	93	14	231	33	11	8.9	14	5.3	60	23	1	0.4	51	7	2	0.5	7	3.9	6	1.1
Tautoga onitis					4	1.1					8	6.5													1	0.2
Tautogolabrus adspersus											78	63	11	4.2					1	0.1					1	0.2
Unidentified fish									1	0.1	1	0.8														
Urophycis regia					2	0.6																				

Table 11. Data used for PCA and CCA analyses of larval supply to Barnegat Bay broken down by month, year, and sampling location.

	Jun-10	Aug-10	Oct-10	Feb-11	Apr-11	Feb-12	Apr-12	Jun-12	Aug-12	Feb-13	Apr-13	Jun-13	Aug-13	Oct-13
LSHCB	X	X	X	X	X	X	X	X	X	X	X	X	X	X
JIMMYS	X	X	X	X	X									
LTHORO	X	X	X	X	X									
PTPLSNT						X	X	X	X	X	X	X	X	X
BRNLIGHT						X	X	X	X	X	X	X	X	X

Table 12. Larval fish supply within Barnegat Bay as estimated by larval fish density and total number of fish collected from the Oyster Creek Nuclear Generating Station (OCNGS Intake and Discharge), and the Rt. 72 and 37 bridges in February, April, June, August, and October of 2014. See Figure 1 for a map of each sampling location. For each year, total volume and numbers of fish were summed across all months sampled at each location and fish density was calculated as the number of fish per 1000m^3.

	OCNGS				Rt. 37 Bridge		Rt. 72 Bridge	
	Intake		Discharge					
Species	Number	Density	Number	Density	Number	Density	Number	Density
Ammodytes sp.	114	16.21	86	8.7	54	7.37	89	12.38
Anchoa hepsetus			1	0.1				
Anchoa mitchilli	562	79.89	274	27.72	46	6.28	13	1.81
Anchoa sp.	14	1.99	7	0.71	3	0.41	24	3.34
Anguilla rostrata	25	3.55	16	1.62	121	16.51	22	3.06
Apeltes quadracus					1	0.14		
Bairdiella chrysoura	29	4.12	2	0.2				
Blenniidae sp.	1	0.14						
Brevoortia tyrannus	129	18.34	43	4.35	15	2.05	35	4.87
Chasmodes bosquianus					1	0.14	2	0.28
Chilomycterus schoepfi			1	0.1				
Clupeiformes sp.	6	0.85			1	0.14	2	0.28
Ctenogobius boleosoma	2	0.28	1	0.1				
Fundulus heteroclitus							1	0.14
Fundulus majalis					1	0.14		
Gadus morhua			2	0.2				
Gobiesox strumosus	5	0.71	4	0.4				
Gobiidae sp.							1	0.14
Gobionellus oceanicus	1	0.14	1	0.1				
Gobiosoma bosc	7	1	11	1.11	13	1.77	2	0.28
Gobiosoma ginsburgi	2	0.28	2	0.2			5	0.7
Gobiosoma sp.	11	1.56	10	1.01	1	0.14	38	5.29
Hippocampus erectus	4	0.57	1	0.1			3	0.42

Hypsoblennius hentz	1	0.14	1	0.1				
Leiostomus xanthurus	1	0.14	1	0.1	1	0.14		
Menidia beryllina	1	0.14			1	0.14		
Menidia menidia	76	10.8	125	12.65	150	20.47	42	5.84
Menidia sp.	15	2.13	7	0.71	4	0.55	8	1.11
Menticirrhus saxatilis	1	0.14						
Microgobius thalassinus	14	1.99	6	0.61	1	0.14		
Micropogonias undulatus	25	3.55	2	0.2	2	0.27		
Opsanus tau			1	0.1				
Paralichthys dentatus	37	5.26	12	1.21	17	2.32	6	0.83
Pholis gunnellus	1	0.14						
Pomatomus saltatrix	1	0.14						
Prionotus evolans	1	0.14						
Pseudopleuronectes americanus	35	4.98	47	4.75	102	13.92	2	0.28
Sphoeroides maculatus	5	0.71	2	0.2	3	0.41	4	0.56
Strongylura marina			1	0.1	2	0.27		
Syngnathus fuscus	18	2.56	4	0.4	21	2.87	61	8.48
Trinectes maculatus					1	0.14		
Urophycis regia							1	0.14

Table 13. Data used for PCA and CCA analyses of larval supply within Barnegat Bay broken down by month, year, and sampling location.

	Early Apr-14	Late Apr-14	Jun-14	Aug-14	Oct-14
OYSIN	X	X	X	X	X
OYSOUT	X	X	X	X	X
RT37	X	X	X	X	X
RT72	X	X	X	X	X

Table 14. Fish and crab species composition and abundance (CPUE = number per tow) by otter trawl sample and month across all clusters in Barnegat Bay during 2014. Individuals caught in April (n= 623 individuals), June (n= 2,900 individuals), August (n= 9,850 individuals), and October (n= 8,288) varied by month.

Scientific Name	Common Name	April	June	August	October	Total CPUE for 2014
Fishes						
Anchoa hepsetus	Striped Anchovy	0.00	0.00	0.22	0.03	0.06
Anchoa mitchilli	Bay Anchovy	0.03	3.38	31.31	29.59	16.08
Anchoa sp.	Anchovy	0.00	0.00	1.03	0.03	0.27
Anguilla rostrata	American Eel	0.03	0.10	0.01	0.02	0.04
Apeltes quadracus	Four spine Stickleback	0.10	2.46	4.93	5.26	3.18
Bairdiella chrysoura	Silver perch	0.00	0.00	1.77	1.41	0.79
Brevoortia sp.	Menhaden	0.01	0.00	0.00	0.00	0.00
Brevoortia tyrannus	Atlantic menhaden	0.00	1.48	0.24	0.06	0.45
Caranx crysos	Blue runner	0.00	0.00	0.02	0.00	0.00
Caranx hippos	Crevalle jack	0.00	0.00	0.03	0.00	0.01
Centropristis striata	Black sea bass	0.04	0.07	0.15	0.08	0.08
Chaetodon ocellatus	Spotfin butterflyfish	0.00	0.00	0.01	0.01	0.00
Chasmodes bosquianus	Striped blenny	0.00	0.00	0.14	0.05	0.05
Chilomycterus schoepfi	Striped burrfish	0.00	0.03	0.08	0.00	0.03
Clupeiformes sp.	Herring/Shad/Menhaden	0.00	0.00	0.41	0.01	0.10
Cynoscion regalis	Weakfish	0.00	0.00	0.07	0.03	0.03
Etropus microstomus	Smallmouth flounder	0.02	0.04	0.01	0.02	0.02
Fundulus heteroclitus	Mummichog	0.08	0.07	0.13	0.02	0.08
Fundulus majalis	Striped killifish	0.01	0.00	0.00	0.00	0.00
Gadus morhua	Atlantic cod	0.01	0.00	0.00	0.00	0.00
Gobiesox strumosus	Skilletfish	0.00	0.00	0.02	0.03	0.01
Gobiosoma bosc	Naked goby	0.13	0.12	1.04	0.81	0.53
Gobiosoma ginsburgi	Seaboard goby	0.00	0.00	0.10	0.28	0.09
Gobiosoma sp.	Goby	0.00	0.01	0.01	0.02	0.01
Hippocampus erectus	Lined seahorse	0.02	0.02	0.08	0.06	0.04
Hypsoblennius hentz	Feather blenny	0.00	0.00	0.08	0.05	0.03
Lagodon rhomboides	Pinfish	0.00	0.00	0.01	0.00	0.00
Leiostomus xanthurus	Spot croaker	0.01	0.20	0.00	0.00	0.05
Lepomis gibbosus	Pumpkinseed	0.00	0.00	0.05	0.02	0.02
Lepomis macrochirus	Bluegill	0.00	0.00	0.00	0.01	0.00
Lucania parva	Rainwater killifish	0.00	0.00	0.00	0.02	0.00
Lutjanus griseus	Mangrove snapper	0.00	0.00	0.00	0.02	0.00
Menidia beryllina	Inland silverside	0.00	0.00	0.25	0.00	0.06
Menidia menidia	Atlantic silverside	0.09	1.81	24.33	18.20	11.11
Menidia sp.	Silverside	0.00	0.05	0.02	0.00	0.02
Menticirrhus saxatilis	Northern kingfish	0.00	0.00	0.07	0.01	0.02

Microgobius thalassinus	Green goby	0.00	0.00	0.02	0.00	0.00
Micropogonias undulatus	Atlantic croaker	0.00	0.00	0.00	1.55	0.39
Morone americana	Silver perch	0.00	0.02	0.00	0.07	0.02
Morone saxatilis	Striped bass	0.01	0.00	0.00	0.00	0.00
Morone sp.	Bass	0.00	0.45	0.24	0.00	0.17
Mugil curema	White mullet	0.00	0.00	0.03	0.00	0.01
Mustelus canis	Smooth dogfish	0.00	0.00	0.01	0.01	0.00
Opsanus tau	Oyster toadfish	0.01	0.12	0.50	0.19	0.20
Paralichthys dentatus	Summer flounder	0.04	0.41	0.36	0.10	0.23
Peprilus sp.	Butterfish	0.00	0.00	0.01	0.00	0.00
Peprilus triacanthus	Atlantic butterfish	0.00	0.00	0.07	0.02	0.02
Pogonias cromis	Black drum	0.00	0.00	0.01	0.01	0.00
Pollachius virens	Pollock	0.07	0.00	0.00	0.00	0.02
Pomatomus saltatrix	Bluefish	0.00	0.06	0.04	0.02	0.03
Prionotus carolinus	Northern sea robin	0.02	0.01	0.01	0.01	0.01
Pseudopleuronectes americanus	Winter Flounder	0.04	3.93	0.33	0.13	1.11
Raja erinacea	Little skate	0.00	0.00	0.00	0.01	0.00
Sciaenidae sp.	Drum/croaker	0.00	0.00	0.01	0.00	0.00
Scophthalmus aquosus	Windowpane flounder	0.03	0.02	0.00	0.00	0.01
Selene setapinnis	Atlantic moonfish	0.00	0.00	0.00	0.01	0.00
Selene vomer	Lookdown	0.00	0.00	0.02	0.00	0.01
Sphoeroides maculatus	Northern puffer	0.00	0.44	0.31	0.03	0.20
Stenotomus chrysops	Scup	0.00	0.02	0.00	0.00	0.00
Strongylura marina	Atlantic needlefish	0.00	0.02	0.00	0.00	0.00
Symphurus plagiusa	Blackcheek tounguefish	0.00	0.00	0.00	0.02	0.00
Syngnathus fuscus	Northern pipefish	0.26	0.66	3.35	3.24	1.88
Tautoga onitis	Tautog	0.01	0.01	0.13	0.16	0.08
Tautogolabrus adspersus	Cunner	0.00	0.00	0.20	0.03	0.06
Trinectes maculatus	Hogchoker	0.02	0.04	0.01	0.02	0.02
Urophycis regia	Spotted hake	0.21	0.00	0.00	0.00	0.05
Crabs						
Callinectes sapidus	Blue crab	3.54	7.33	7.66	5.54	6.02
Cancer irroratus	Rock crab	0.04	0.02	0.01	0.00	0.02
Libinia dubia	Longnose spider crab	0.01	0.10	0.09	0.01	0.05
Libinia emarginata	Common Spider crab	0.14	0.08	0.03	0.05	0.08
Libinia sp.	Spider crab	0.01	0.00	0.00	0.00	0.00
Ovalipes ocellatus	Lady crab	0.01	0.02	0.00	0.01	0.01
Terrapins						
Malaclemys terrapin	Diamondback terrapin	0.01	0.01	0.02	0.01	0.01
Horshoe Crab						
Limulus polyphemus	Horseshoe crab	0.02	0.00	0.00	0.00	0.00

Table 15. Species composition and abundance (CPUE) by habitat (otter trawl) from sampling in 2014.

Scientific Name	Common Name	Bay	Marsh Creek (mouth)	Marsh Creek (upper)	SAV
Fishes					
Anchoa hepsetus	Striped Anchovy	0.14	0.11	0.01	0.00
Anchoa mitchilli	Bay Anchovy	20.53	30.04	14.00	1.23
Anchoa sp.	Anchovy	0.08	0.91	0.10	0.00
Anguilla rostrata	American Eel	0.00	0.09	0.06	0.02
Apeltes quadracus	Four spine Stickleback	0.01	0.45	0.02	11.44
Bairdiella chrysoura	Silver perch	0.13	2.49	0.05	0.54
Brevoortia sp.	Menhaden	0.00	0.00	0.01	0.00
Brevoortia tyrannus	Atlantic menhaden	0.02	0.02	1.79	0.00
Caranx crysos	Blue runner	0.02	0.00	0.00	0.00
Caranx hippos	Crevalle jack	0.00	0.03	0.00	0.00
Centropristis striata	Black sea bass	0.12	0.12	0.00	0.10
Chaetodon ocellatus	Spotfin butterflyfish	0.00	0.00	0.00	0.02
Chasmodes bosquianus	Striped blenny	0.01	0.12	0.04	0.02
Chilomycterus schoepfi	Striped burrfish	0.06	0.02	0.00	0.04
Clupeiformes sp.	Herring/Shad/Menhaden	0.05	0.13	0.16	0.08
Cynoscion regalis	Weakfish	0.04	0.04	0.03	0.00
Etropus microstomus	Smallmouth flounder	0.05	0.02	0.00	0.02
Fundulus heteroclitus	Mummichog	0.00	0.02	0.18	0.10
Fundulus majalis	Striped killifish	0.00	0.00	0.00	0.01
Gadus morhua	Atlantic cod	0.00	0.00	0.01	0.00
Gobiesox strumosus	Skilletfish	0.00	0.04	0.02	0.00
Gobiosoma bosc	Naked goby	0.12	1.08	0.93	0.03
Gobiosoma ginsburgi	Seaboard goby	0.12	0.01	0.02	0.22
Gobiosoma sp.	Goby	0.00	0.03	0.01	0.00
Hippocampus erectus	Lined seahorse	0.03	0.02	0.02	0.11
Hypsoblennius hentz	Feather blenny	0.01	0.09	0.03	0.01
Lagodon rhomboides	Pinfish	0.01	0.00	0.00	0.00
Leiostomus xanthurus	Spot croaker	0.00	0.01	0.21	0.00
Lepomis gibbosus	Pumpkinseed	0.00	0.00	0.08	0.00
Lepomis macrochirus	Bluegill	0.00	0.00	0.01	0.00
Lucania parva	Rainwater killifish	0.00	0.01	0.00	0.01
Lutjanus griseus	Mangrove snapper	0.00	0.01	0.01	0.00
Menidia beryllina	Inland silverside	0.00	0.00	0.26	0.00
Menidia menidia	Atlantic silverside	0.59	0.82	2.46	37.89
Menidia sp.	Silverside	0.03	0.00	0.01	0.02
Menticirrhus saxatilis	Northern kingfish	0.00	0.07	0.01	0.00

Microgobius thalassinus	Green goby	0.00	0.00	0.01	0.01
Micropogonias undulatus	Atlantic croaker	0.33	0.82	0.44	0.00
Morone americana	Silver perch	0.00	0.00	0.08	0.00
Morone saxatilis	Striped bass	0.00	0.01	0.00	0.00
Morone sp.	Bass	0.00	0.00	0.71	0.00
Mugil curema	White mullet	0.00	0.00	0.03	0.00
Mustelus canis	Smooth dogfish	0.00	0.01	0.00	0.01
Opsanus tau	Oyster toadfish	0.08	0.42	0.20	0.13
Paralichthys dentatus	Summer flounder	0.39	0.29	0.14	0.09
Peprilus sp.	Butterfish	0.00	0.00	0.01	0.00
Peprilus triacanthus	Atlantic butterfish	0.03	0.00	0.07	0.00
Pogonias cromis	Black drum	0.00	0.00	0.02	0.00
Pollachius virens	Pollock	0.01	0.03	0.00	0.03
Pomatomus saltatrix	Bluefish	0.03	0.01	0.06	0.02
Prionotus carolinus	Northern sea robin	0.02	0.00	0.01	0.02
Pseudopleuronectes americanus	Winter Flounder	0.67	0.63	1.39	1.68
Raja erinacea	Little skate	0.01	0.00	0.00	0.00
Sciaenidae sp.	Drum/croaker	0.00	0.01	0.00	0.00
Scophthalmus aquosus	Windowpane flounder	0.03	0.01	0.00	0.02
Selene setapinnis	Atlantic moonfish	0.00	0.01	0.00	0.00
Selene vomer	Lookdown	0.00	0.03	0.00	0.00
Sphoeroides maculatus	Northern puffer	0.08	0.20	0.07	0.42
Stenotomus chrysops	Scup	0.02	0.00	0.00	0.00
Strongylura marina	Atlantic needlefish	0.00	0.00	0.00	0.02
Symphurus plagiusa	Blackcheek tounguefish	0.00	0.01	0.01	0.00
Syngnathus fuscus	Northern pipefish	0.34	0.96	0.04	5.78
Tautoga onitis	Tautog	0.03	0.15	0.00	0.13
Tautogolabrus adspersus	Cunner	0.16	0.01	0.00	0.07
Trinectes maculatus	Hogchoker	0.02	0.02	0.07	0.00
Urophycis regia	Spotted hake	0.04	0.03	0.02	0.12
Crabs					
Callinectes sapidus	Blue crab	2.54	9.24	10.18	2.48
Cancer irroratus	Rock crab	0.03	0.00	0.00	0.04
Libinia dubia	Longnose spider crab	0.03	0.03	0.00	0.13
Libinia emarginata	Common Spider crab	0.18	0.02	0.00	0.11
Libinia sp.	Spider crab	0.00	0.00	0.00	0.01
Ovalipes ocellatus	Lady crab	0.02	0.00	0.00	0.02
Terrapins					
Malaclemys terrapin	Diamondback terrapin	0.00	0.00	0.04	0.00
Horshoe Crab					
Limulus polyphemus	Horseshoe crab	0.01	0.00	0.00	0.01

Table 16. Total CPUE and abundance of fish species caught for 2012 (day) and 2013 (day-June, night-other months) in gillnet sampling.

		Cluster 1				Cluster 3				Cluster 5			
		2012		2013		2012		2013		2012		2013	
Genus	**Species**	**CPUE**	**#**	**CPUE**	**#**	**CPUE**	**#**	**CPUE**	**#**	**CPUE**	**#**	**CPUE**	**#**
Fishes													
Alosa	*mediocris*			0.03	2								
Bairdiella	*chrysoura*							0.03	1				
Brevoortia	*tyrannus*	0.22	15	1.67	113	0.02	1	1.16	45	0.34	18	0.67	25
Carcharhinus	*plumbeus*	0.06	4	0.01	1								
Cyanea	*capillata*							0.05	2				
Cynoscion	*regalis*			0.15	10	0.02	1	0.10	4	0.02	1	0.03	1
Dasyatis	*say*			0.01	1								
Dorosoma	*cepedianum*	0.01	1	0.01	1					0.02	1	0.29	11
Leiostomus	*xanthurus*	0.25	17	0.31	21	0.48	25	0.23	9	0.39	21	0.72	27
Menticirrhus	*saxatilis*	0.01	1							0.02	1	0.05	2
Micropogonias	*undulatus*			0.01	1	0.11	6	0.13	5	0.21	11		
Morone	*americana*	0.01	1	0.01	1								
Morone	*saxatilis*			0.01	1			0.03	1				
Mustelus	*canis*	0.26	18	0.72	49	0.23	12	0.39	15				
Myliobatis	*freminvillii*			0.01	1								
Opisthonema	*oglinum*					0.06	3						
Paralichthys	*dentatus*	0.04	3					0.03	1				
Pogonias	*cromis*									0.02	1		
Pomatomus	*saltatrix*	0.06	4	0.13	9	0.08	4	0.15	6	0.21	11	0.37	14
Rhinoptera	*bonasus*			0.06	4	0.02	1	0.08	3				
Strongylura	*marina*			0.01	1								
Trinectes	*maculatus*							0.03	1				
Unidentified	*fish*	0.01	1										
Unidentified	*sp.*					0.02	1						
Crabs													
Callinectes	*sapidus*	0.20	14	0.22	15	0.11	6	0.15	6	0.24	13	0.72	27
Cancer	*irroratus*	0.07	5										
Libinia	*emarginata*	0.54	37	0.25	17			0.05	2				
Limulus	*polyphemus*	0.04	3	0.07	5	0.02	1						
Malaclemys	*terrapin*	0.01	1	0.03	2								

Table 17. Comparison of fish usage of Barnegat Bay as a spawning and nursery area by resident species, warm-water migrants, and cool-water migrants in the 1970s - early 1980s based on Tatham et al. (1984) relative to recent collections in 2012 - 2014 and Able and Fahay (2010).

Categories and Species	1970-1980s			2012-2014		
	Spawning	Significant Usage	Minor Usage	Spawning	Significant Usage	Minor Usage
Resident Species						
Anguilla rostrata		X			X	
Opsanus tau	X	X		X	X	
Ophidion marginatum			X	X	X	
Cyprinodon variegatus	X	X		X	X	
Fundulus heteroclitus	X	X		X	X	
Fundulus majalis	X	X		X	X	
Lucania parva	X	X		X	X	
Menidia beryllina	X	X		X	X	
Menidia menidia	X	X		X	X	
Apeltes quadracus	X	X		X	X	
Hippocampus erectus	X	X		X	X	
Syngnathus fuscus	X	X		X	X	
Morone americana	X	X		X	X	
Tautoga onitis	X	X		X	X	
Tautogolabrus adspersus	X	X		X	X	
Chasmodes bosquianus	X	X		X	X	
Hypsoblennius hentzi	X	X		X	X	
Gobiosoma bosci	X	X		X	X	
Pseudopleuronectes americanus[f]	X	X		X	X	
Trinectes maculatus	X	X		?	?	
Dorosoma cepedianum						X
Cool-Water Migrants						
Alosa aestivalis	X[d]		?	?	?	
Alosa pseudoharengus	X[d]			X	X	
Alosa sapidissima						
Clupea harengus			X		X	
Merluccius bilinearis			X			?
Urophycis chuss			X			?
Urophycis regia			X			X
Gasterosteus aculeatus	X		X	X	X	
Micropogonias undulatus		X[e]			X	
Etropus microstomus			X		X	
Pseudopleuronectes americanus[g]	X	X		X	X	
Pollachius virens					X	
Myoxocephalus aenaeus					X	
Morone saxatilis					X	
Ammodytes americanus					X	

Warm-Water Migrants

Dasyatis sayi						X
Elops Saurus						X
Brevoortia tyrannus		X			X	
Alosa mediocris					X	
Anchoa mitchilli	X	X		X	X	
Synodus foetens			X			X
Strongylura marina		X		X	X	
Membras martinica		X				X
Fistularia tabacaria						X
Centropristis striata			X		X	
Pomatomus saltatrix		X			X	
Alectis ciliaris						?
Caranx crysos			X		?	
Caranx hippos		X			X	
Selene setapinnis						?
Selene vomer		X				?
Trachinotus carolinus						X
Trachinotus falcatus						
Bairdiella chrysoura		X			X	
Cynoscion regalis		X			X	
Leiostomus xanthurus		X			X	
Menticirrhus saxatilis					X	
Pogonias cromis						X
Mugil cephalus			X			X
Mugil curema		X			X	
Sphyraena borealis					X	
Astroscopus guttatus			X			X
Prionotus carolinus			X		X	
Prionotus evolans			X		X	
Paralichthys dentatus			X		X	
Aluterus schoepfi						?
Monacanthus hispidus						?
Sphoeroides maculatus	X	X[e]		X	X	
Chilomycterus schoepfi				?	X	
Carcharhinus plumbeus				X	X	
Mustelus canis				X	X	
Rhinoptera bonasus					X	
Myrophus punctatus						X
Opisthonema oglinum						X
Anchoa hepsetus						X
Engraulis eurystole						X
Mycteroperca microlepis						X
Lutjanus griseus						X
Lagodon rhomboides						X
Chaetodon ocellatus						X
Hypleurochilus geminatus						X
Ctenogobius boleosoma						X
Gobiosoma ginsburgi				X	X	
Microgobius thalassinus				X	X	

Peprilus triacanthus	X

[a]Significant usage denotes that larvae and young were common to abundant

[b]Minor usage denotes that larvae and young were occasional or uncommon

[c]Catadromous species

[d]Zich (1977) reported spawning migrations in some bay tributaries

[e]Probably significant usage when species is abundant

[f]Immature

[g]Adult

Table 18. Density of larval fish taxa at the Oyster Creek Nuclear Generating Station from September-October 1979 and May-August 1980 (Ecological Analysts, Inc. 1981.), September 1980-August 1981 (Ecological Analysts, Inc. 1982.), and April, June, August, and October during 2012 (No October samples), 2013, and 2014. The 1979-1981 and 2012-2014 samples were based on Bongo (36 cm diameter, 0.5 mm mesh) and plankton (1 m diameter, 1 mm mesh) nets, respectively.

Name	1979-1980	1980-1981	2012	2013	2014
Ammodytes sp.			16.32674	0.520352	11.82173
Anchoa hepsetus			8.640611	0.057817	0.059109
Anchoa mitchilli	29.075	56.912	95.09696	38.96855	49.41482
Anchoa sp.			18.18547	1.676688	1.241281
Anguilla rostrata			21.75224	20.75624	2.423454
Apeltes quadracus			0.050236		
Atherinidae sp.	1.633	6.395			
Bairdiella chrysoura			1.306139	0.115634	1.832368
Blenniidae sp.	3.551	0.634	0.050236		0.059109
Brevoortia tyrannus		0.046	65.70883	43.30481	10.16669
Callinectes sapidus			7.987541	0.925069	2.068802
Callinectes similis			0.050236		
Chilomycterus schoepfi					0.059109
Chilomycterus schoepfii			0.100472	0.173451	
Chrysaora quinquecirrha				0.289084	
Clupea harengus			13.11162	2.948659	
Clupeidae sp.			0.050236	0.057817	
Clupeiformes sp.			5.626444	1.329787	0.354652
Conger oceanicus			0.050236		
Ctenogobius boleosoma			0.452125	0.057817	0.177326
Cyanea capillata				0.057817	
Enchelyopus cimbrius			0.602833		
Engraulidae sp.			2.71275	0.057817	
Engraulis eurystole			0.050236		
Fundulus heteroclitus			0.150708		
Gadus morhua					0.118217
Gobiesox strumosus				0.115634	0.531978
Gobiidae sp.	48.364	26.408	5.325028	1.907956	
Gobionellus oceanicus					0.118217
Gobiosoma bosc			5.576208	7.689639	1.063956
Gobiosoma ginsburgi			0.653069	3.758094	0.236435
Gobiosoma sp.			6.179041	8.556892	1.241281
Hippocampus erectus			0.351653		0.295543
Hyporhamphus meeki			0.050236		
Hypsoblennius hentz			0.150708	0.057817	0.118217

Lagodon rhomboides			1.456847		
Leiostomus xanthurus			41.44479	0.115634	0.118217
Menidia beryllina			0.050236	0.231267	0.059109
Menidia menidia			3.918417	0.520352	11.88084
Menidia sp.			1.306139	0.231267	1.30039
Menticirrhus saxatilis			0.050236		0.059109
Microgobius thalassinus			6.028333	2.023589	1.182173
Micropogonias undulatus	0.078		0.150708	0.057817	1.595933
Mnemiopsis leidyi			288.506	325.6244	
Mugil cephalus			0.050236		
Mugil curema				0.115634	
Myrophis punctatus			0.100472		
Myoxocephalus aenaeu		0.479			
Opisthonema oglinum			1.155431	0.520352	
Opsanus tau			0.050236	0.057817	0.059109
Paralichthys dentatus		0.121	34.41174	8.672525	2.896323
Pholis gunnellus					0.059109
Pogonias cromis			0.050236		
Pomatomus saltatrix				0.057817	0.059109
Prionotus evolans				0.057817	0.059109
Pseudopleuronectes americanus		17.886	0.100472	5.955134	4.846909
Sciaenidae sp.			0.90425		
Scophthalmus aquosus		0.223			
Sphoeroides maculatus	0.308	0.273			
Sphoeroides maculatus					0.41376
Strongylura marina		0.050	0.401889		0.059109
Syngnathus fuscus			8.037778	3.989362	1.30039
Tautoga onitis	0.115	0.030			
Trinectes maculatus	0.200	0.060			
Tylosurus acus	0.063		0.050236		
Unidentified fish	0.181	0.110	0.050236	0.057817	
Urophycis regia			0.100472		

Table 19. Results of PCA on fish and crab assemblage of Barnegat Bay, all samples, reduced species inventory

Number of samples 603
Number of species 102
Number of occurrences 3049
No. of active species: 57
Total sum of squares in species data = 3232.54
Total standard deviation in species data TAU = 0.306673

Axes	1	2	3	4	Total variance
Eigenvalues	0.382	0.206	0.134	0.045	1.000
Cumulative percentage variance of species data	38.2	58.8	72.2	76.7	

Table 20. Results of CPCA on fish and crab assemblage of Barnegat Bay, all samples, all species inventory

Axes	1	2	3	4
Eigenvalues :	0.220	0.117	0.110	0.094
Species-environment correlations :	0.711	0.591	0.473	0.508
Cumulative percentage variance				
of species data :	1.6	2.5	3.3	4.0
of species-environment relation:	30.0	46.0	61.0	73.9

Table 21.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.381	0.301	0.242	0.176	1.803
Species-environment correlations :	0.986	1.000	0.982	0.914	
Cumulative percentage variance					
of species data :	21.1	37.8	51.2	61.0	
of species-environment relation:	28.3	50.7	68.6	81.7	

Sum of all eigenvalues 1.803
Sum of all canonical eigenvalues 1.345

Table 22. Annual sex ratios (M:F) including only adults (A) and adults plus prepubertal females (P) by gear at each cluster.

	2012				2013				2014			
	Trap		Trawl		Trap		Trawl		Trap		Trawl	
Cluster	A	A & P	A	A & P	A	A & P	A	A & P	A	A & P	A	A & P
I	2.0	1.7	3.5	1.2	3.1	2.7	3.3	1.4	6.2	5.1	1.4	0.8
II	5.0	3.1	2.0	0.4	5.0	4.3	6.5	2.3	6.6	3.6	3.8	1.1
III	2.1	1.9	3.7	0.7	3.1	3.0	2.9	0.7	5.1	3.7	1.9	1.1
IV	18.1	8.8	2.2	0.5	9.7	6.3	2.0	0.3	6.9	3.9	1.5	1.1
V	45.1	14.2	8.0	1.6	10.4	5.5	9.0	9.0	23.3	9.4	13.5	1.5

Table 23. Total (all data) and salinity control (24-26ppt only) mean (± 1 SD in parentheses) male fraction (% of males) and sex ratio (# males/# females) values in each cluster. Values sharing superscripted letters are not significantly different at P<0.05. Cluster 5 has no values from the salinity control range.

	Cluster				
Value	1	2	3	4	5
Total Male Fraction	0.69[a] (0.37)	0.79[bc] (0.28)	0.75[ac] (0.31)	0.86[bd] (0.20)	0.88[d] (0.18)
Salinity Control Male Fraction	0.72[a] (0.30)	0.84[a] (0.24)	0.77[a] (0.30)	0.88[a] (0.13)	- -
Total Sex Ratio	2.92[a] (2.82)	3.19[a] (2.58)	3.03[a] (2.61)	3.86[b] (2.82)	5.07[c] (3.61)
Salinity Control Sex Ratio	2.30[a] (1.94)	3.92[a] (3.08)	3.21[a] (2.74)	4.14[a] (2.01)	- -

Table 24. Average movement and number of days at large for tagged crabs recaptured at each urbanized creek type and cluster. Numbers in parentheses are standard deviations.

	Movement (Km/day)		Days at Large	
Cluster	Low	High	Low	High
I (low)	1.07 (1.31)	0.16 (0.20)	20.33 (26.86)	12.46 (13.88)
III (medium)	0.31 (0.36)	0.51 (0.59)	10.41 (8.89)	7.44 (8.09)
V (high)	0.76 (1.79)	2.13 (6.62)	10.43 (11.52)	12.63 (25.08)

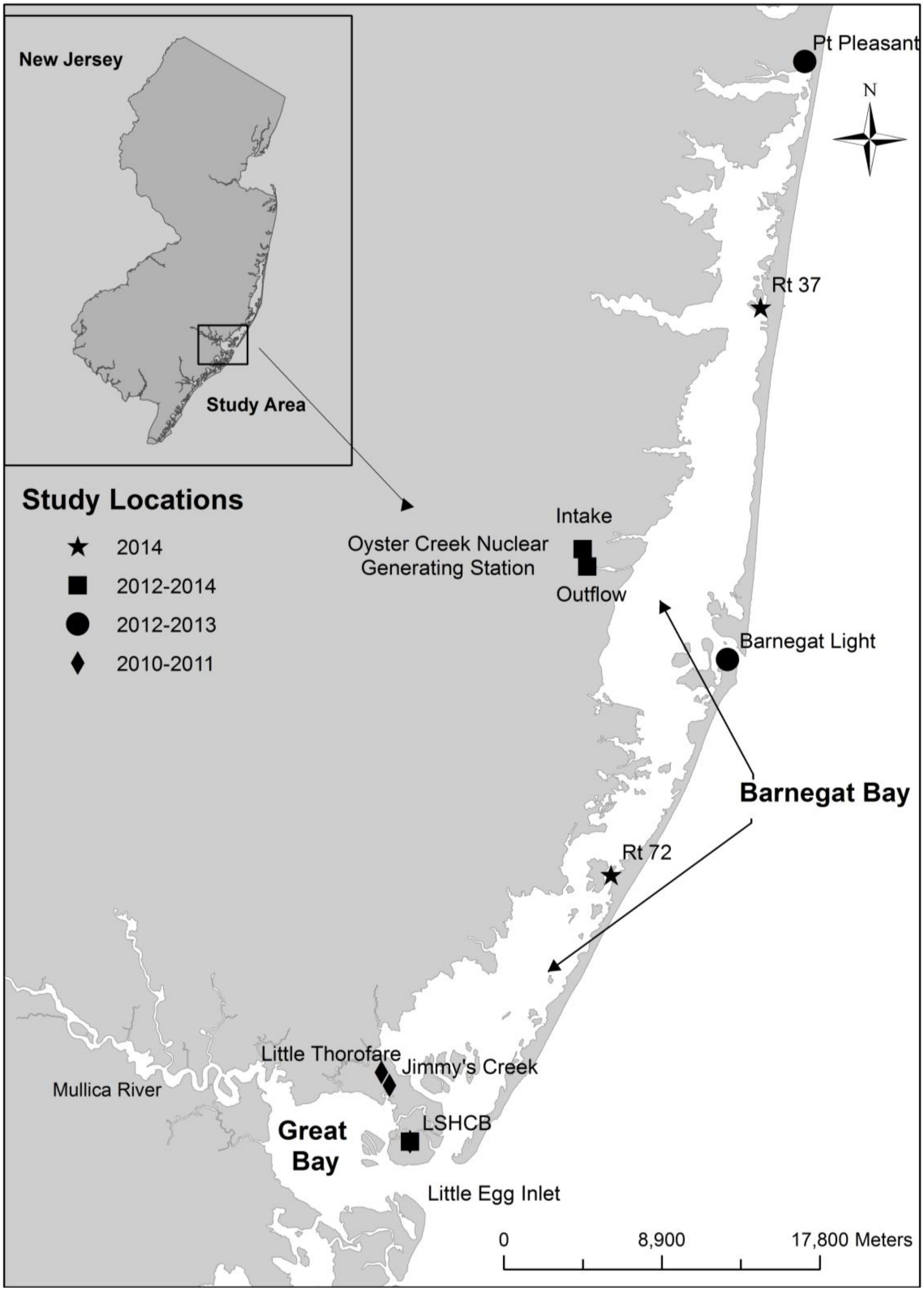


Figure 1. Location of larval fish sampling sites at inlets (Little Egg, Barnegat), thoroughfares (Pt. Pleasant Canal, Jimmy's Creek, Little Thoroughfare), and within the bay (Oyster Creek Nuclear Generating Station (intake and outflow), and Rt. 37 and 72 bridges.

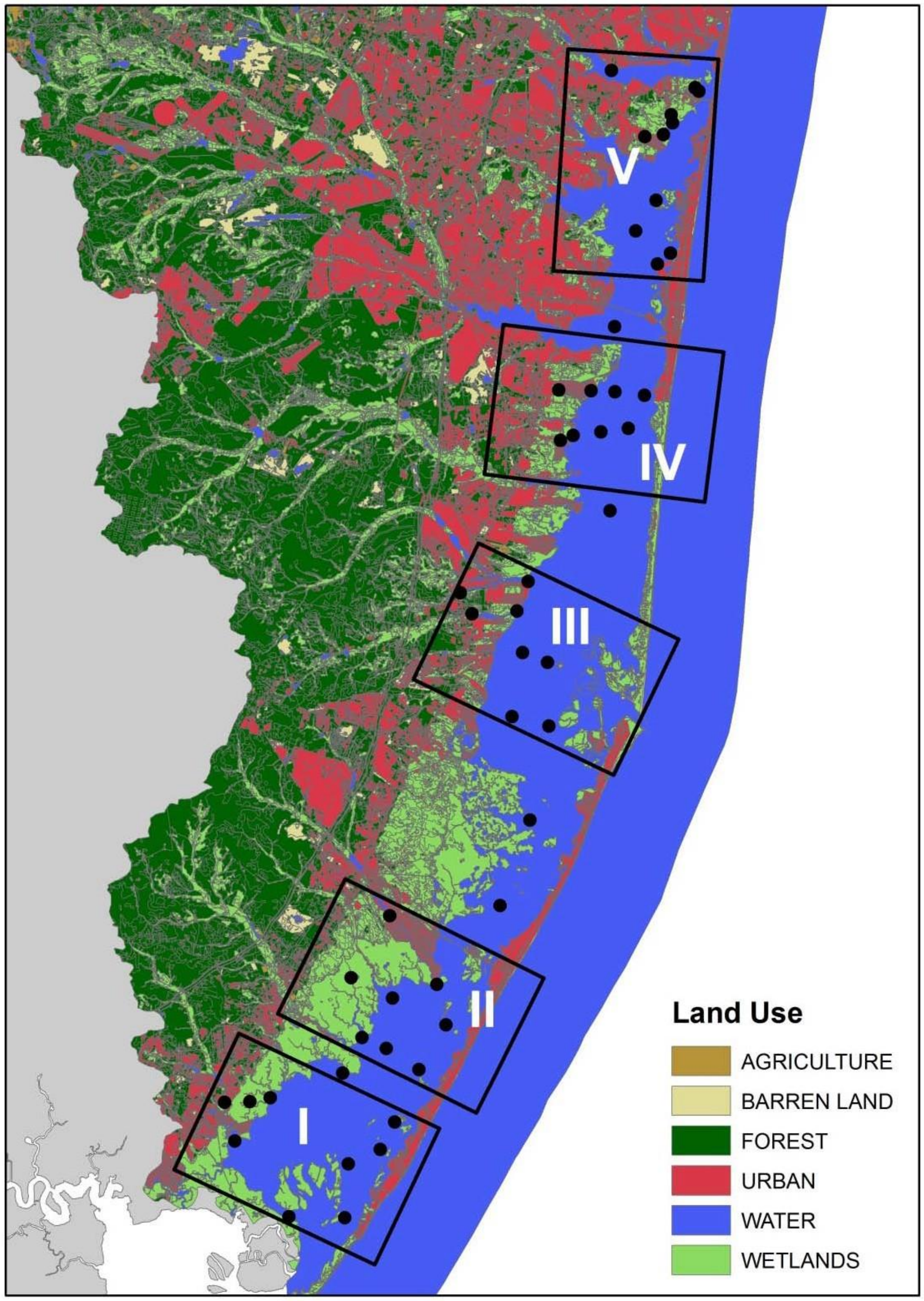


Figure 2. Location of individual sampling sites (clusters I-V) in Barnegat Bay along the urbanization gradient. See Table 1 for characteristics of each cluster.

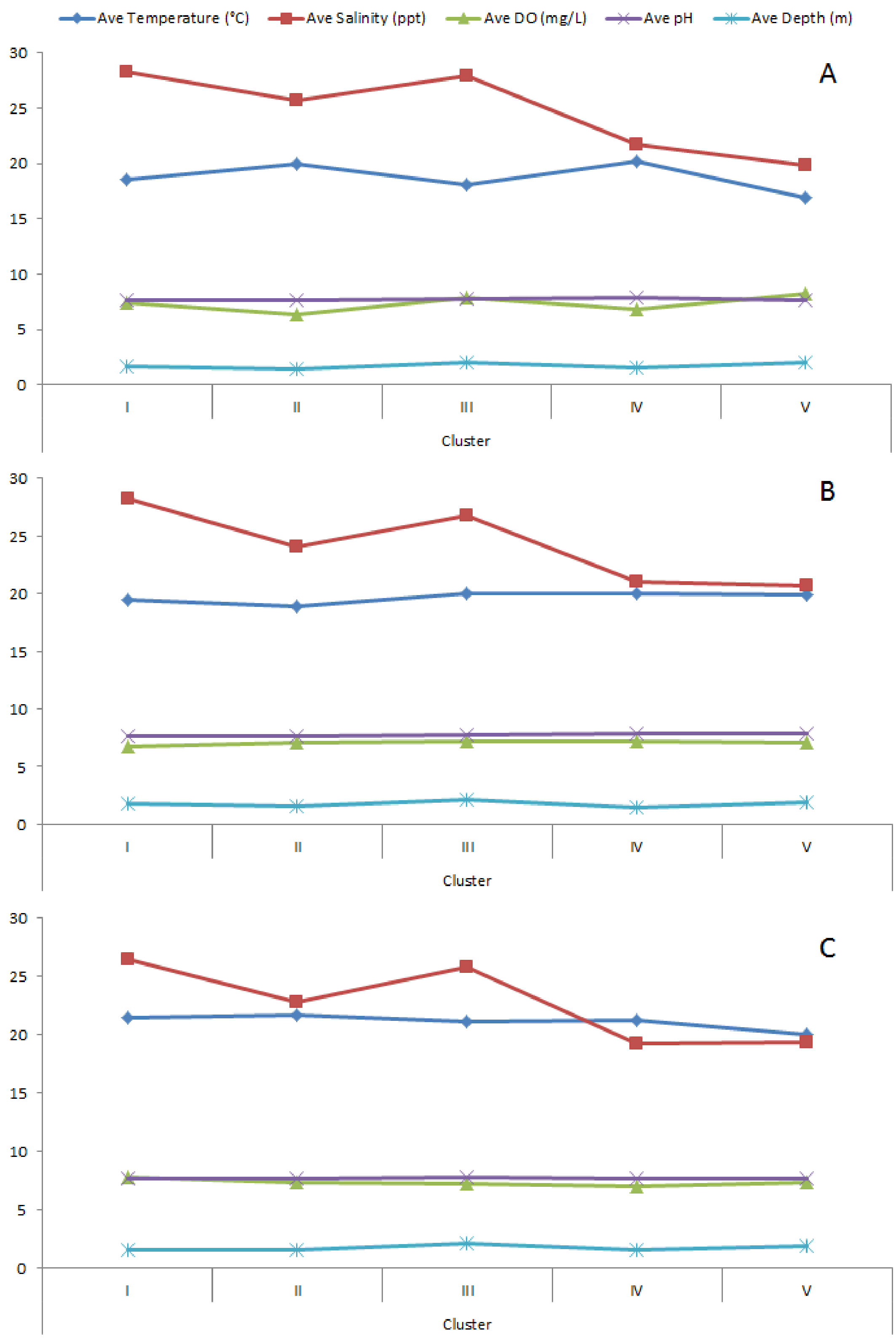


Figure 3. Variation in environmental variables (temperature, salinity, dissolved oxygen, pH, depth) by cluster (see Fig. 1) across all otter trawl sampling in 2012 (A), 2013 (B), and 2014 (C).

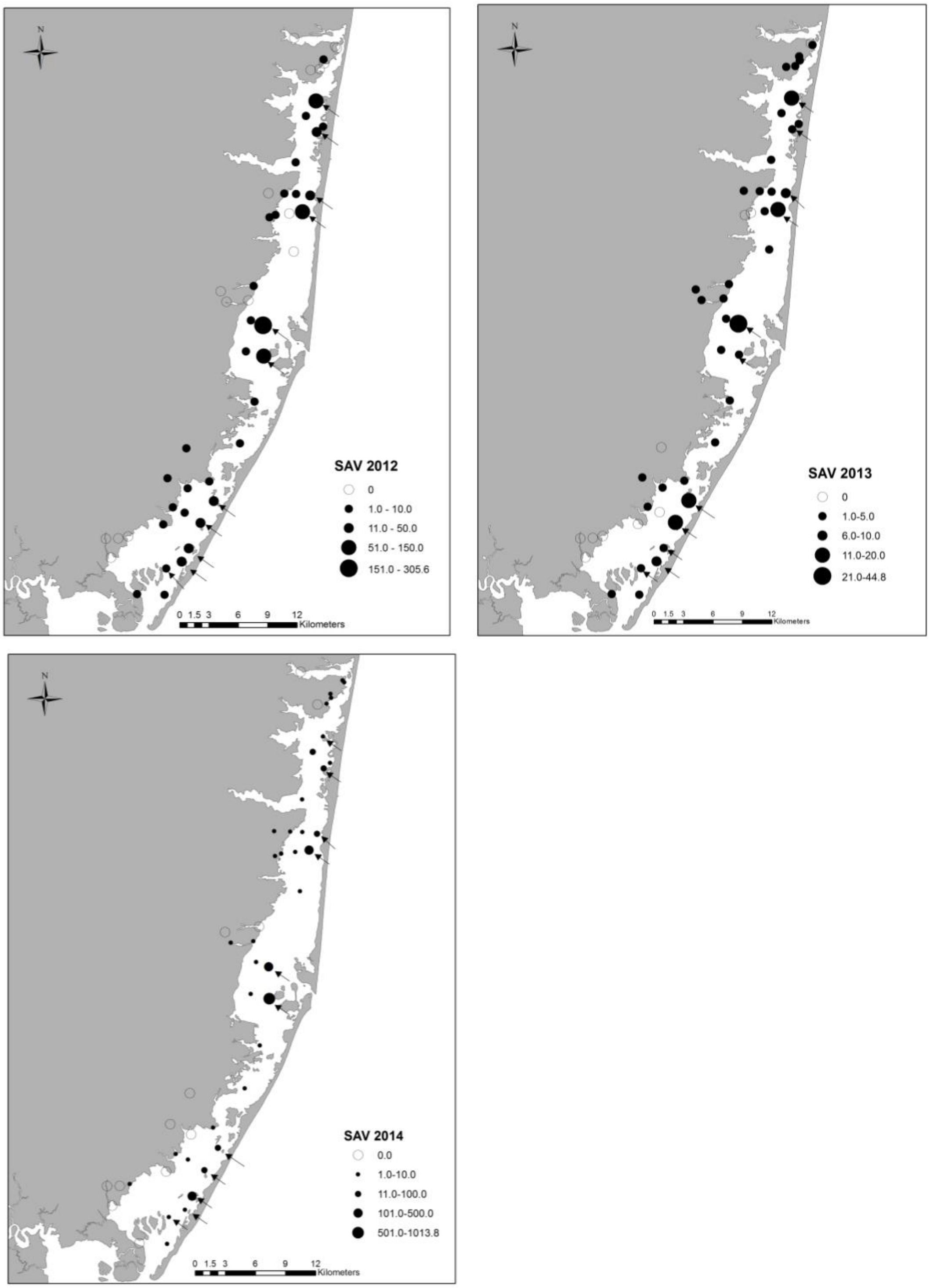


Figure 4. Distribution of SAV in composite samples during 2012, 2013, and 2014 sampling. Closed circles with arrows indicate SAV beds. Closed circles without arrows indicate where SAV blades were detected but no beds were evident. Blades possibly drifted in from beds at other sites. Values indicated in liters. Open circles indicate where no SAV was collected. Units are in total L per year

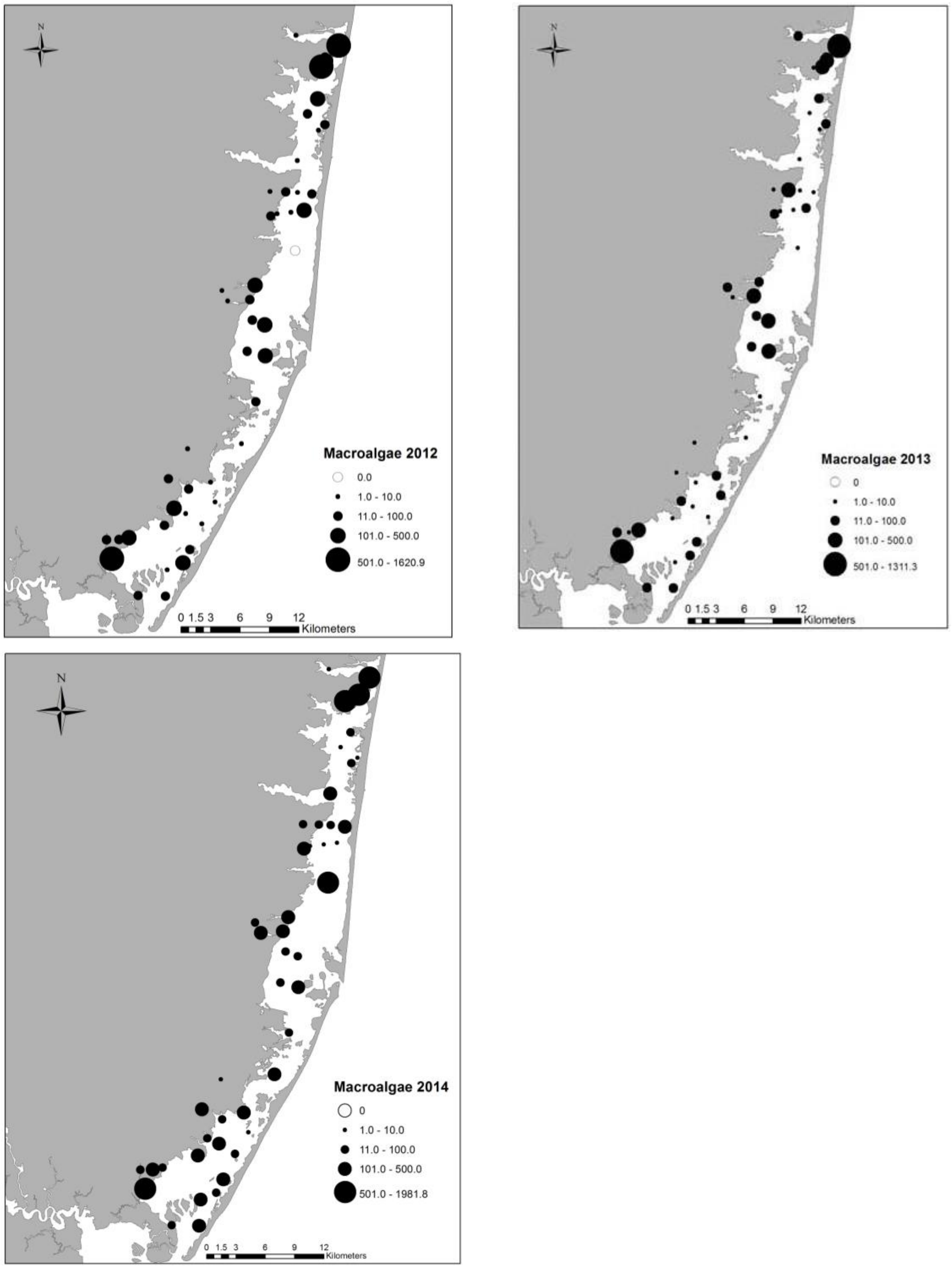


Figure 5. Distribution of macroalgae (closed circles) in composite otter trawl samples during 2012, 2013, and 2014 sampling. Open circles indicate where macroalgae was not collected. Values indicated in liters. Units are in total L per year.

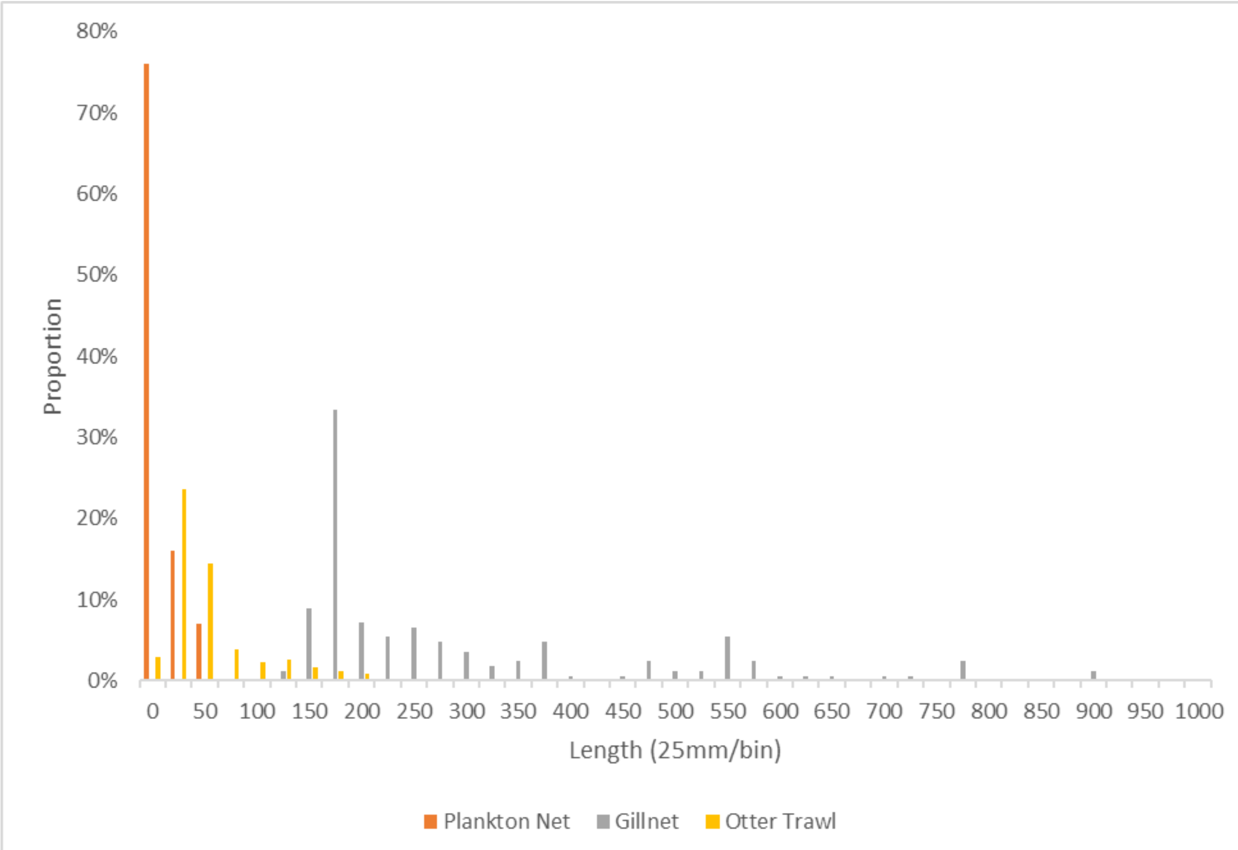


Figure 6. Composition of fish lengths by sampling gear from 2012-2014 (Gillnet data are for 2012 and 2013 only).

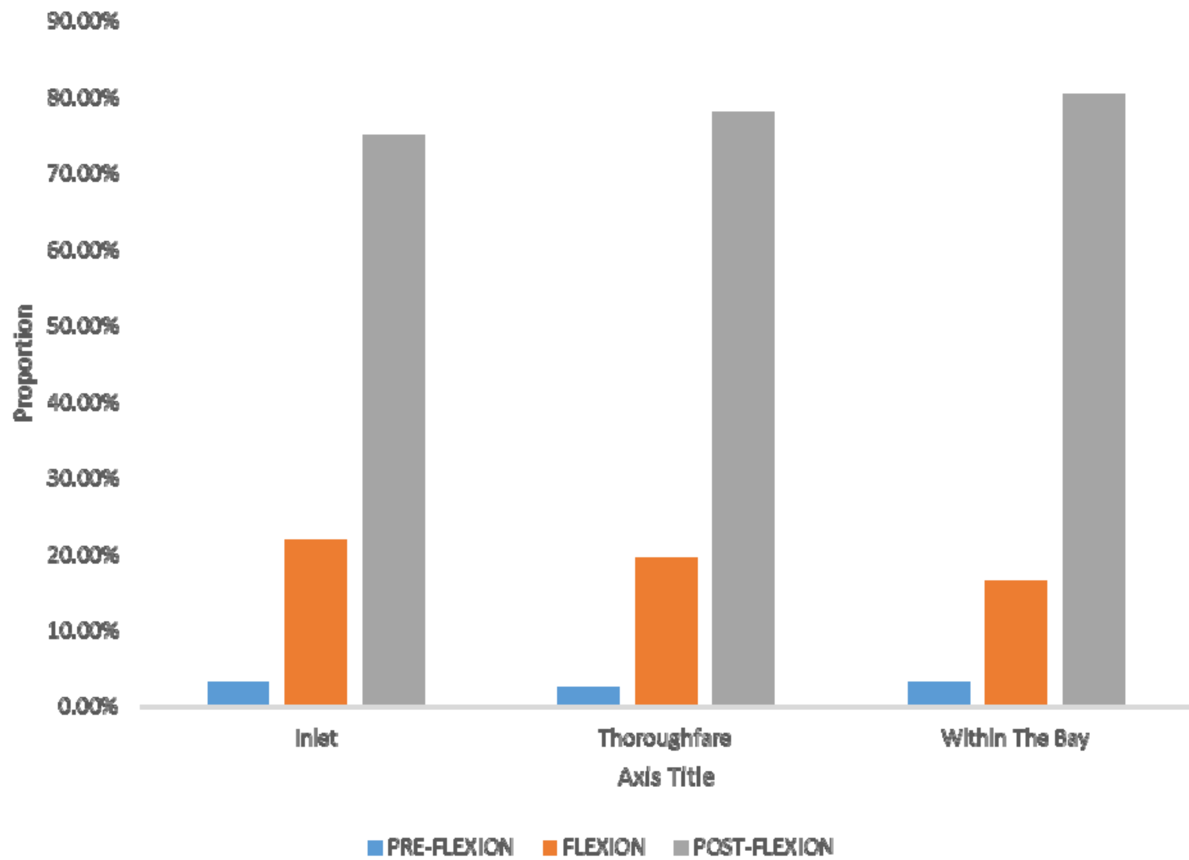


Figure 7. Proportion of larval fish by flexion stage in Barnegat Bay as estimated by fish collected from Jimmy's Creek, Little Sheepshead Creek, and Little Thoroughfare in May, June, July, August, October, and December of 2010 and in February and April of 2011, from Barnegat Inlet, the intake and discharge at the Oyster Creek Nuclear Generating Station, and Pt. Pleasant Canal in February, April, June, August, and October of 2012 and 2013, from the Rt 37 and Rt 72 bridges in February, April, June, August, and October of 2014, and from Little Sheepshead Creek in February, April, June, August, and October of 2012, 2013, and 2014. See Figure 1 for a map of each sampling location. Locations are grouped into Inlets (Little Sheepshead Creek and Barnegat Light), Thoroughfares (Jimmy's Creek, Little Thoroughfare, and Point Pleasant Canal), and locations within Barnegat Bay (Rt 37 and Rt 72 bridges and the intake and discharge at the Oyster Creek Nuclear Generating Station).

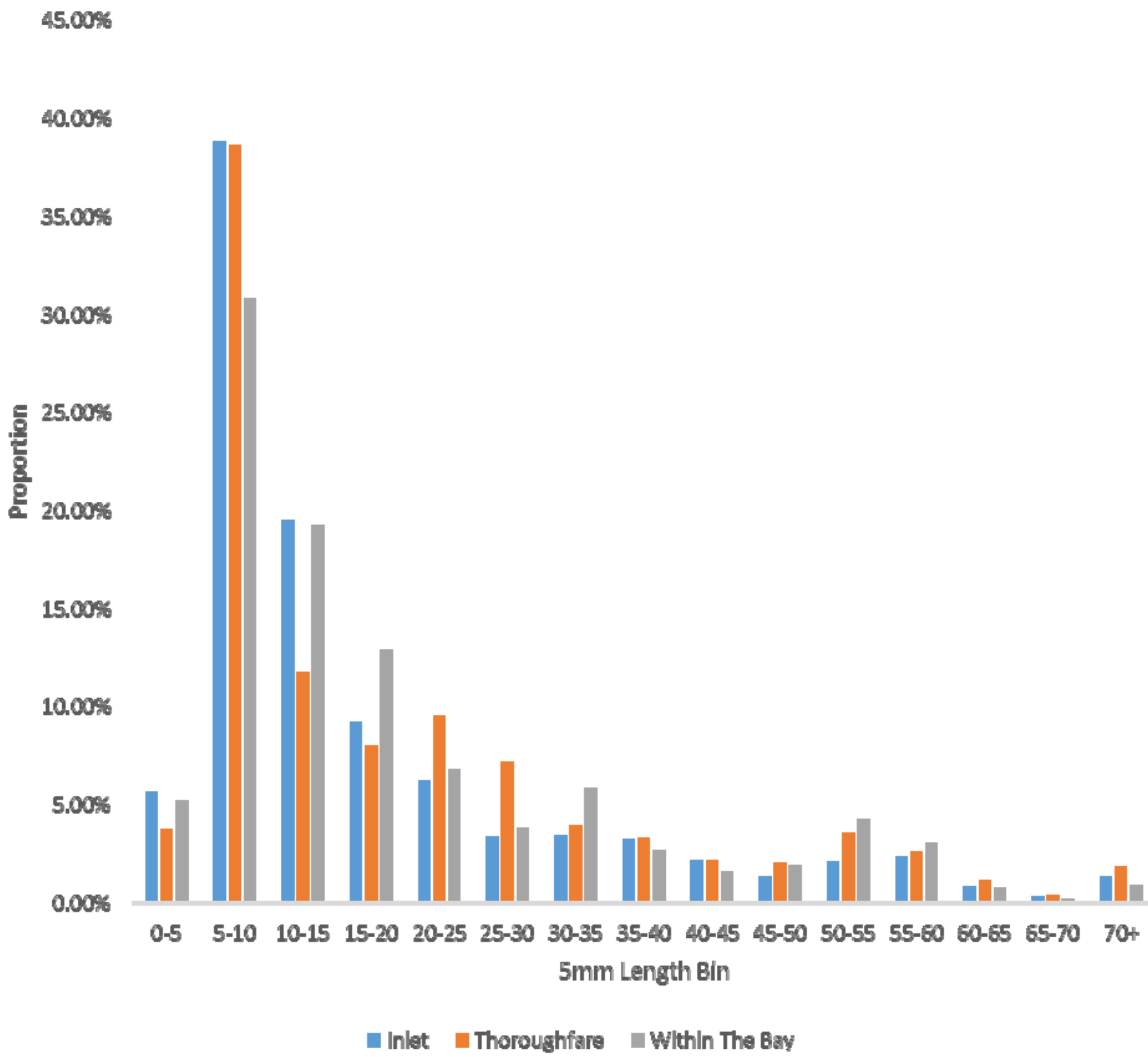


Figure 8. Length frequency of larval fish in Barnegat Bay as estimated by fish collected from Jimmy's Creek, Little Sheepshead Creek, and Little Thoroughfare in May, June, July, August, October, and December of 2010 and in February and April of 2011, from Barnegat Inlet, the intake and discharge at the Oyster Creek Nuclear Generating Station, and Pt. Pleasant Canal in February, April, June, August, and October of 2012 and 2013, from the Rt 37 and Rt 72 bridges in February, April, June, August, and October of 2014, and from Little Sheepshead Creek in February, April, June, August, and October of 2012, 2013, and 2014. See Figure 1 for a map of each sampling location. Locations are grouped into Inlets (Little Sheepshead Creek and Barnegat Light), Thoroughfares (Jimmy's Creek, Little Thoroughfare, and Point Pleasant Canal), and locations within Barnegat Bay (Rt 37 and Rt 72 bridges and the intake and discharge at the Oyster Creek Nuclear Generating Station).

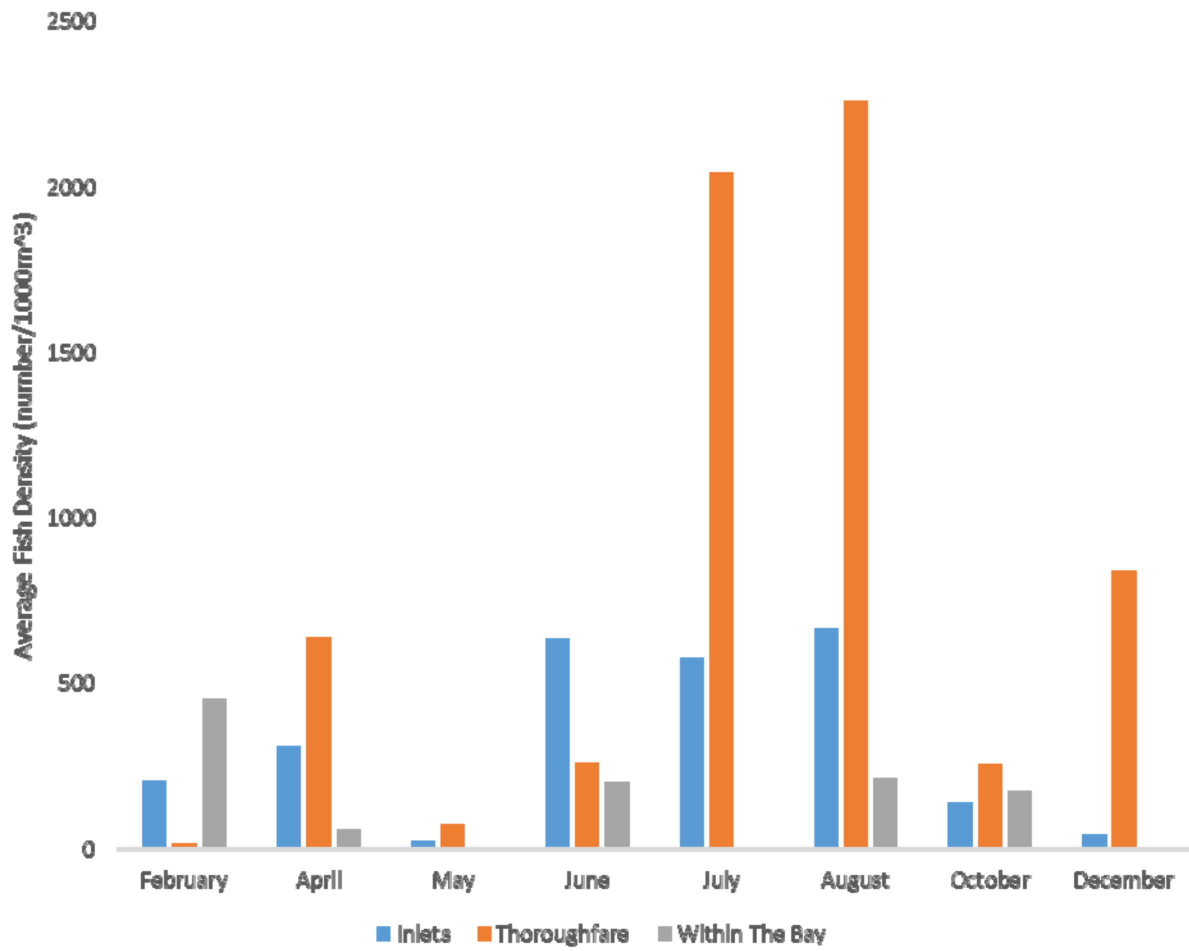


Figure 9. Average larval fish density (number/1000m^3) in Barnegat Bay as estimated by fish collected from Jimmy's Creek, Little Sheepshead Creek, and Little Thoroughfare in May, June, July, August, October, and December of 2010 and in February and April of 2011, from Barnegat Inlet, the intake and discharge at the Oyster Creek Nuclear Generating Station, and Pt. Pleasant Canal in February, April, June, August, and October of 2012 and 2013, from the Rt 37 and Rt 72 bridges in February, April, June, August, and October of 2014, and from Little Sheepshead Creek in February, April, June, August, and October of 2012, 2013, and 2014. See Figure 1 for a map of each sampling location. Locations are grouped into Inlets (Little Sheepshead Creek and Barnegat Light), Thoroughfares (Jimmy's Creek, Little Thoroughfare, and Point Pleasant Canal), and locations within Barnegat Bay (Rt 37 and Rt 72 bridges and the intake and discharge at the Oyster Creek Nuclear Generating Station). Error bars are omitted to allow better visualization of the pattern.

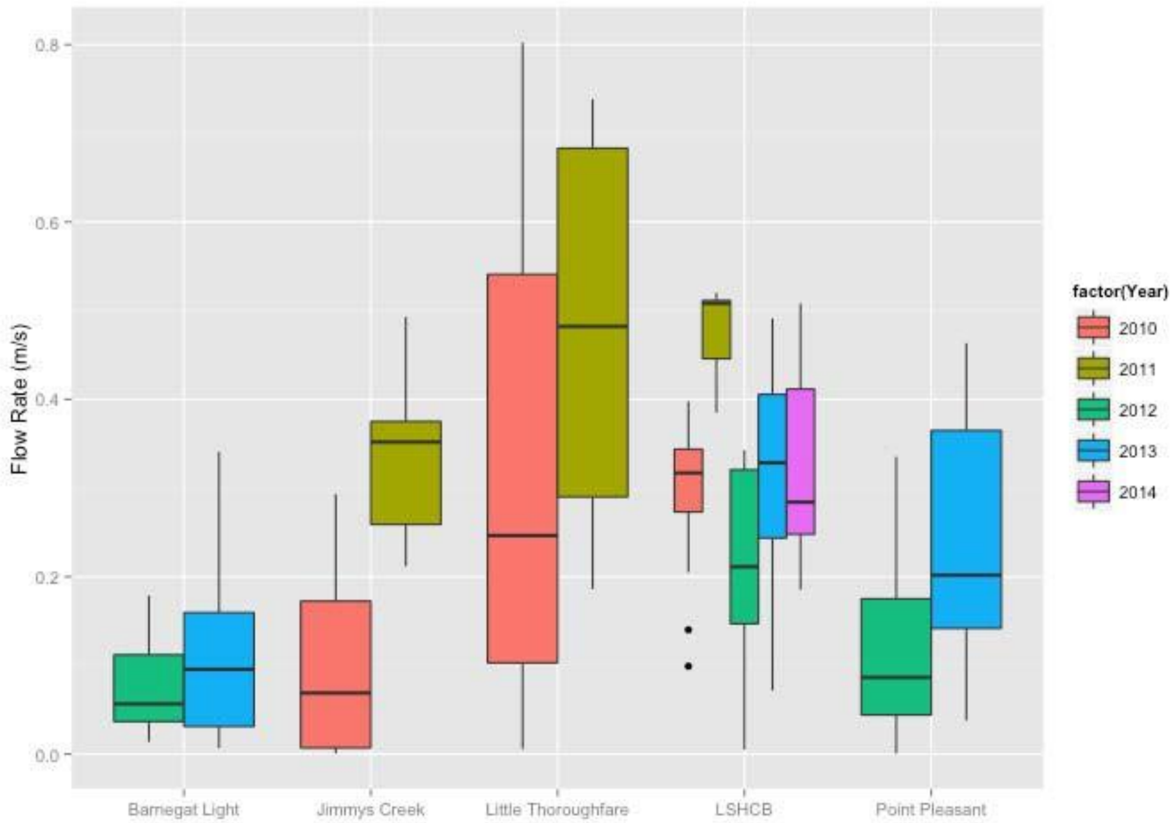


Figure 10. Boxplot display of the distribution of flow rates measured at Jimmy's Creek, Little Sheepshead Creek, and Little Thoroughfare in May, June, July, August, and October of 2010 and in February and April of 2011, from Barnegat Inlet and Pt. Pleasant Canal in February, April, June, August, and October of 2012 and 2013, and from Little Sheepshead Creek in February, April, June, August, and October of 2012, 2013, and 2014. See Figure 1 for a map of each sampling location.

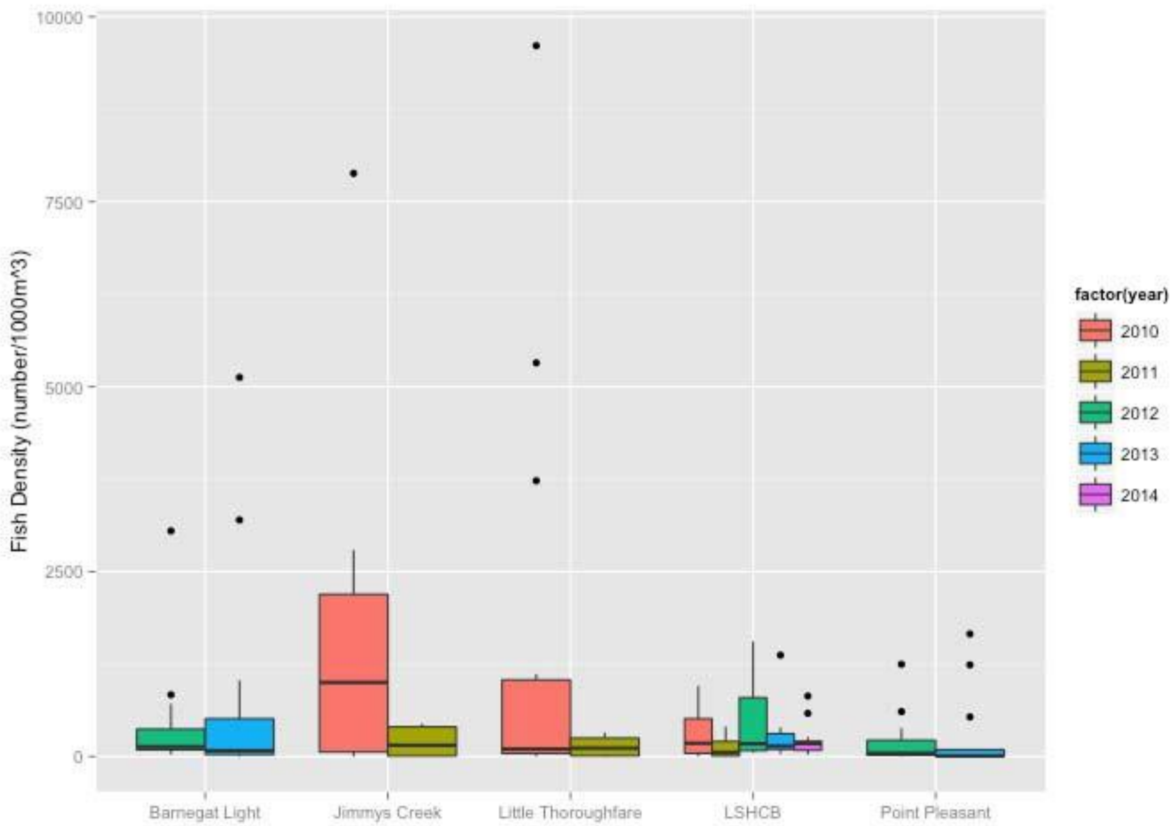


Figure 11. Boxplot display of the distribution of larval fish density (number/1000m^3) estimated at Jimmy's Creek, Little Sheepshead Creek, and Little Thoroughfare in May, June, July, August, and October of 2010 and in February and April of 2011, from Barnegat Inlet and Pt. Pleasant Canal in February, April, June, August, and October of 2012 and 2013, and from Little Sheepshead Creek in February, April, June, August, and October of 2012, 2013, and 2014. See Figure 1 for a map of each sampling location.

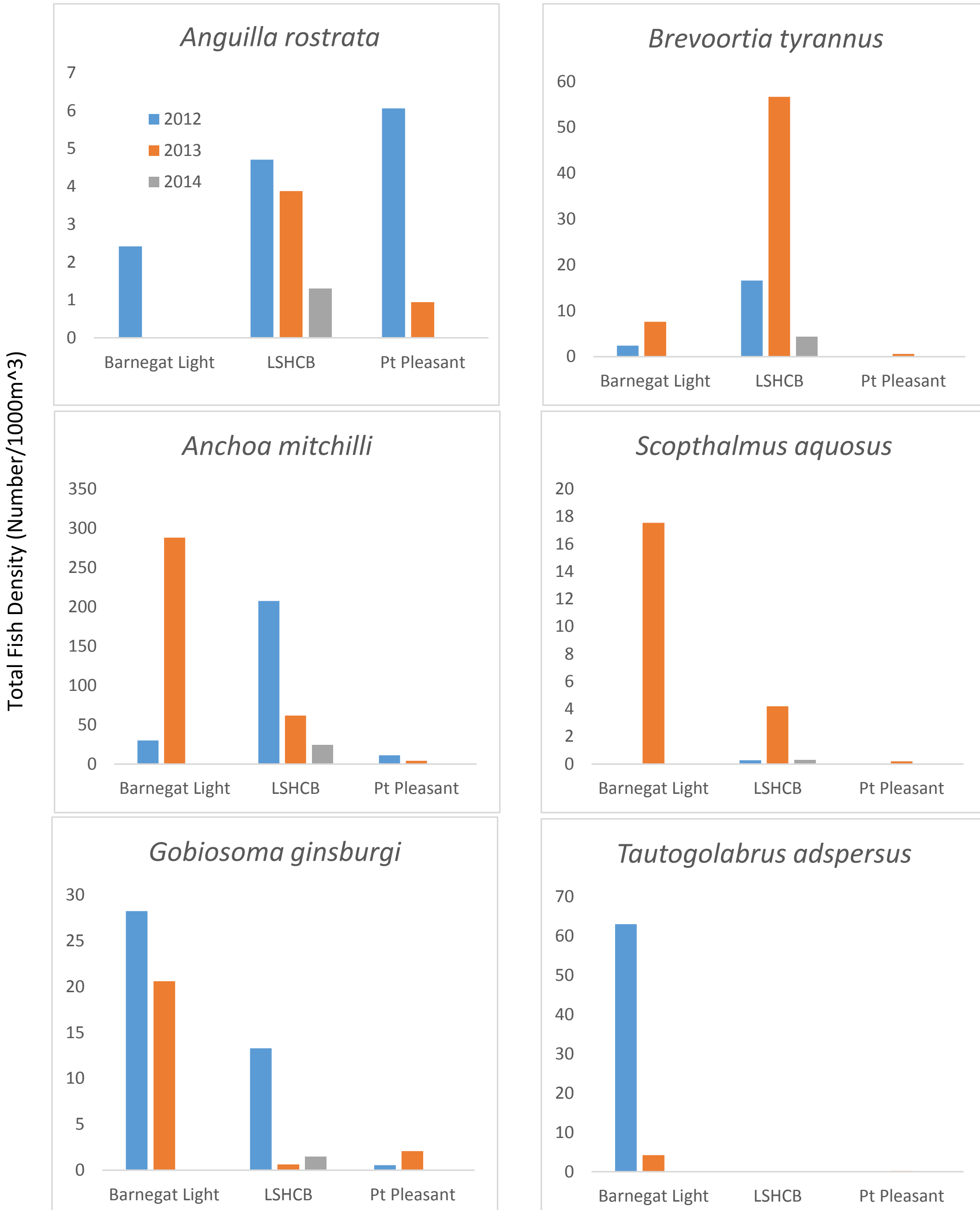


Figure 12. Total larval fish density (numbers of fish per 1000m^3) of some commonly collected transient fish sampled in 2012 (February, April, June, and August) and 2013-2104 (February, April, June, August, and October; Barnegat Light and Pt. Pleasant were not sampled in 2014). All of these species spawn in the ocean with the exception of *A. mitchilli* which may spawn in the estuary and the ocean (Able and Fahay 2010). Total number of fish and total volume were summed across all tows for a given year and location.

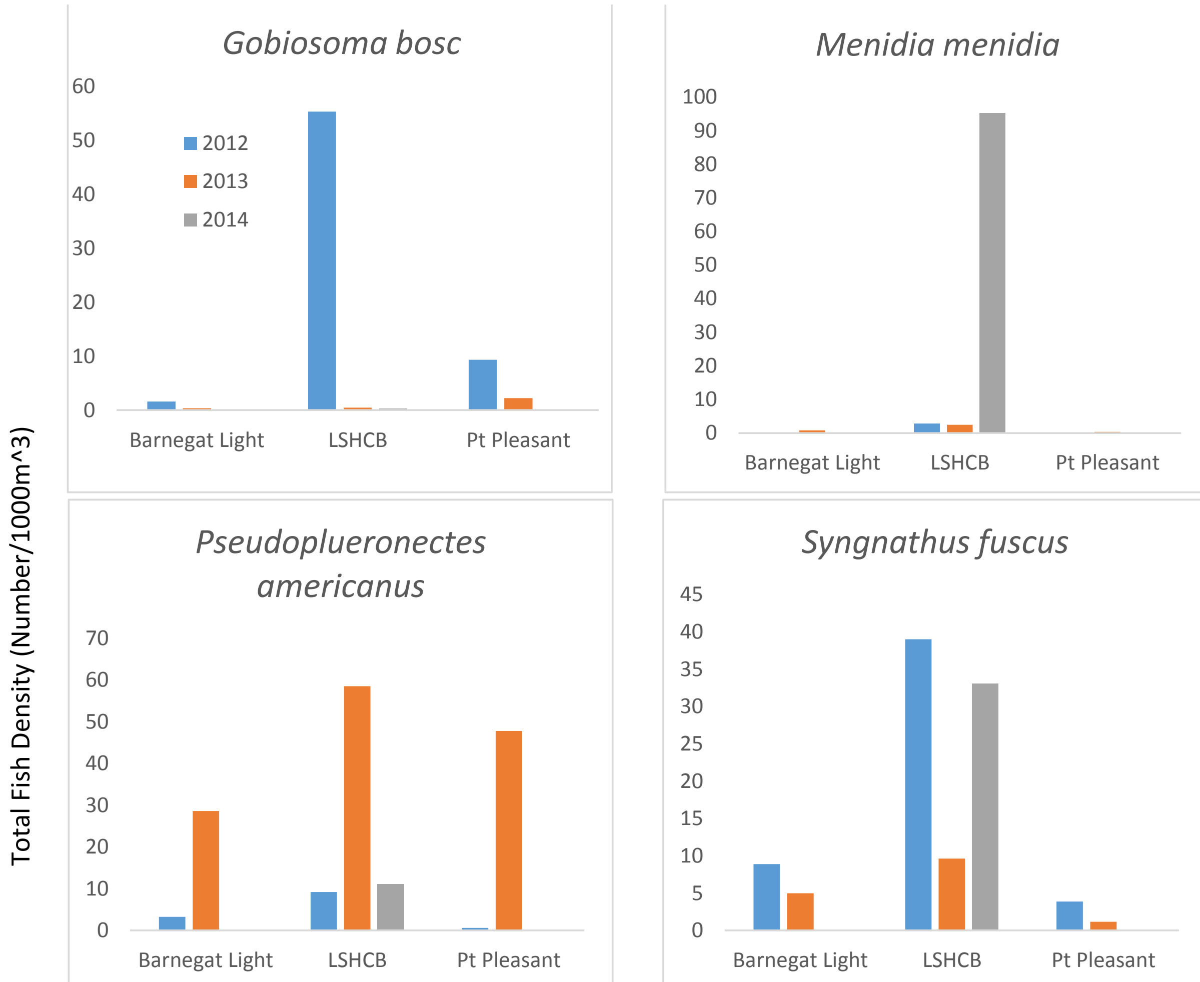


Figure 13. Total larval fish density (numbers of fish per 1000m^3) of some commonly collected resident fish sampled in 2012 (February, April, June, and August) and 2013-2104 (February, April, June, August, and October; Barnegat Light and Pt. Pleasant were not sampled in 2014). Total number of fish and total volume were summed across all tows for a given year and location.

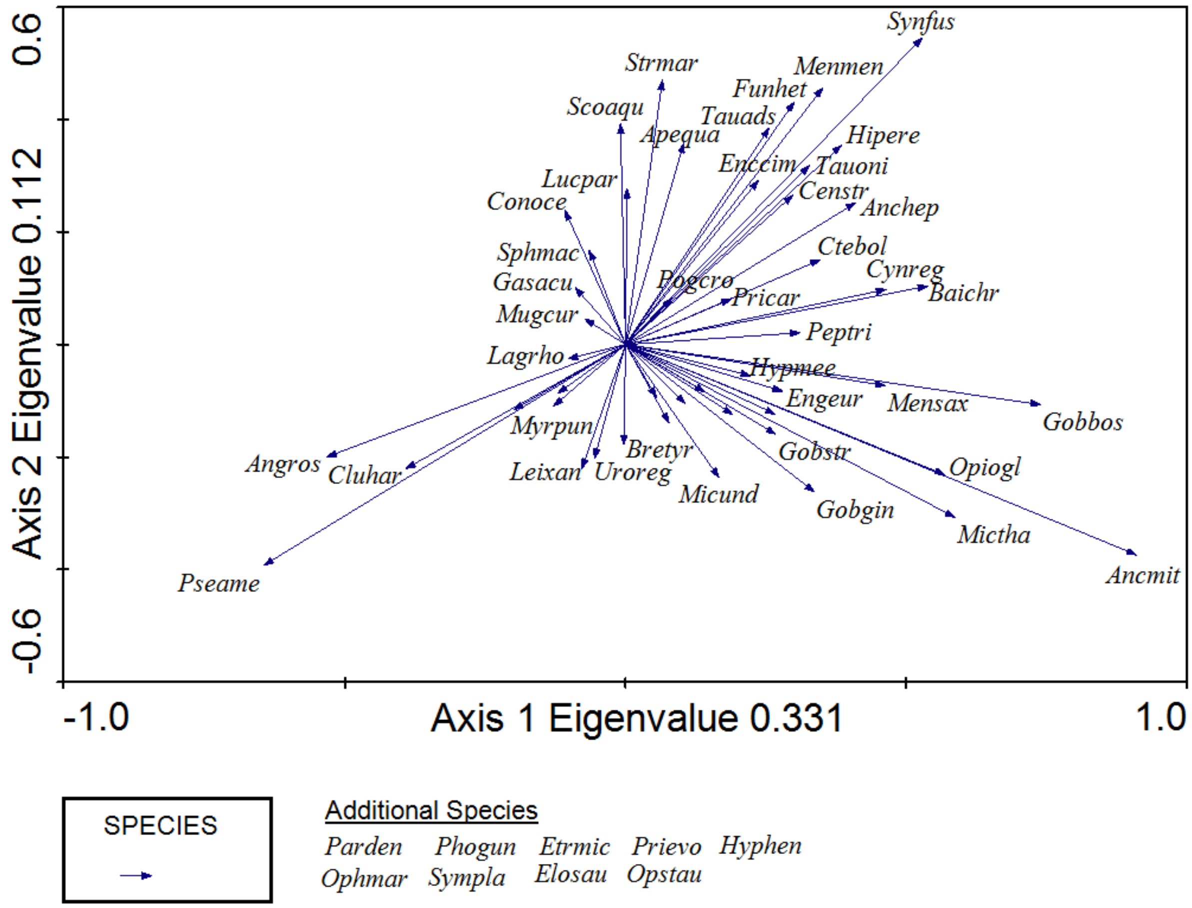


Figure 14. PCA showing species distributed along the first two eigenaxes. Vectors point in the direction of increasing species abundance. Scientific names were abbreviated by combining the first three letters of the genus and the species. Those listed under "Additional Species" were present in the middle part of the plot and were removed for clarity purposes. This plot is in the same coenospace as the subsequent sample plots, but was separated for legibility.

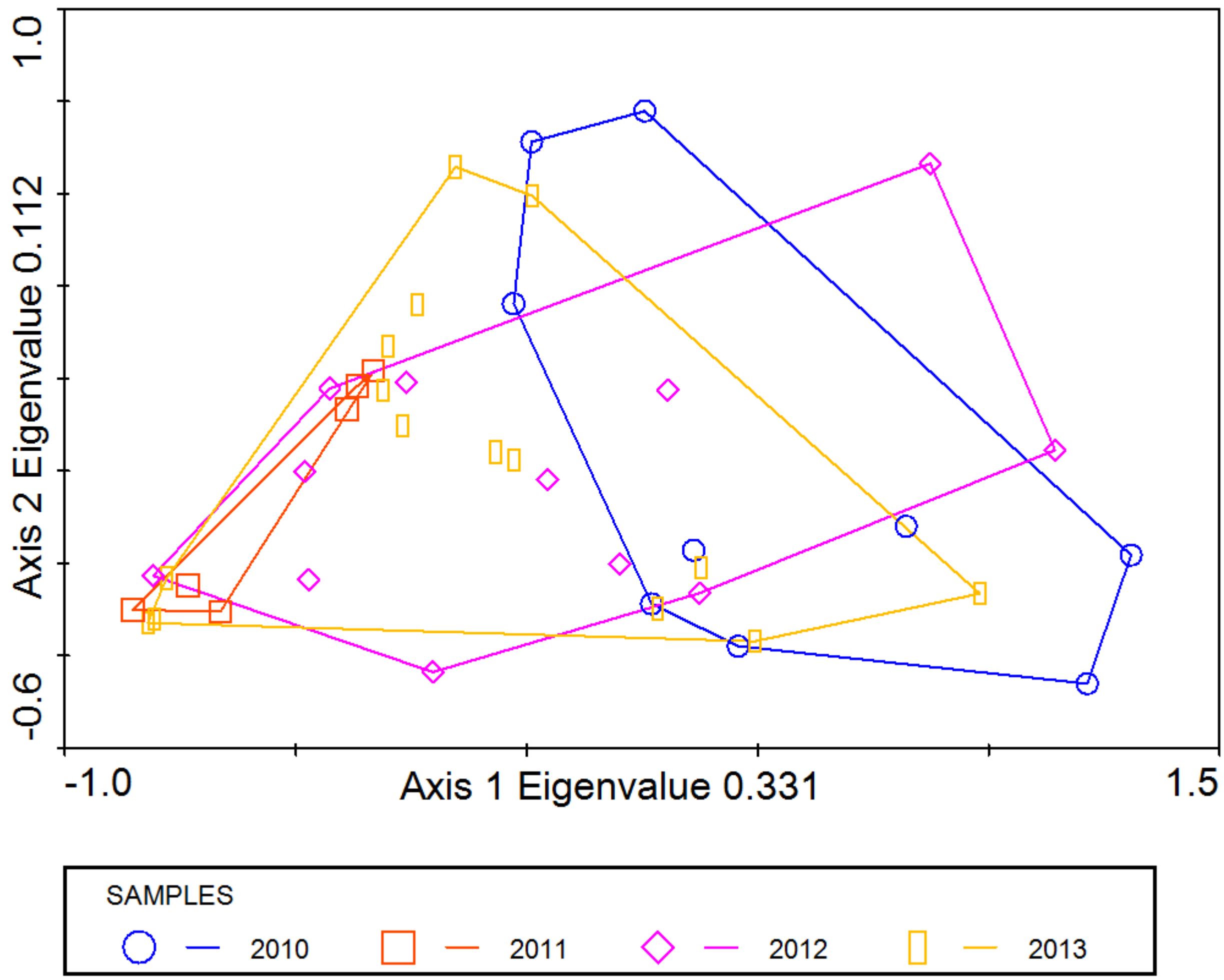


Figure 15. PCA showing samples coded by year. The convex polygons envelop all samples for a particular year. The high degree of overlap between polygons suggests similarity in species composition of larval supply to Barnegat Bay among years. In 2010 only June, August, and October were sampled explaining the smaller convex polygon. In 2011 only February and April were sampled resulting in a small convex polygon. Since larval supply was similar in species composition over all years, data from these years were combined for further analyses.

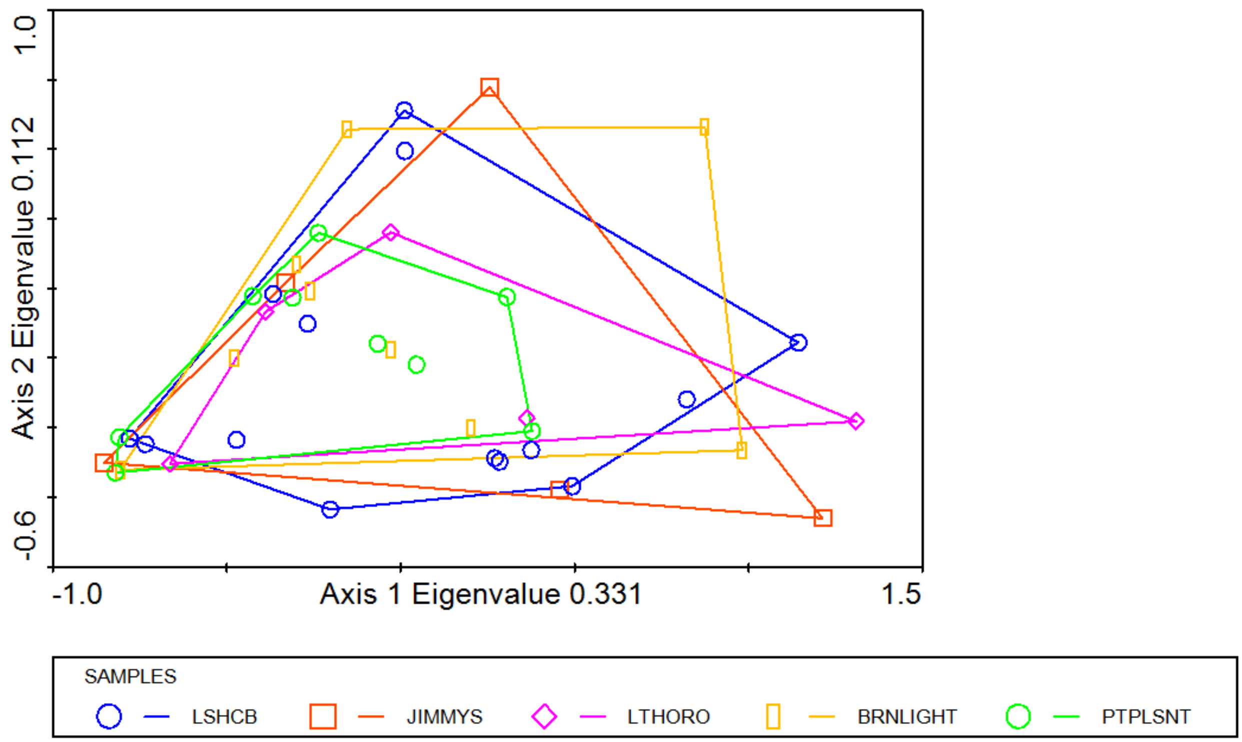


Figure 16. PCA showing samples coded by sampling location. The high degree of overlap between polygons suggests similarity in species composition of larval supply to Barnegat Bay between sampling locations.

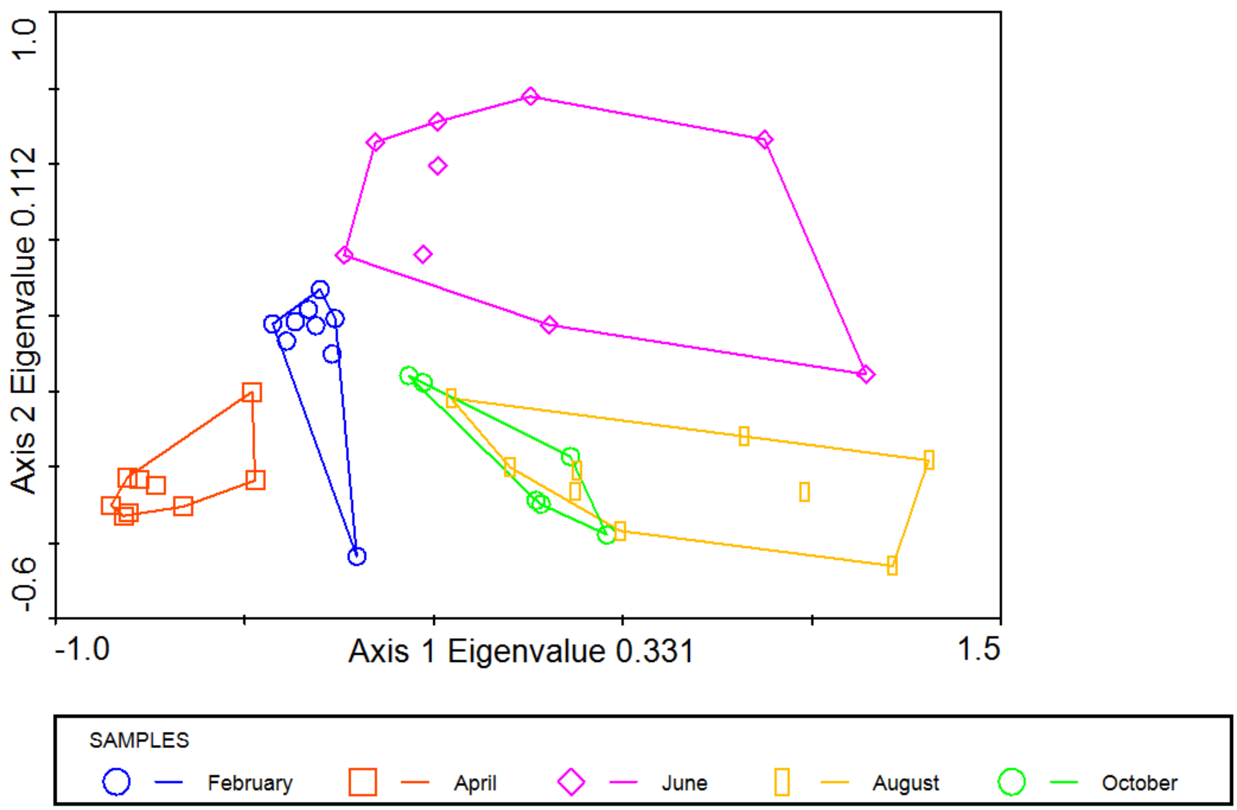


Figure 17. PCA showing samples coded by sampling month. The high degree of separation between polygons suggests differences in species composition of larval supply to Barnegat Bay between months sampled.

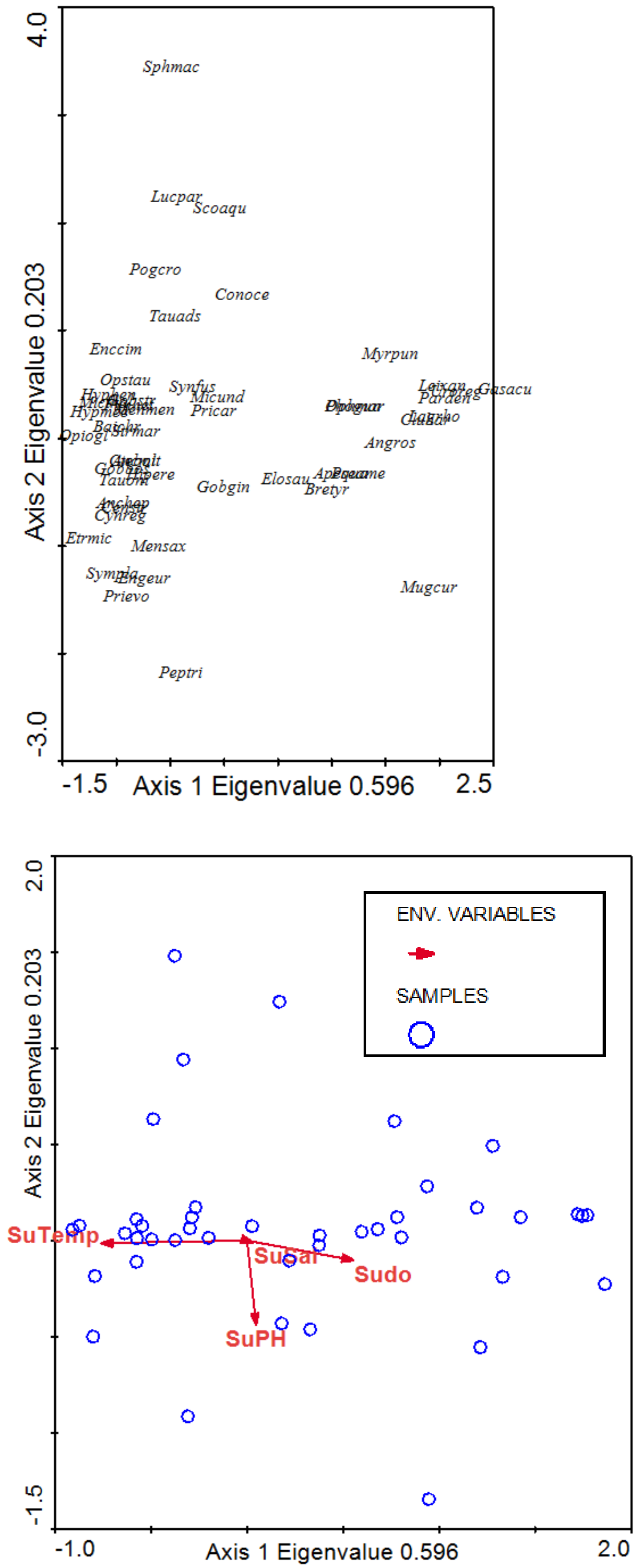


Figure 18. CCA biplot (samples and environmental variables) showing temperature as the driving variable on the first eigenaxis.

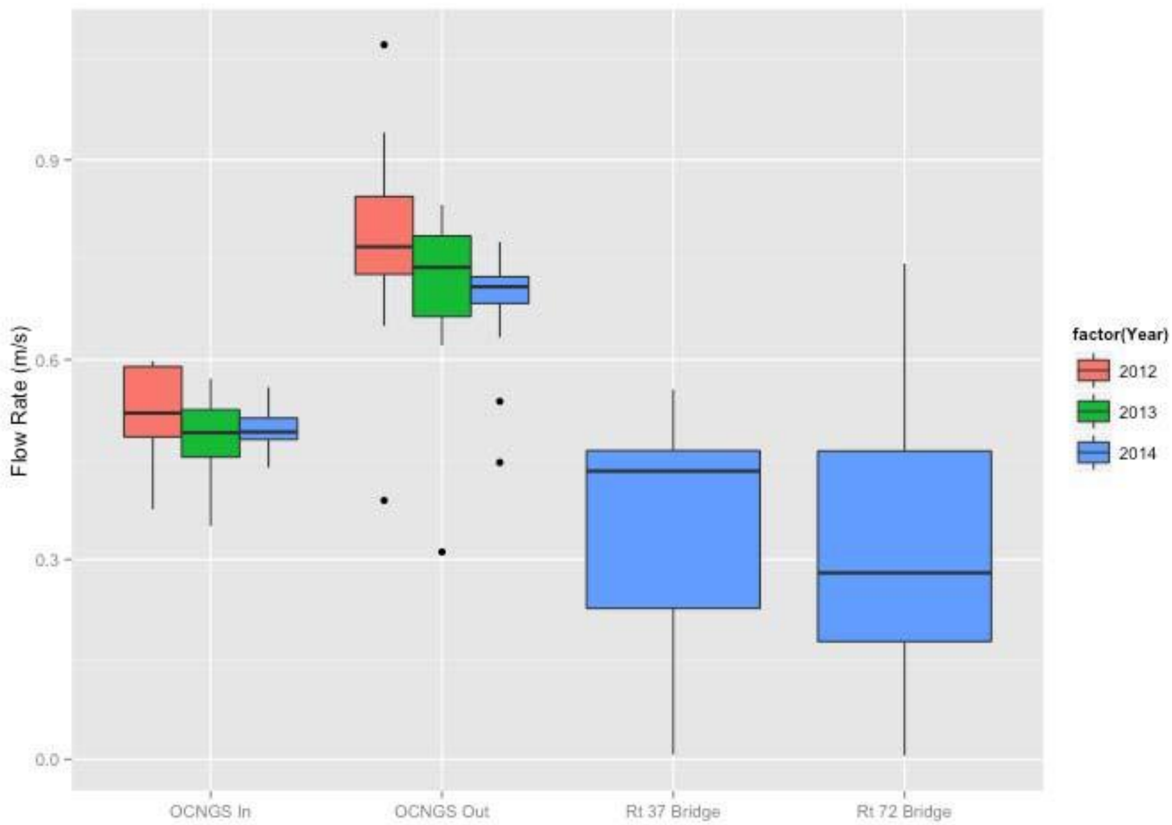


Figure 19. Boxplot display of the distribution of flow rates measured at the Oyster Creek Nuclear Generating Station (OCNGS Intake and Discharge), and the Rt. 72 and 37 bridges in February, April, June, August, and October of 2012 (OCNGS only), 2013 (OCNGS only), and 2014. See Figure 1 for a map of each sampling location.

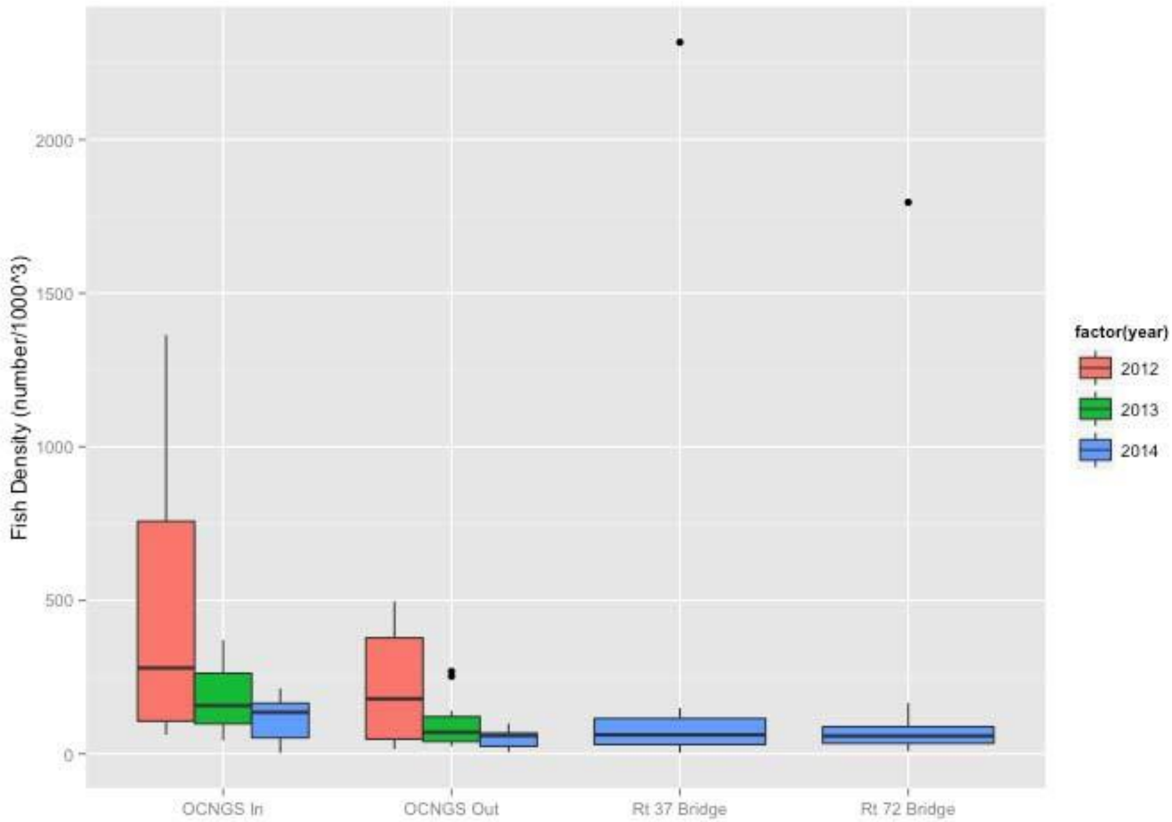


Figure 20. Boxplot display of the distribution of larval fish density (number/1000m^3) estimated at the Oyster Creek Nuclear Generating Station (OCNGS Intake and Discharge) and the Rt. 72 and 37 bridges in February, April, June, August, and October of 2012 (OCNGS only), 2013 (OCNGS only), and 2014. See Figure 1 for a map of each sampling location.

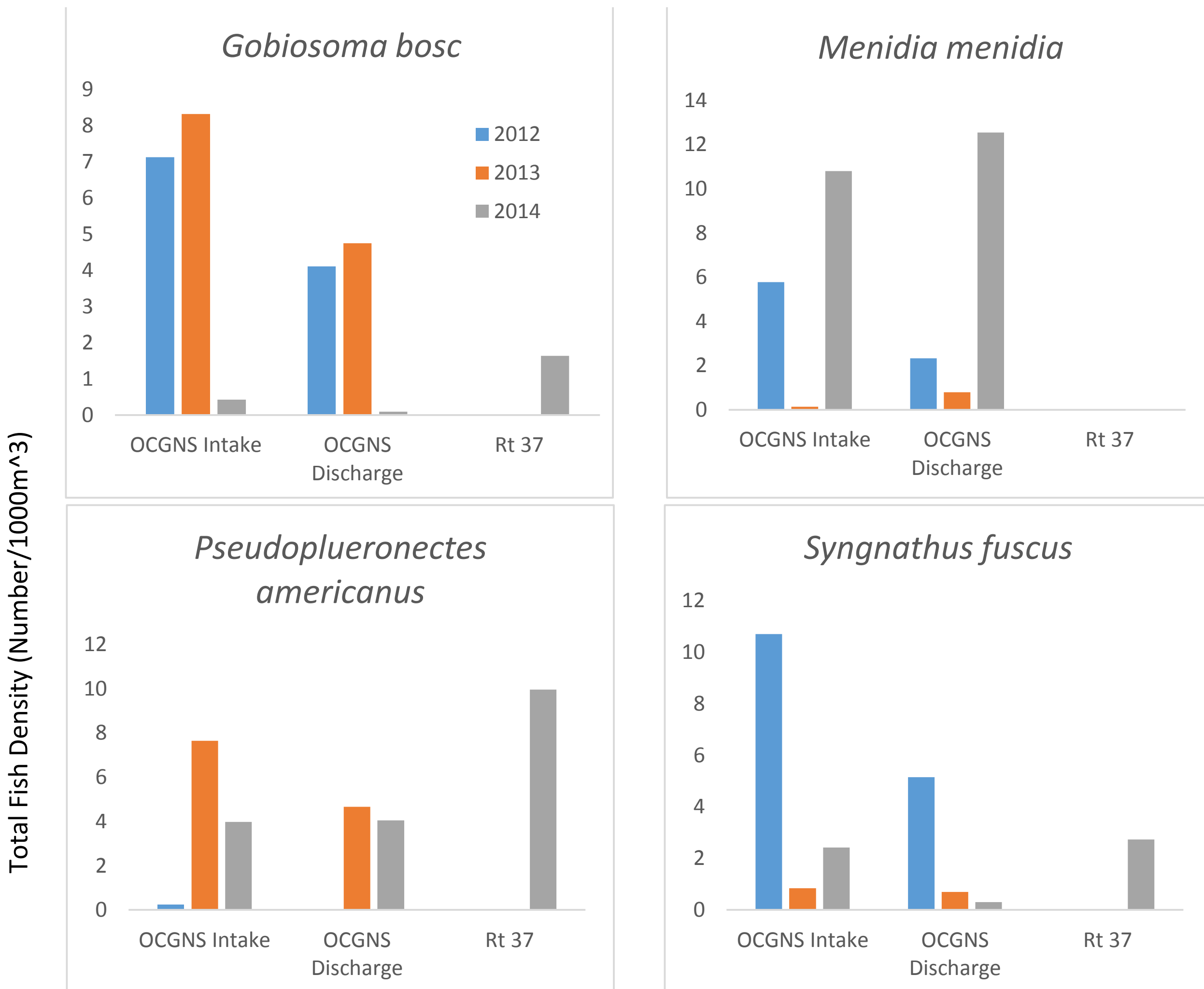


Figure 21. Total larval fish density (numbers of fish per 1000m^3) of some commonly collected resident fish sampled from the Oyster Creek Nuclear Generating Station (OCNGS Intake and Discharge) in February, April, June, August, and October of 2012-2014 and the Rt. 72 and 37 bridges in February, April, June, August, and October of 2014.

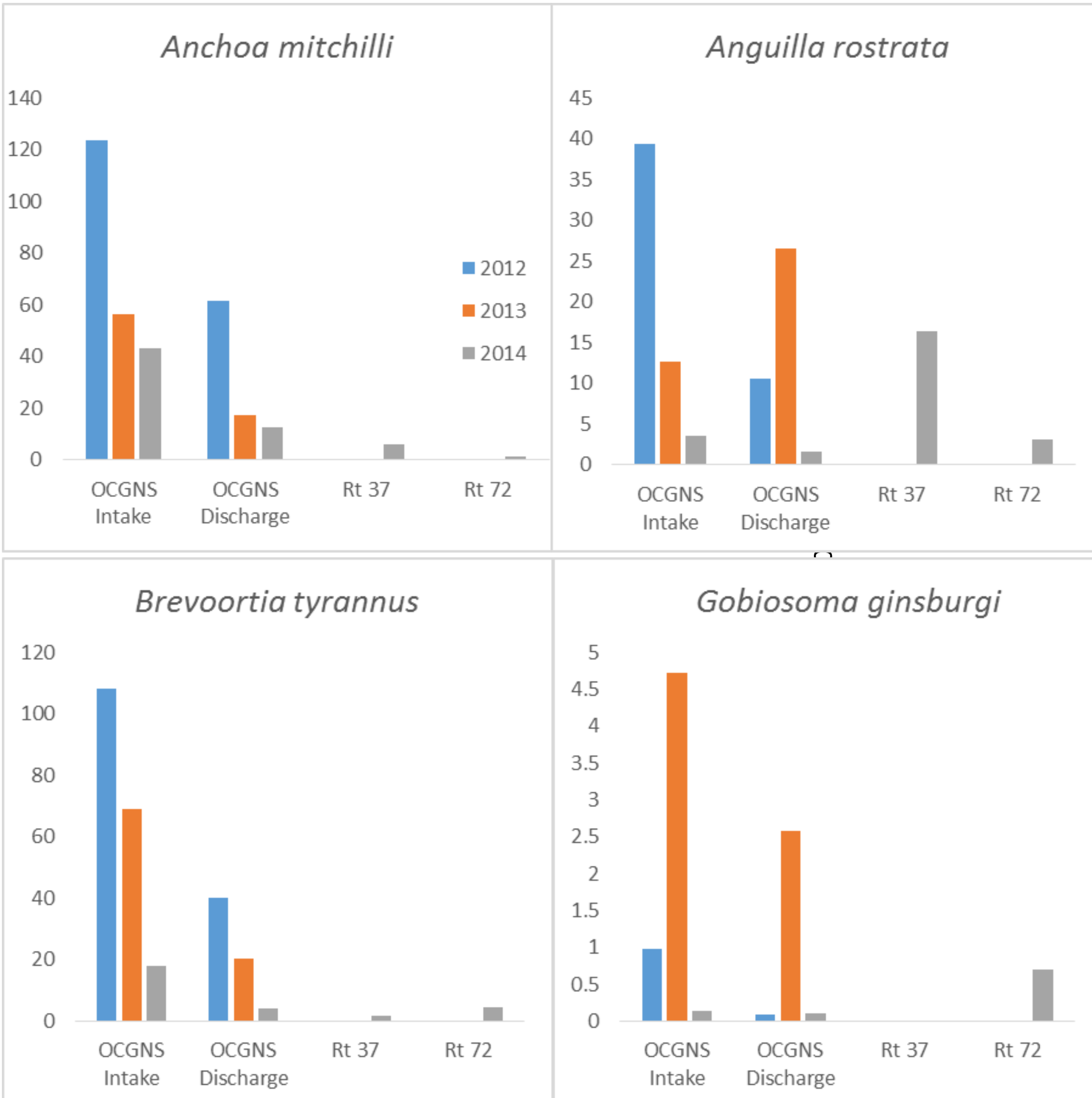


Figure 22. Total larval fish density (numbers of fish per 1000m^3) of some commonly collected transient fish sampled from the Oyster Creek Nuclear Generating Station (OCNGS Intake and Discharge) in February, April, June, August, and October of 2012-2014 and the Rt. 72 and 37 bridges in February, April, June, August, and October of 2014.

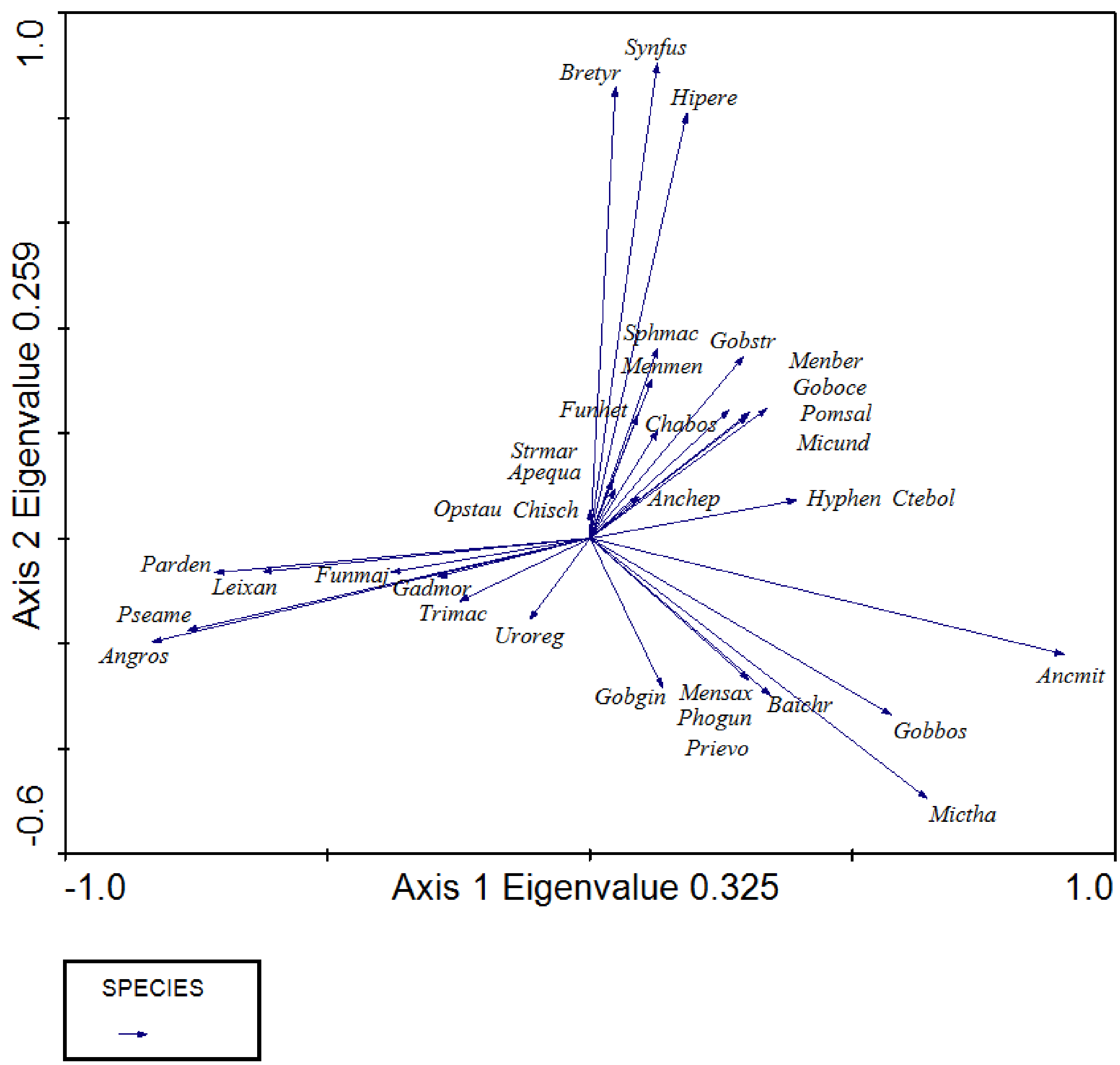


Figure 23. PCA showing species distributed along the first two eigenaxes. Vectors point in the direction of increasing species abundance. Scientific names were abbreviated by combining the first three letters of the genus and the species. This plot is in the same coenospace as the subsequent sample plots, but was separated for legibility.

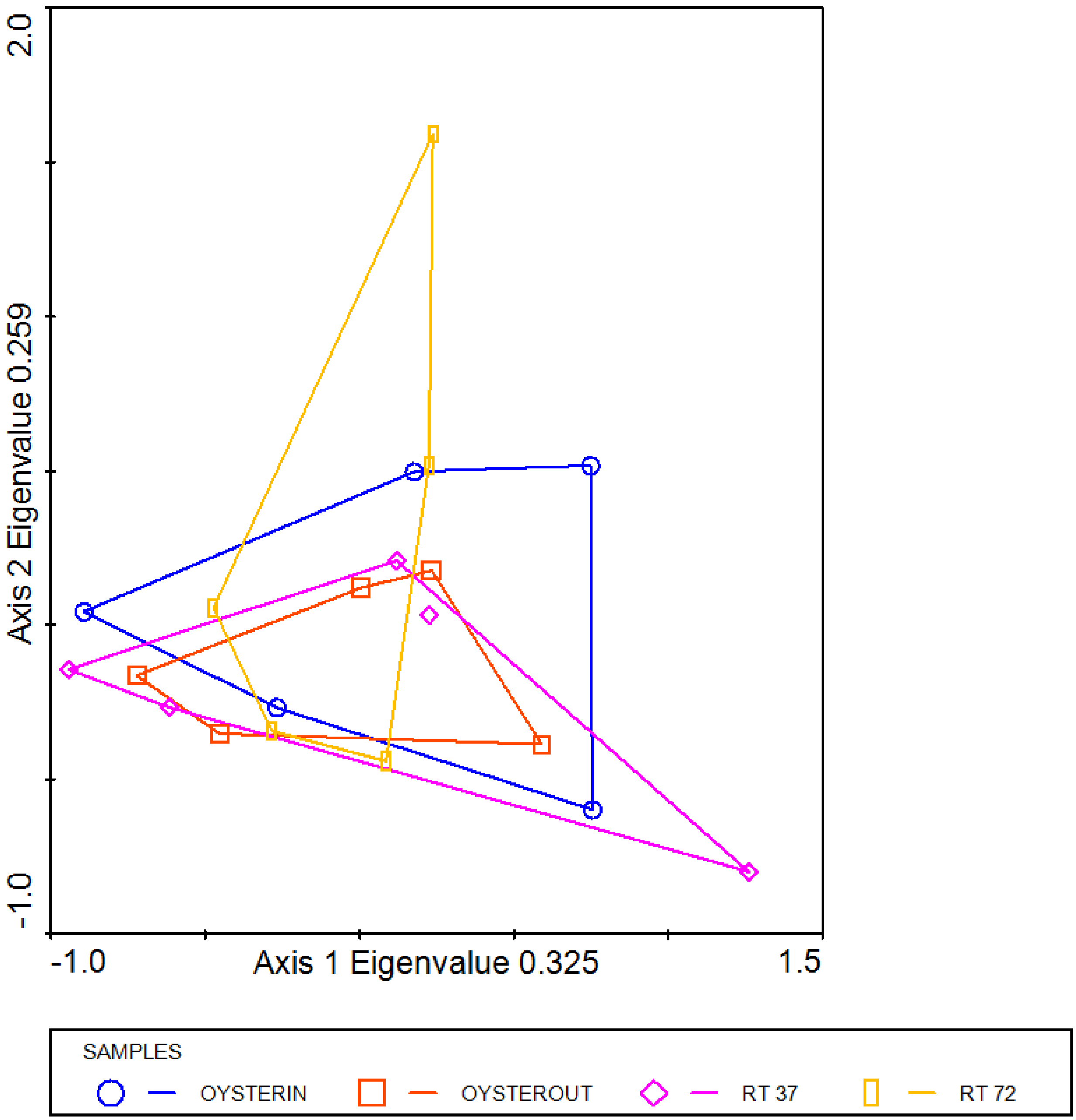


Figure 24. PCA showing samples coded by sampling location. The high degree of overlap between polygons suggests similarity in species composition of larval supply within Barnegat Bay between sampling locations.

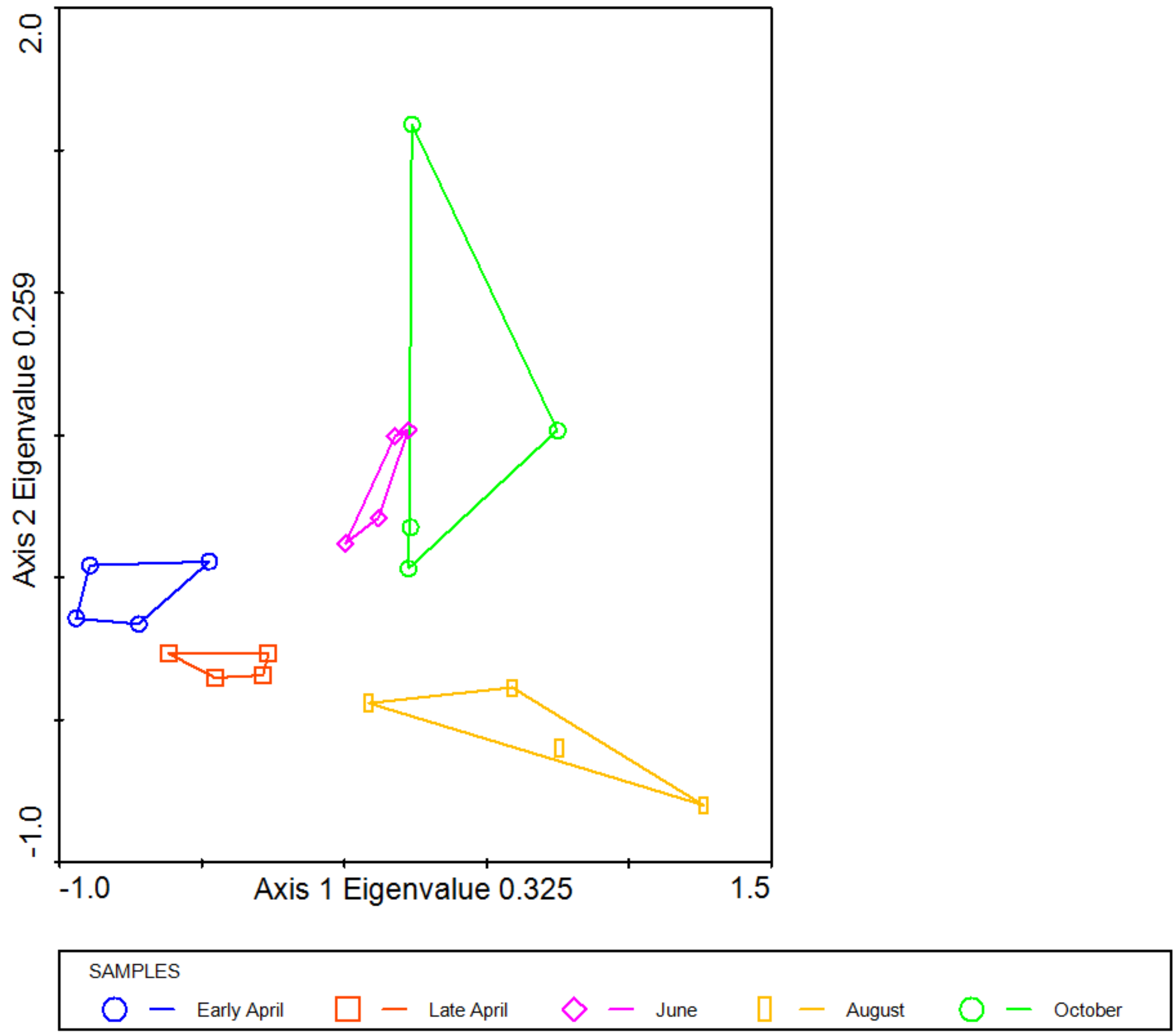
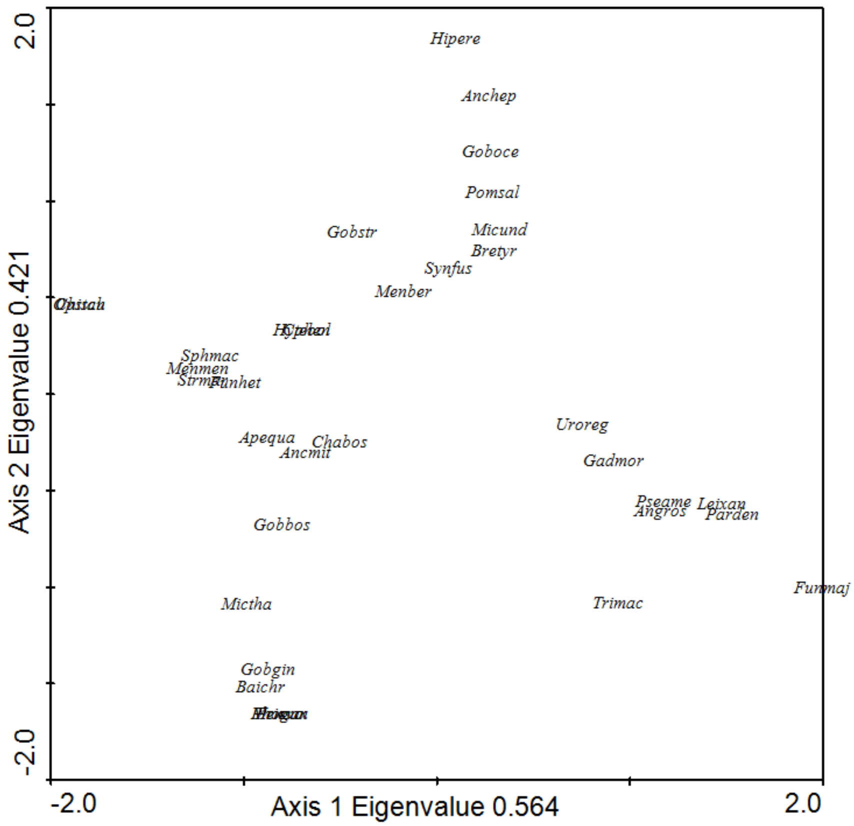


Figure 25. PCA showing samples coded by sampling month. The high degree of separation between polygons suggests differences in species composition of larval supply within Barnegat Bay between months sampled.



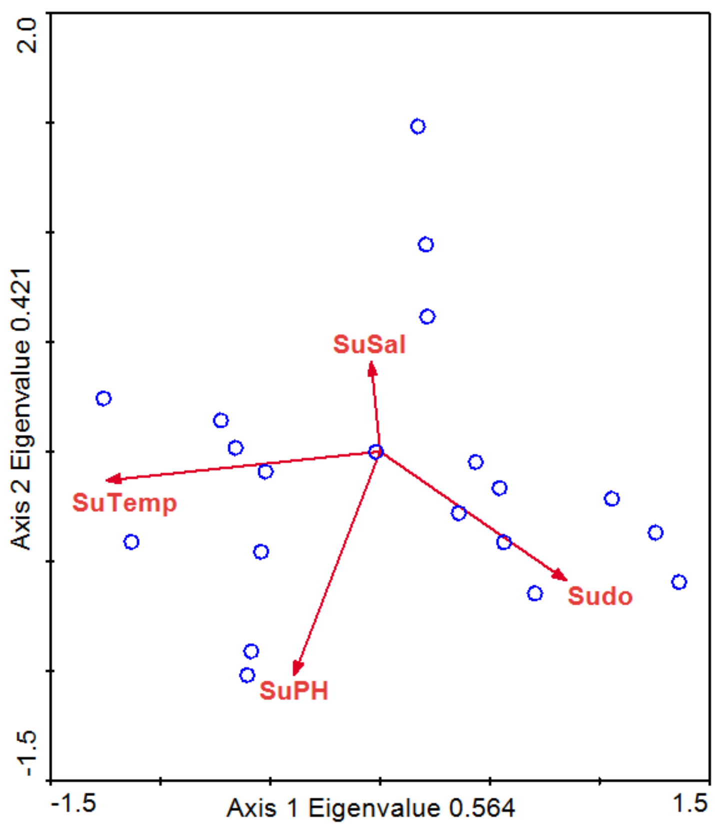


Figure 26. CCA species scatter centroids (above) and biplot (below) showing temperature as the driving variable on the first eigenaxis.

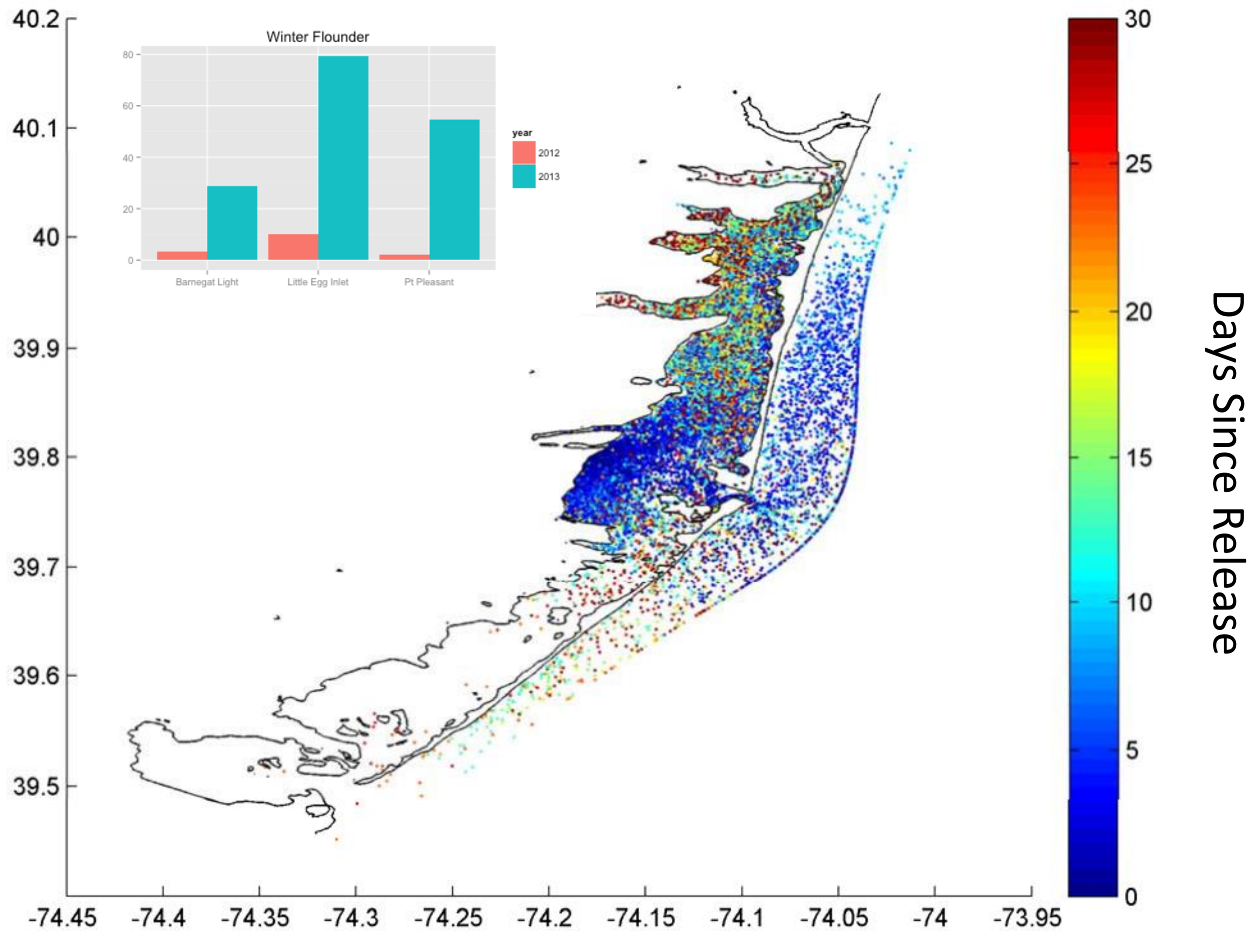


Figure 27. Barnegat Bay Hydrodynamic Model (USGS). Particles Released at South Harbor.

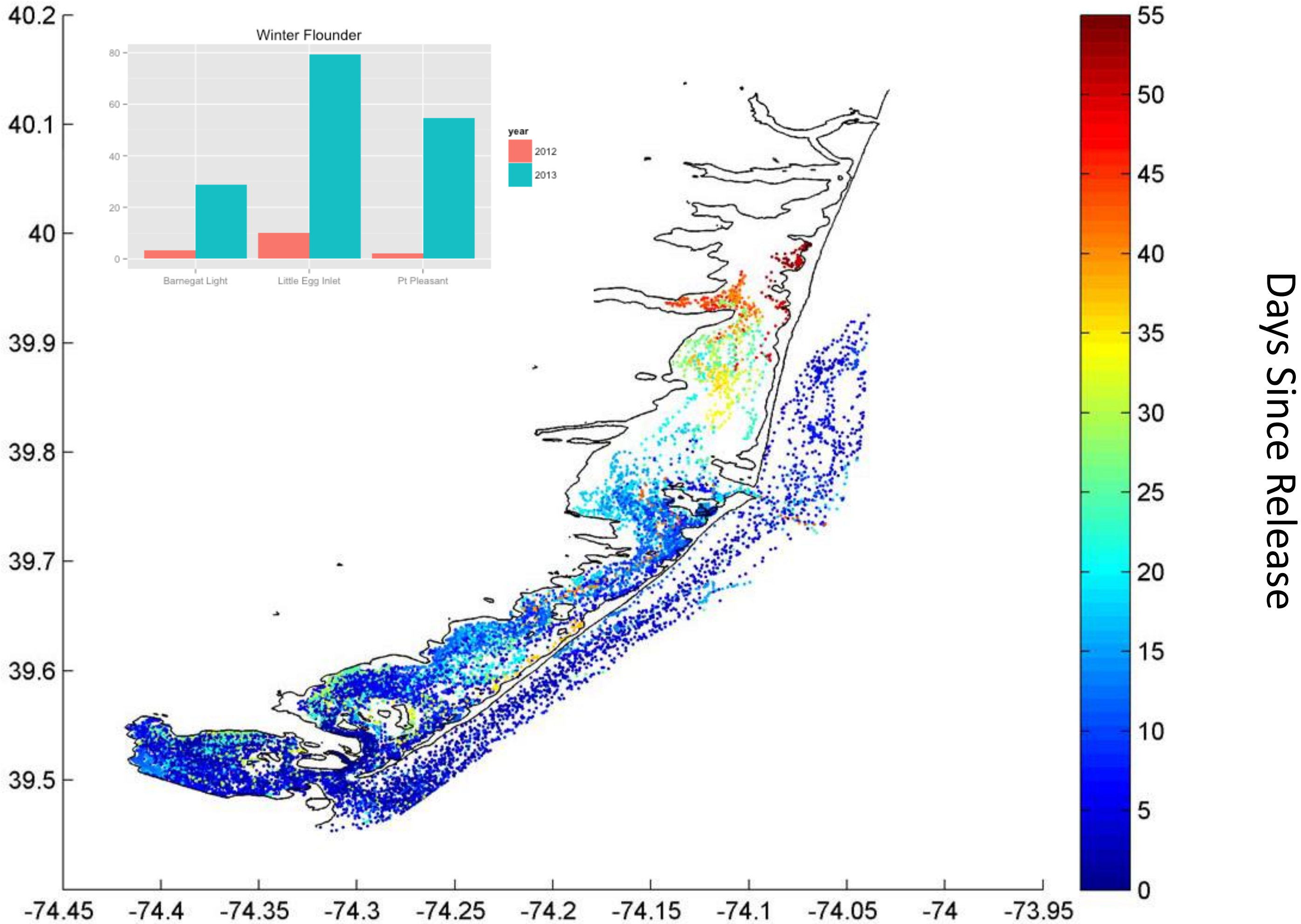


Figure 28. Barnegat Bay Hydrodynamic Model (USGS). Particles Released at Little Sheepshead Creek.

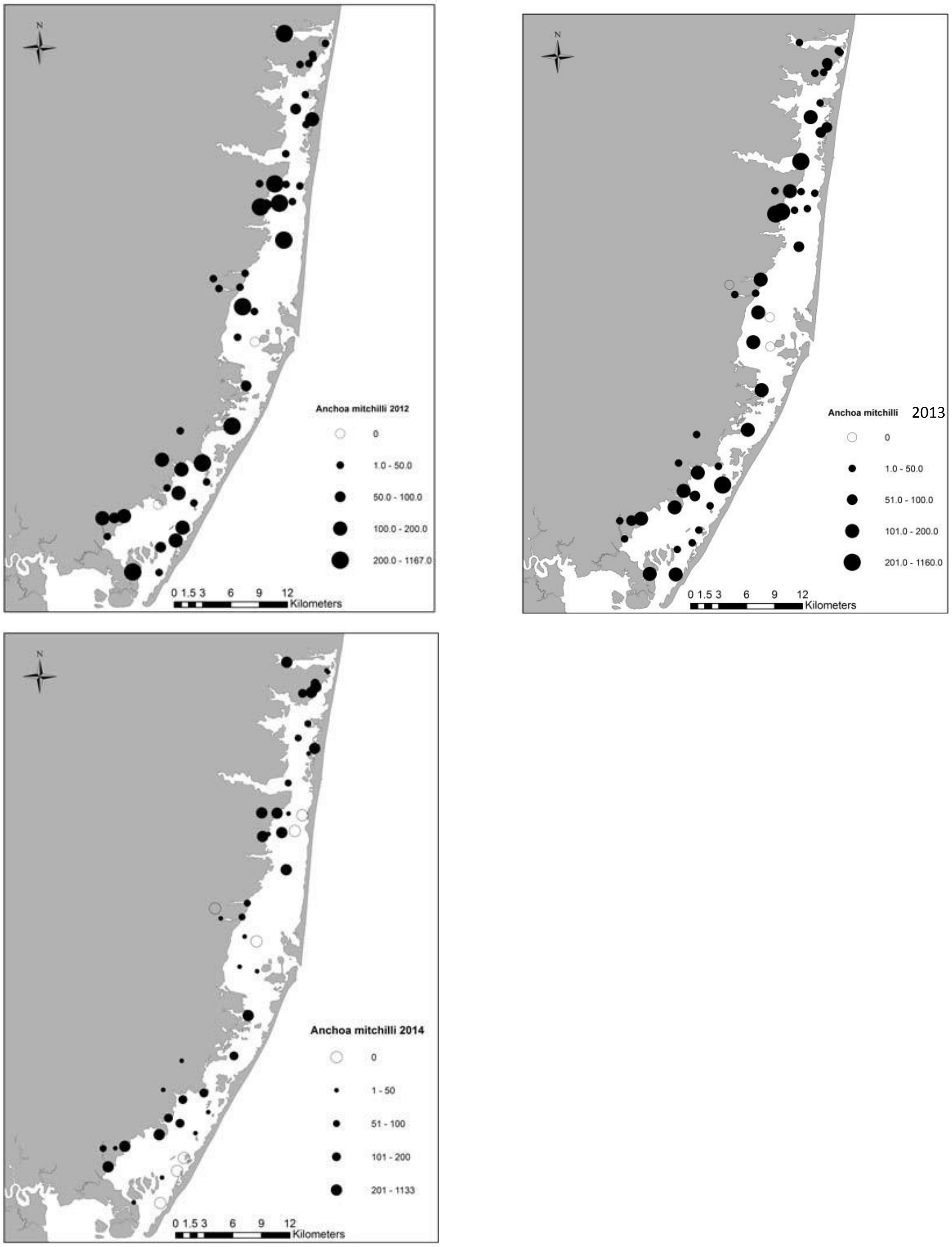


Figure 29. Spatial distribution *Anchoa mitchilli* during all otter trawl samples collected in 2012-2014.

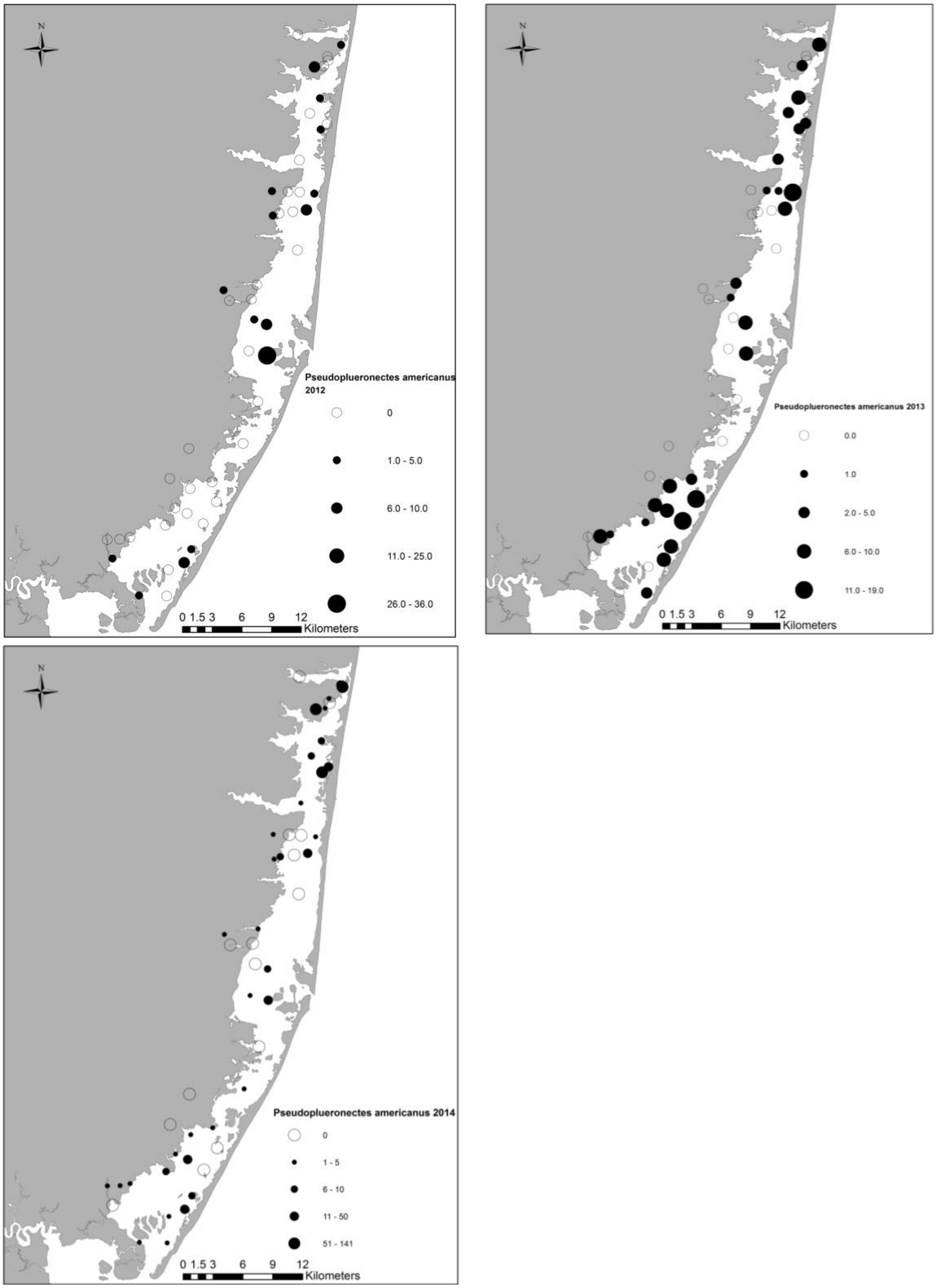


Figure 30. Spatial distribution of *Pseudopleuronectes americanus* during all otter trawl samples collected from 2012 – 2014.

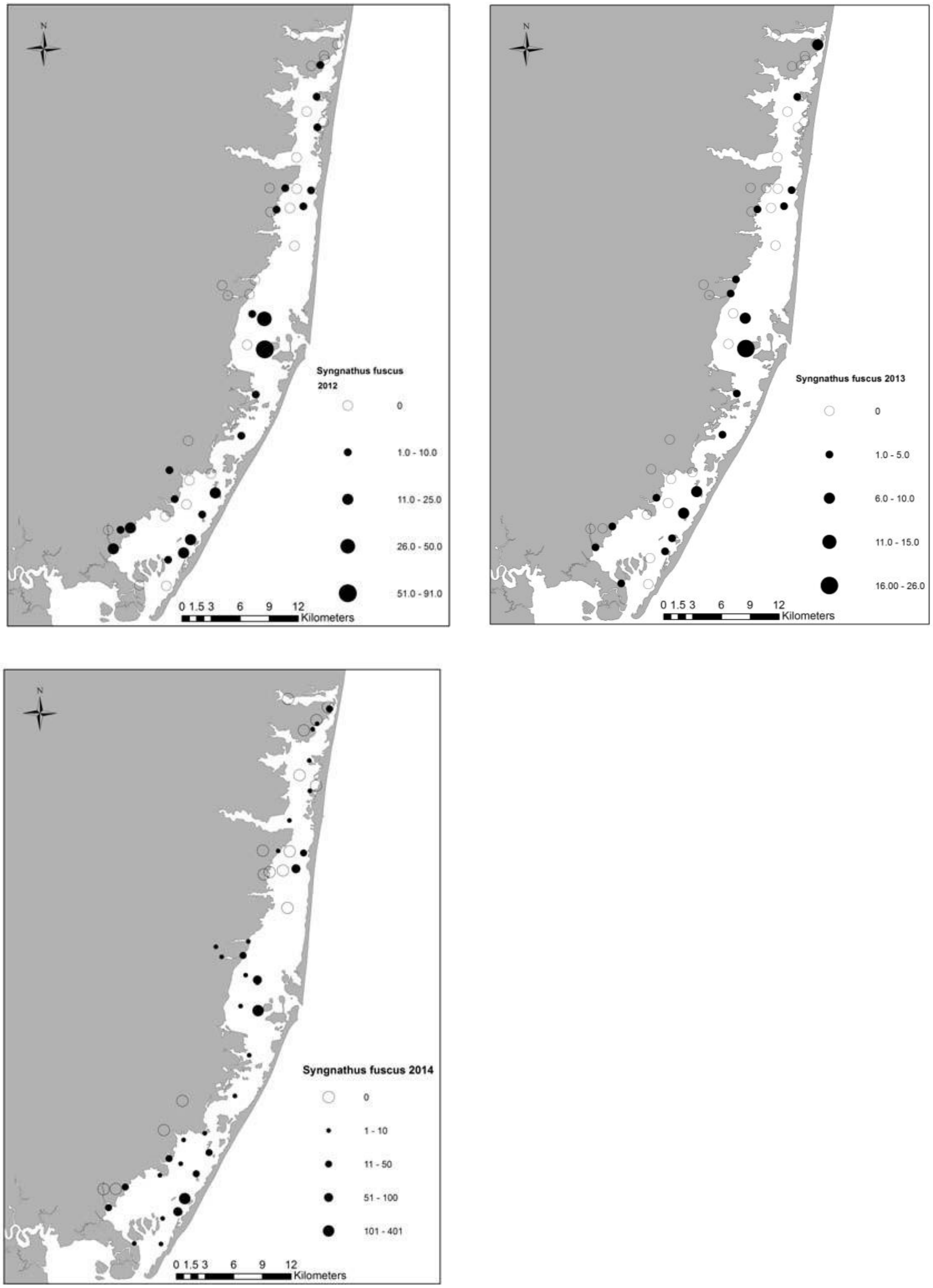


Figure 31. Spatial distribution of *Syngnathus fuscus* during all otter trawl samples collected in 2012-2014.

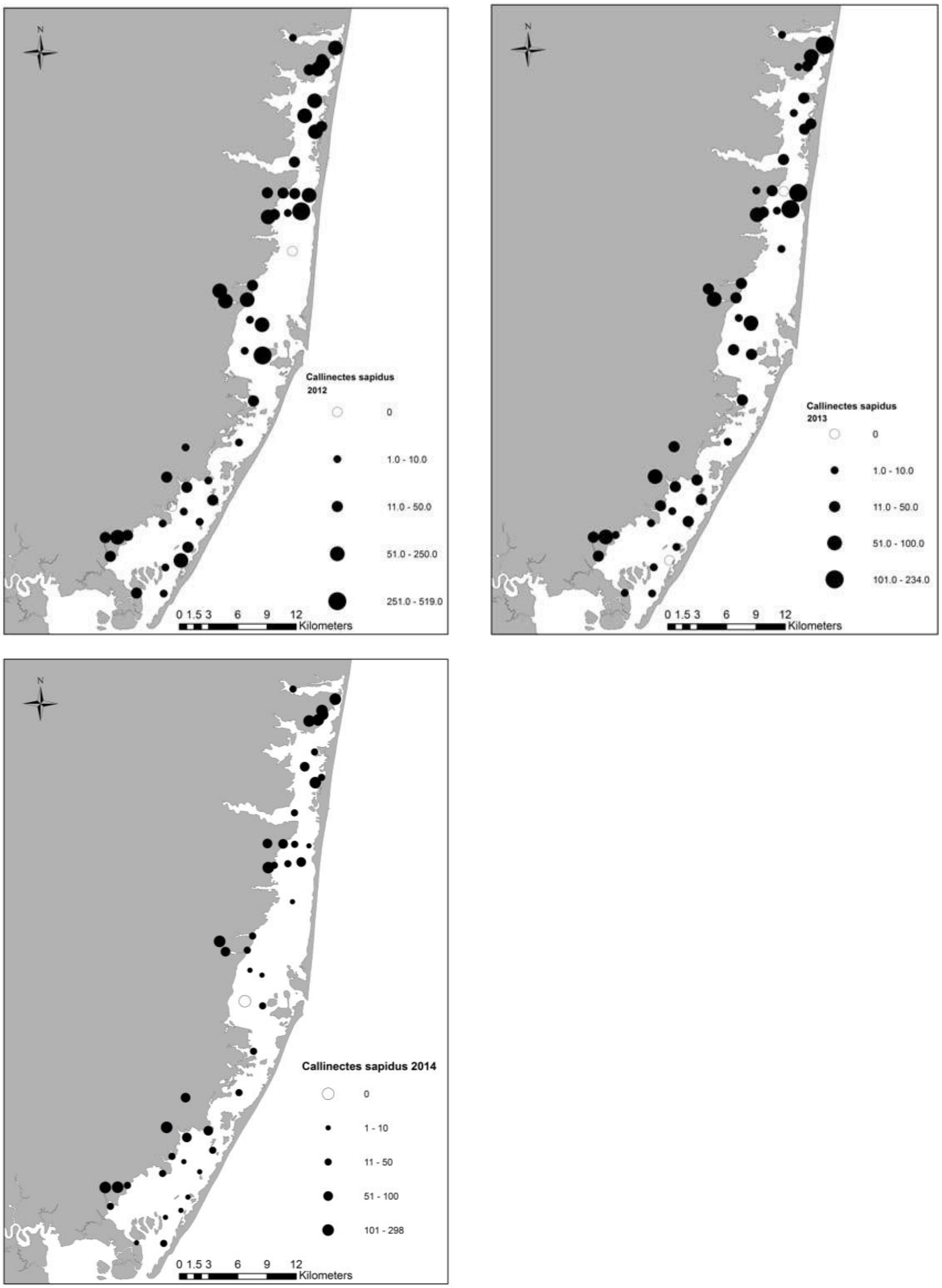


Figure 32. Spatial distribution of *Callinectes sapidus* during all otter trawl samples collected from 2012-2014.

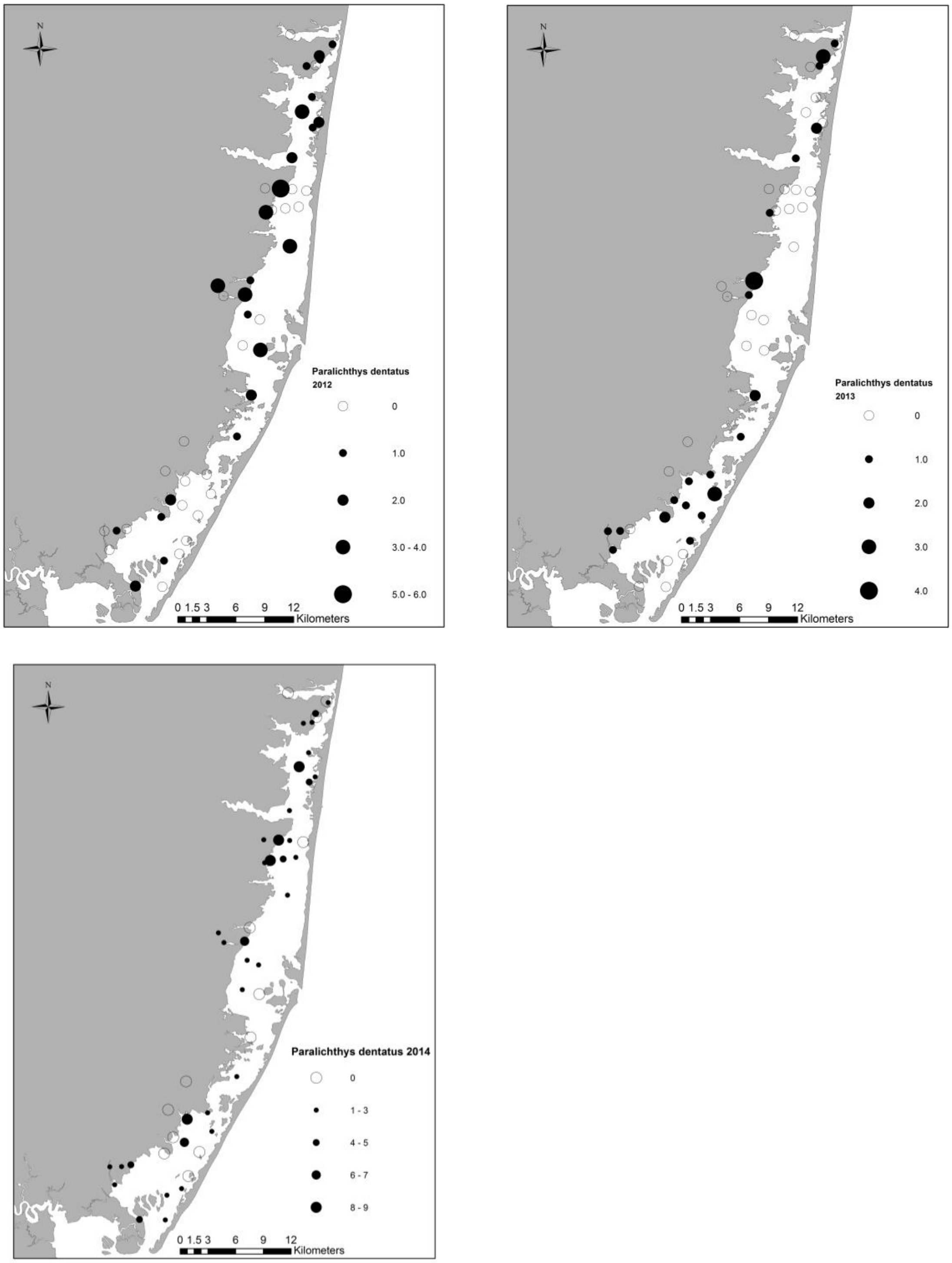


Figure 33. Spatial distribution of *Paralichthys dentatus* during all otter trawl samples collected from 2012-2014.

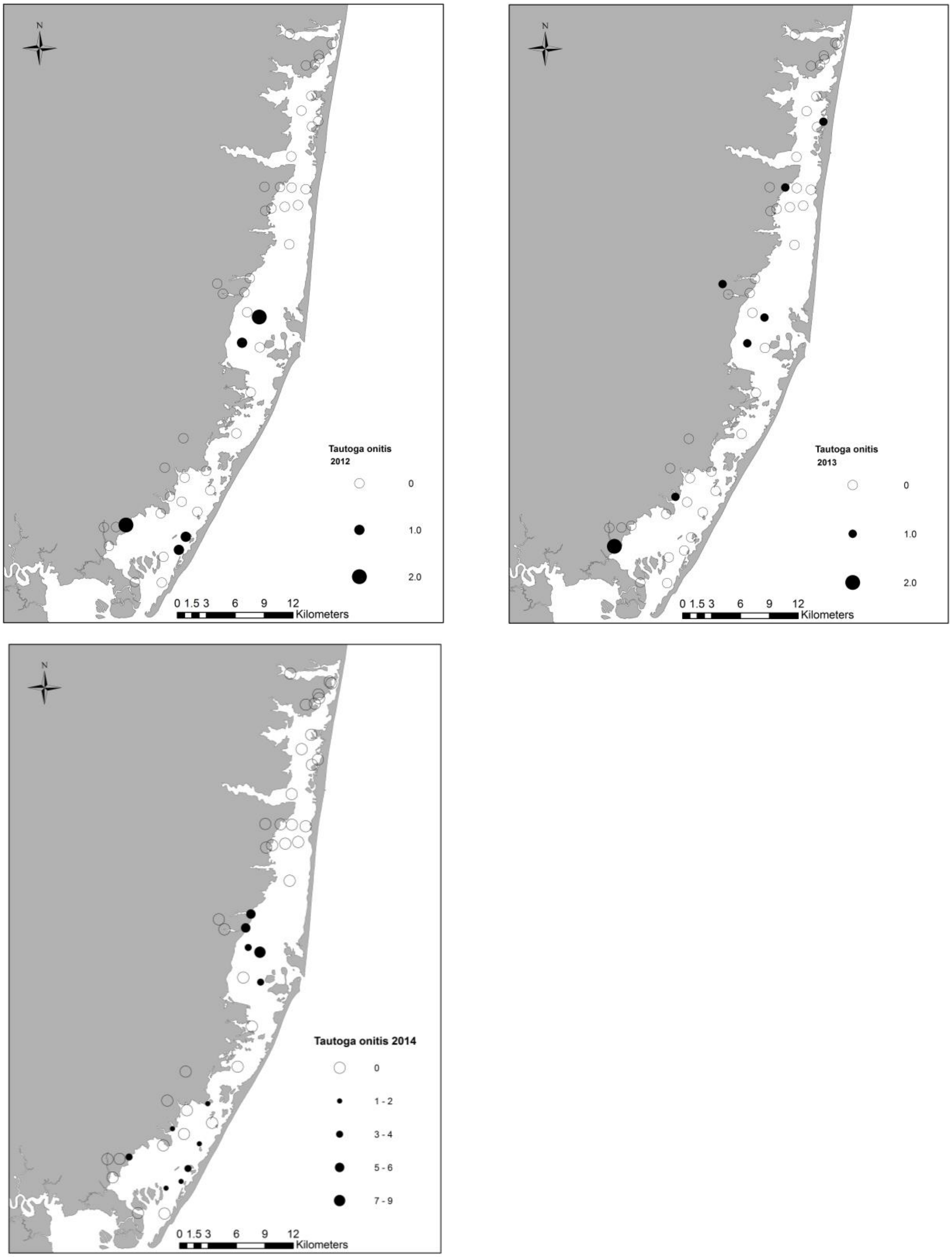


Figure 34. Spatial distribution of *Tautoga onitis* during all otter trawl samples collected from 2012-2014.

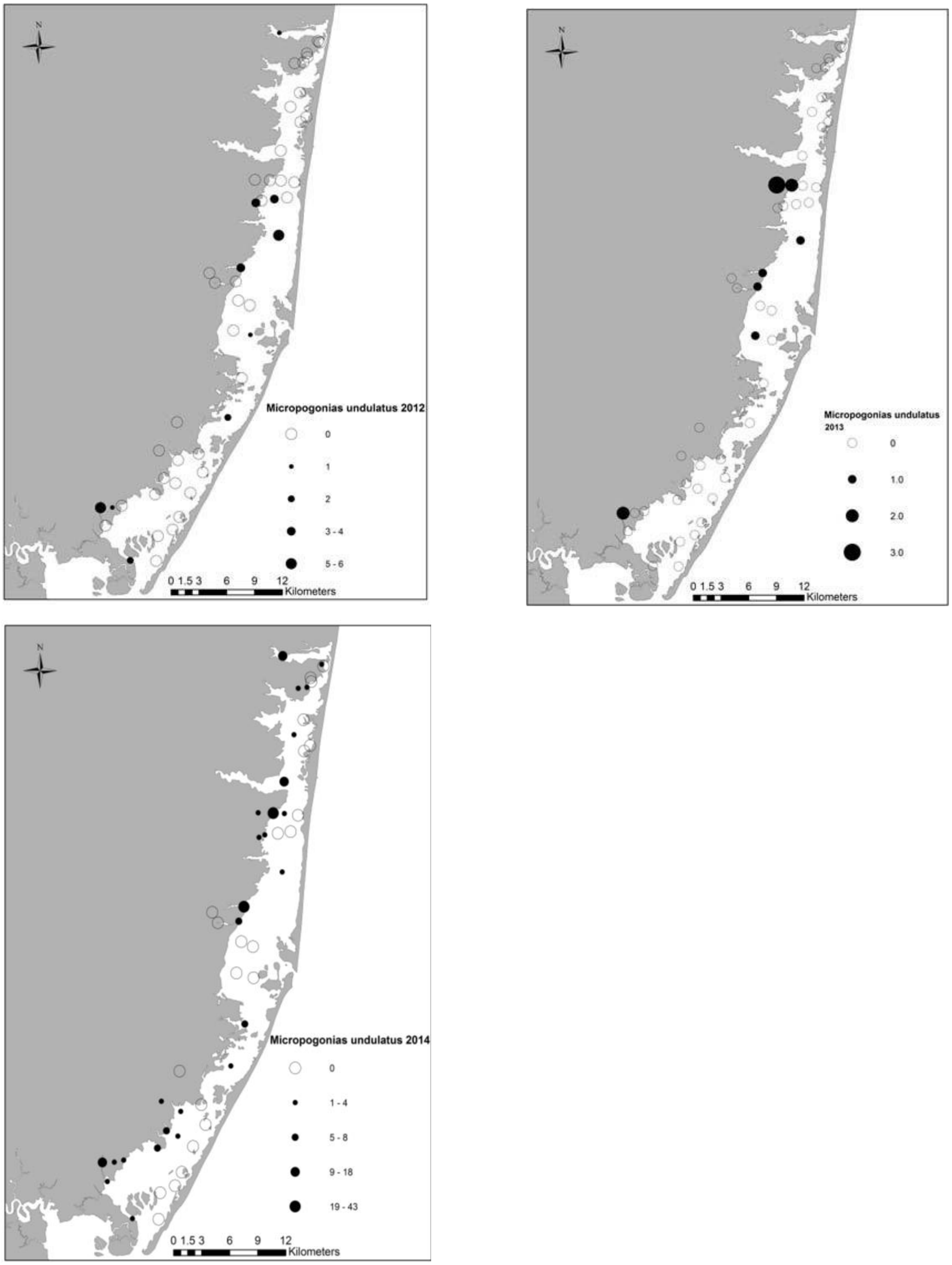


Figure 35. Spatial distribution of *Micropogonias undulatus* during all otter trawl samples collected from 2012-2014.

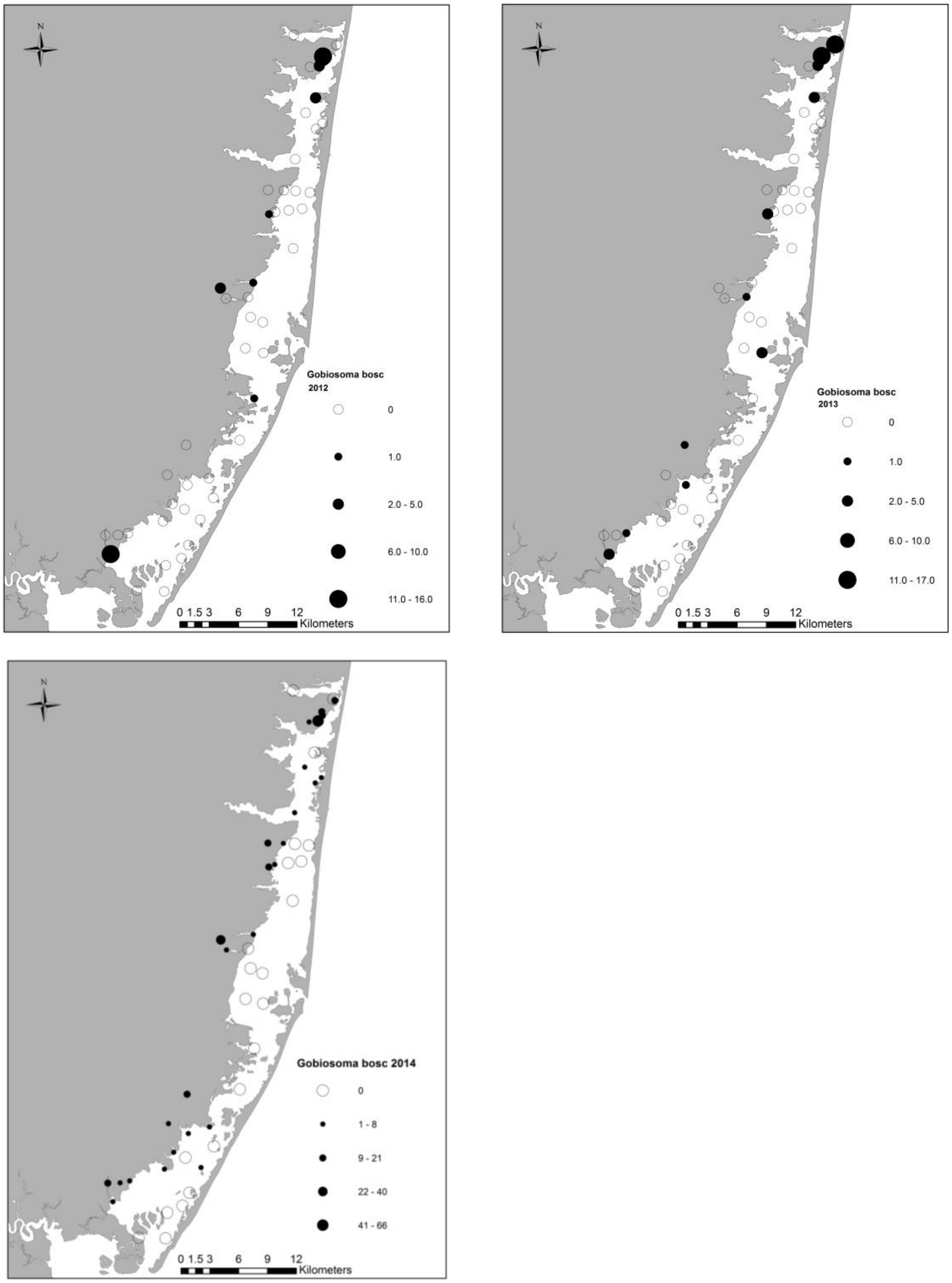


Figure 36. Spatial distribution of *Gobiosoma bosc* during all otter trawl samples collected from 2012-2014.

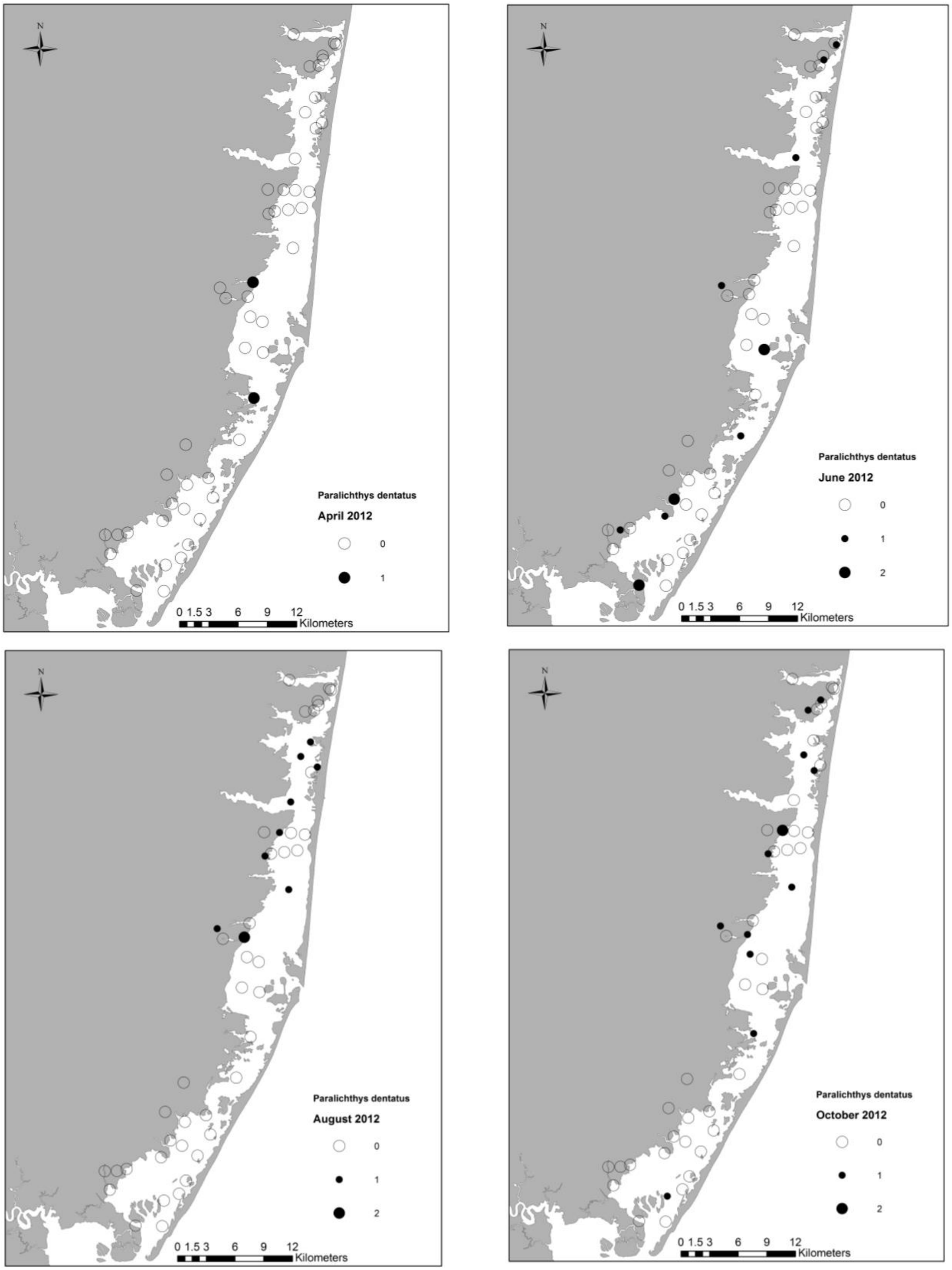


Figure 37. Spatial distribution of *Paralichthys dentatus* from otter trawl sampies by sampling month during 2012.

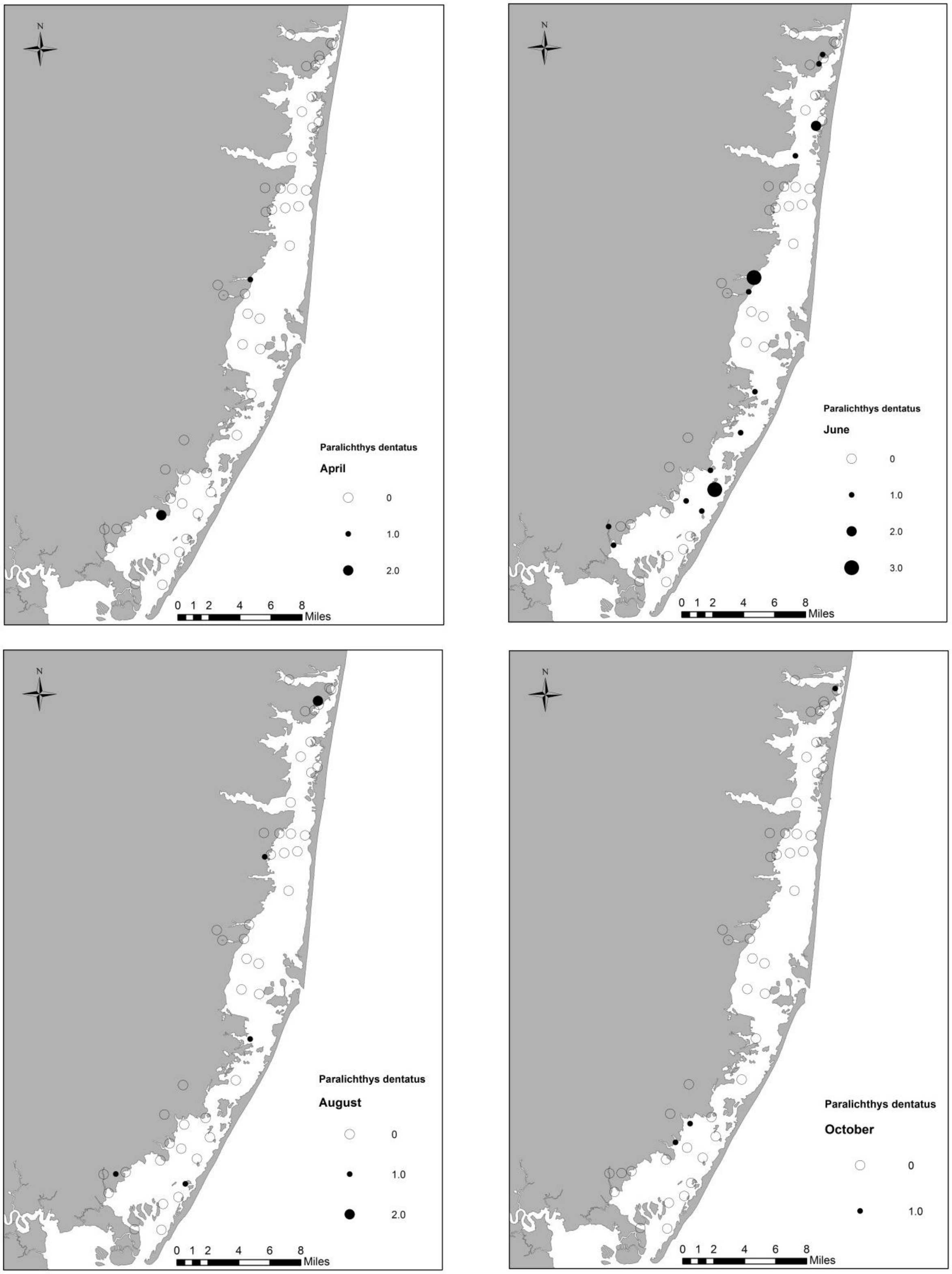


Figure 38. Spatial distribution of *Paralichthys dentatus* from otter trawl samples by sampling month during 2013.

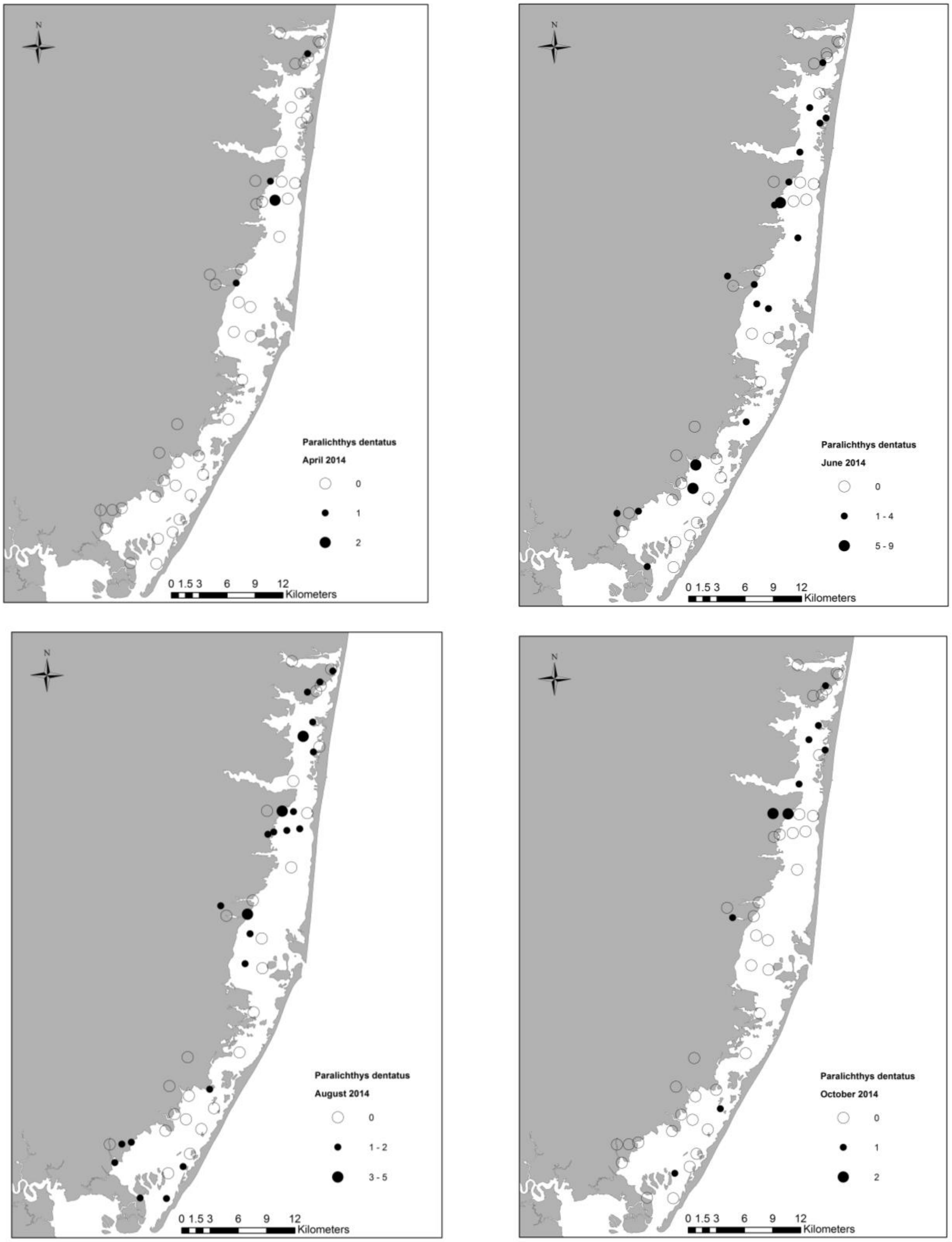


Figure 39. Spatial distribution of *Paralichthys dentatus* from otter trawlsampies by sampling month during 2014.

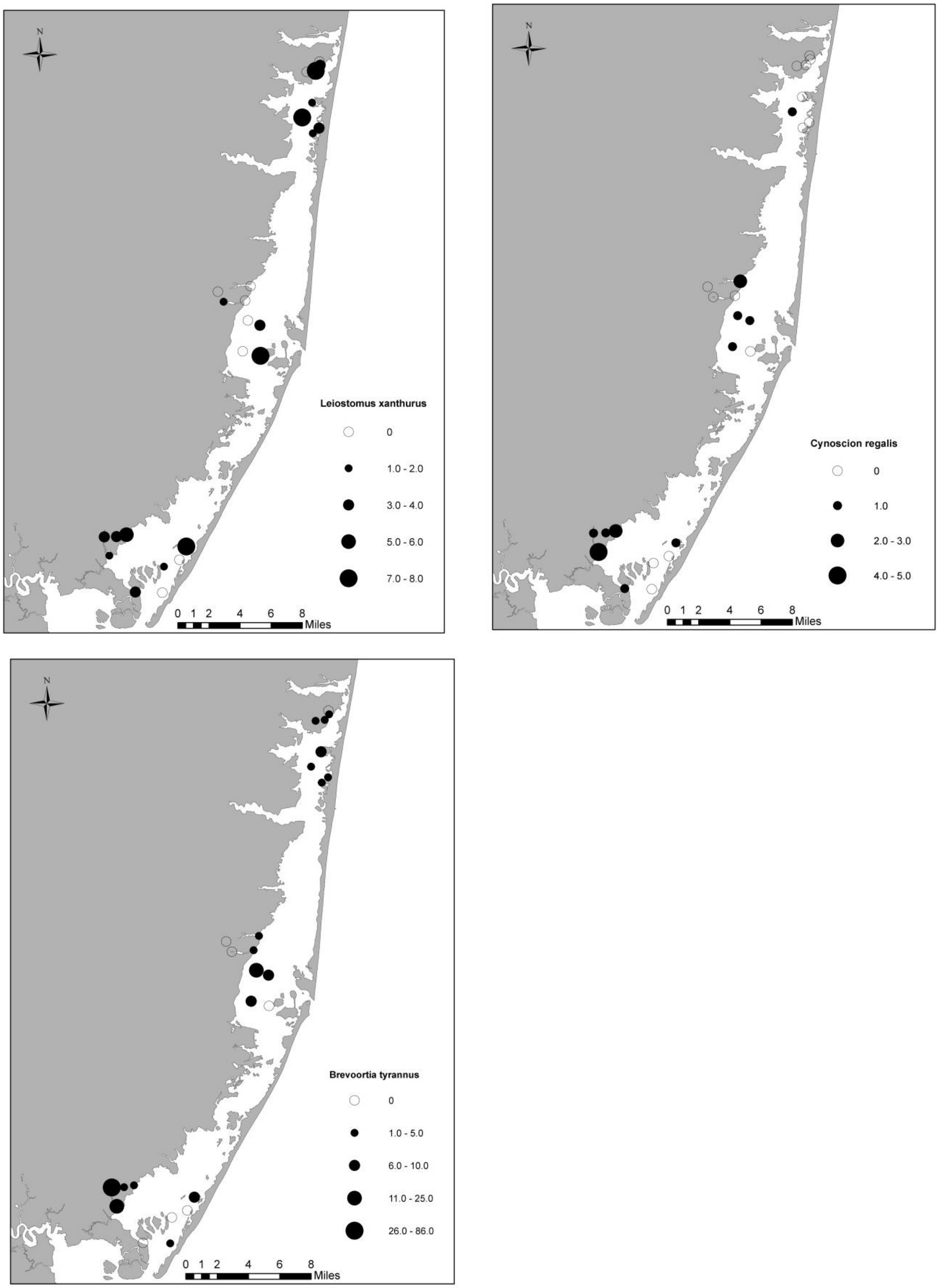


Figure 40. Spatial distribution of dominant species from gill net sampling in 2013 including *Leiostomus xanthurus* (upper leftL *Cynoscion regalis* (upper rightL and *Brevoortia tyrannus* (lower left).

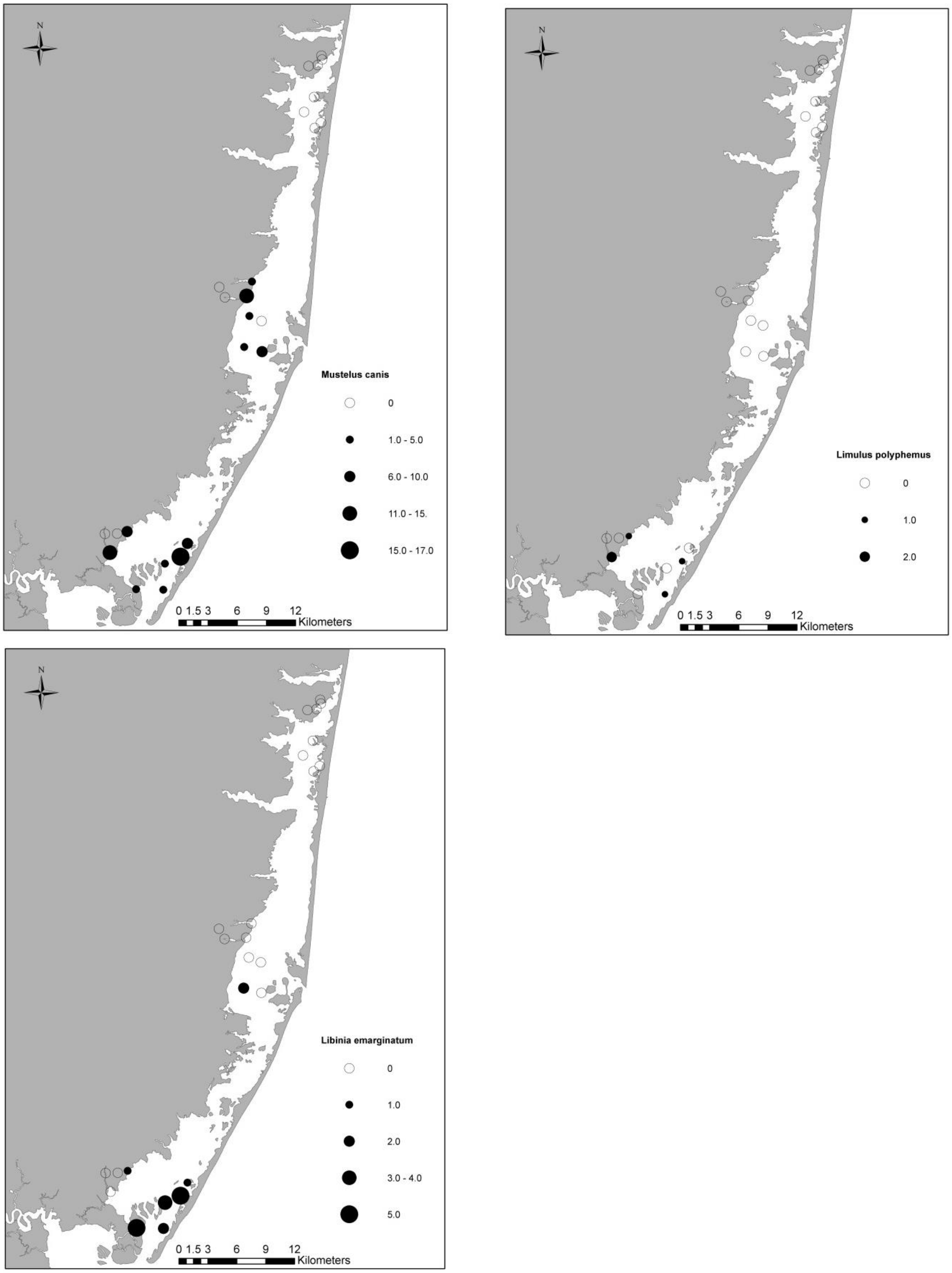


Figure 41. Spatial distribution of dominant species from gill net sampling in 2013 including *Mustelus canis* (upper left), *Limulus polyphemus* (upper right), and *Libinia emarginatum* (lower left).

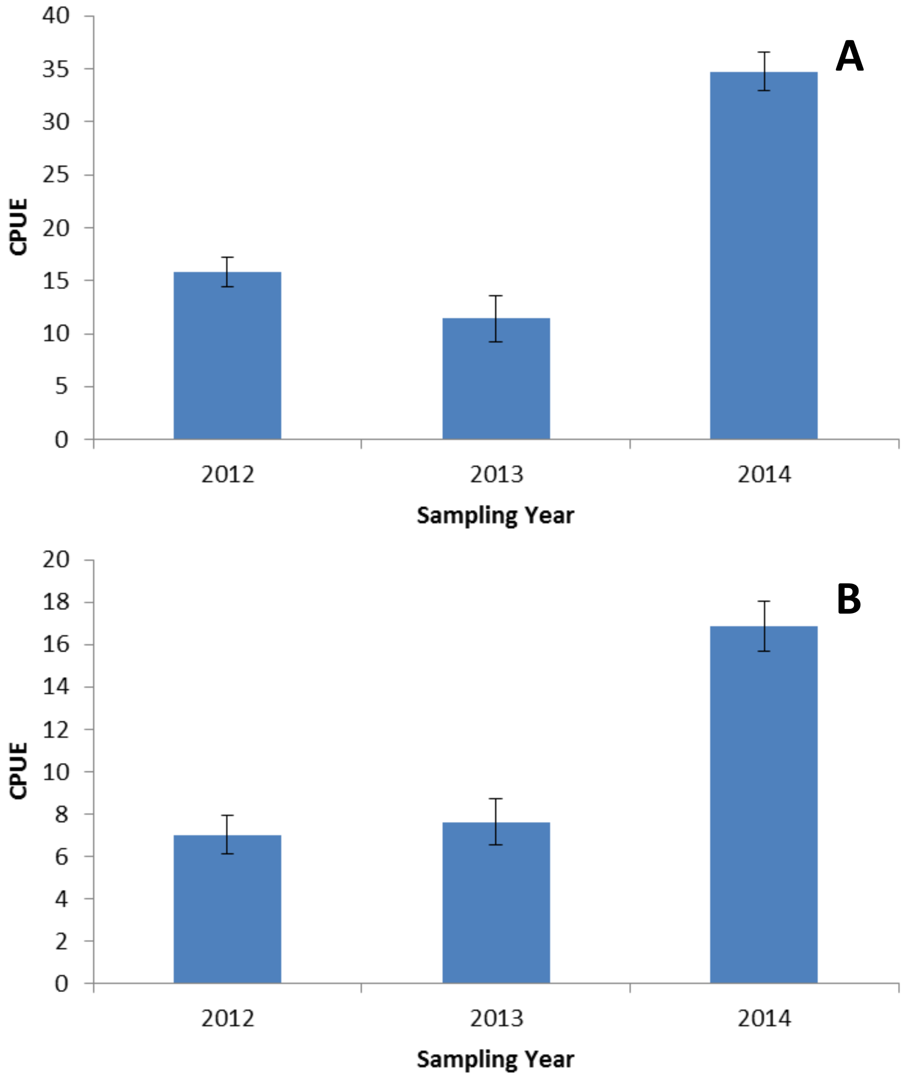


Figure 42. Catch per unit effort (CPUE) (± standard error) by otter trawl for (A) fishes and (B) macroalgae across habitats, clusters and adjacent sampling sites, and sampling dates between April and October of 2012-2014. CPUE calculated as (A) Total Number of Fish / Total Number of Tows and (B) Total Number of Macroalgae / Total Number of Tows.

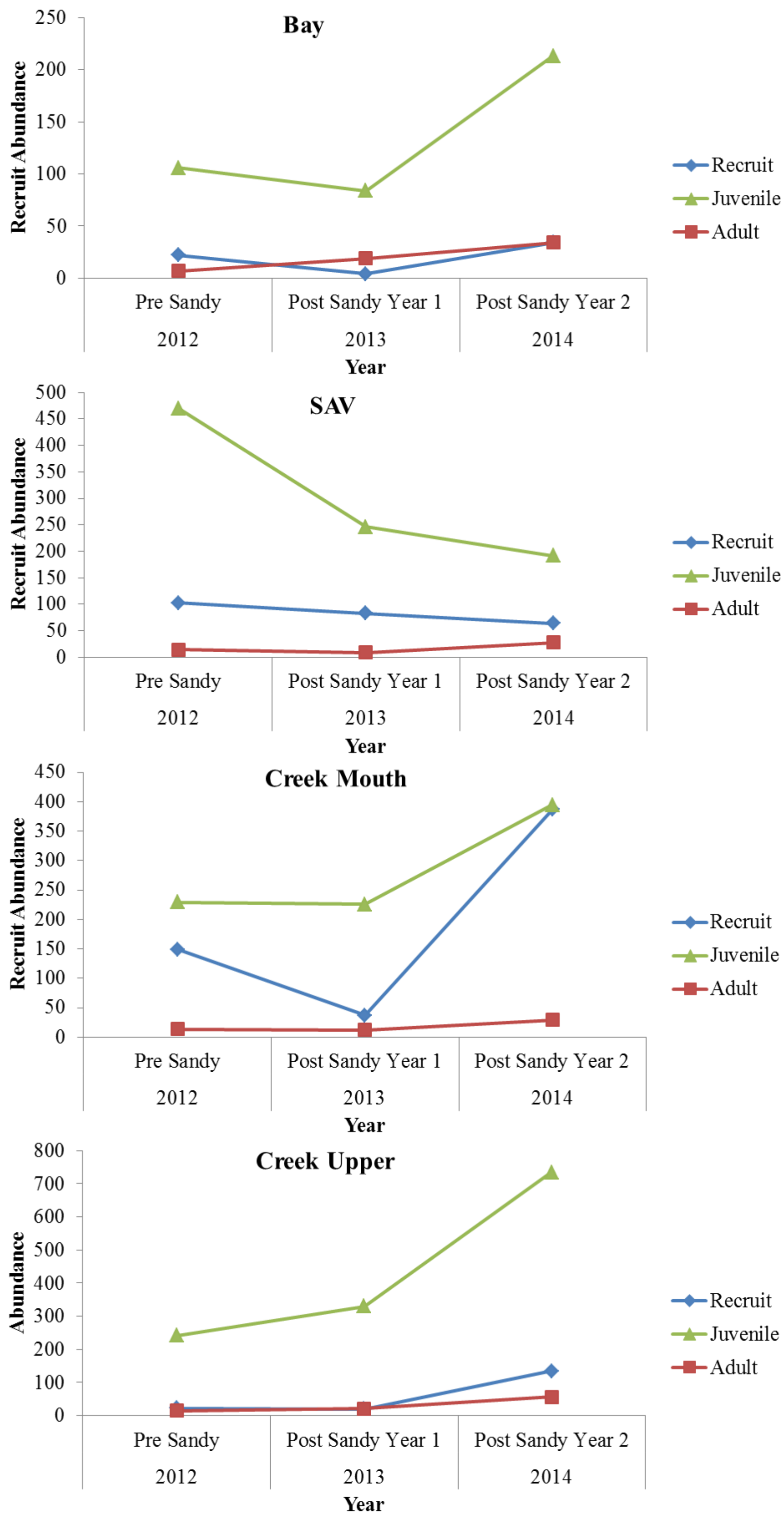


Figure 43. Annual abundance of recruits (≤ 10 mm), juveniles (20mm-110mm), and adult (≥ 120mm) blue crabs from trawl sampling (June, August, October combined) in each habitat.

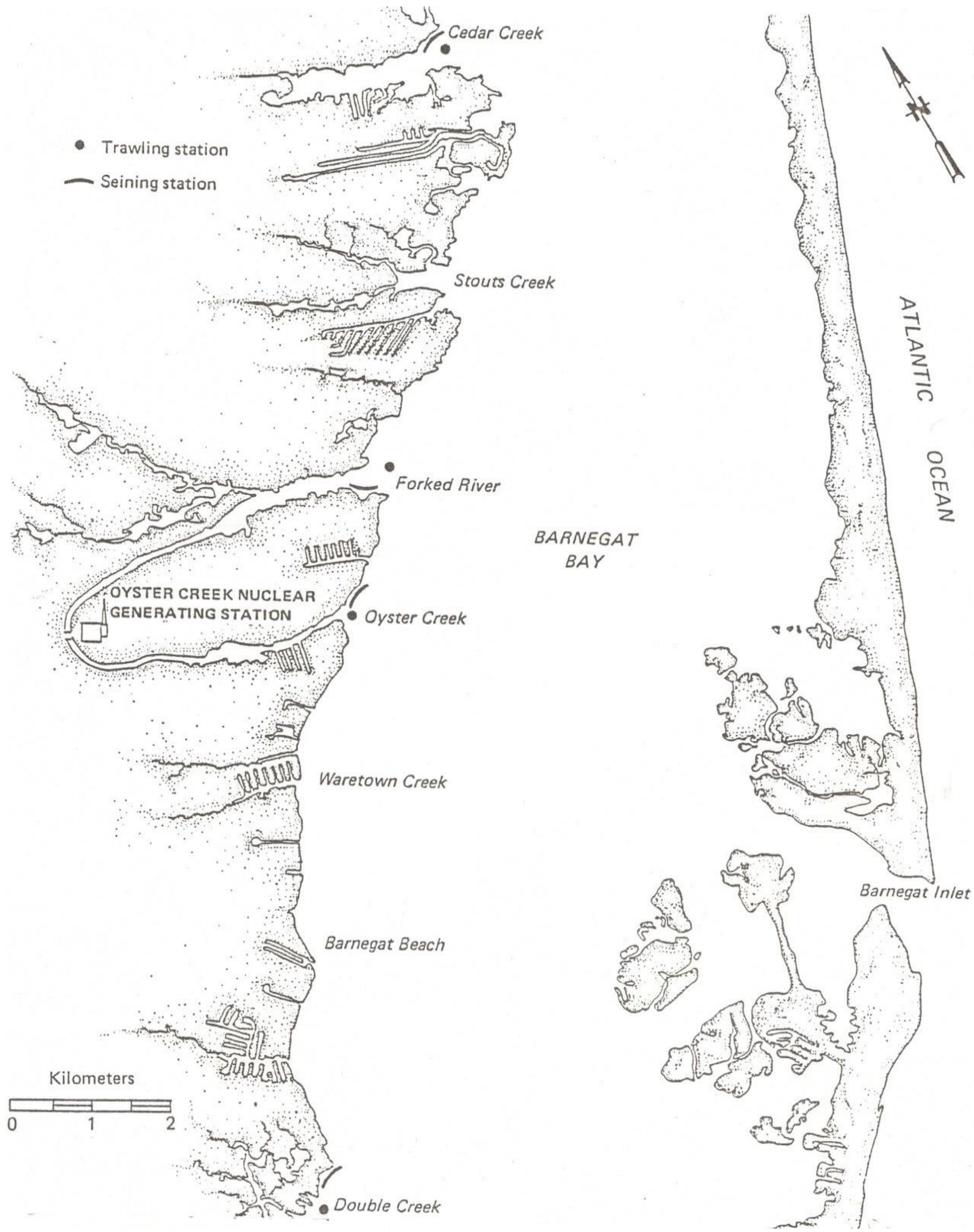


Figure 44. Sites sampled by Ichthyological Associates, Inc. during environmental impact assessment for the OCNGS in 1970's and compared with our own recent sampling in 2012 and 2013.

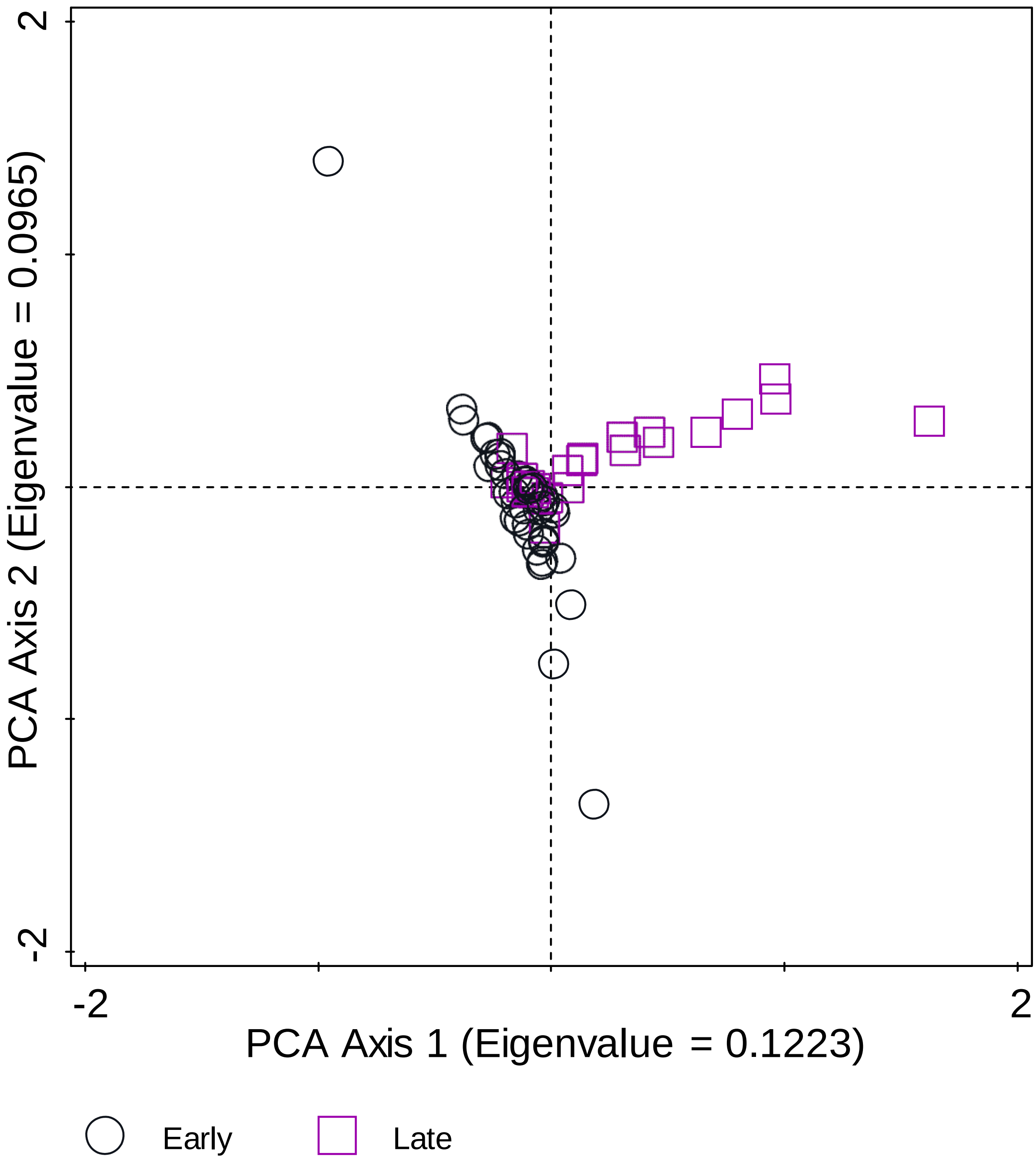


Figure 45. Graphical representation of the first two axes from a principle components analysis on species composition collected at four sites near OCNGS. Early observations include data collected in the late 1970s and early 1980s and Late observations include data collected in 2012 and 2013.

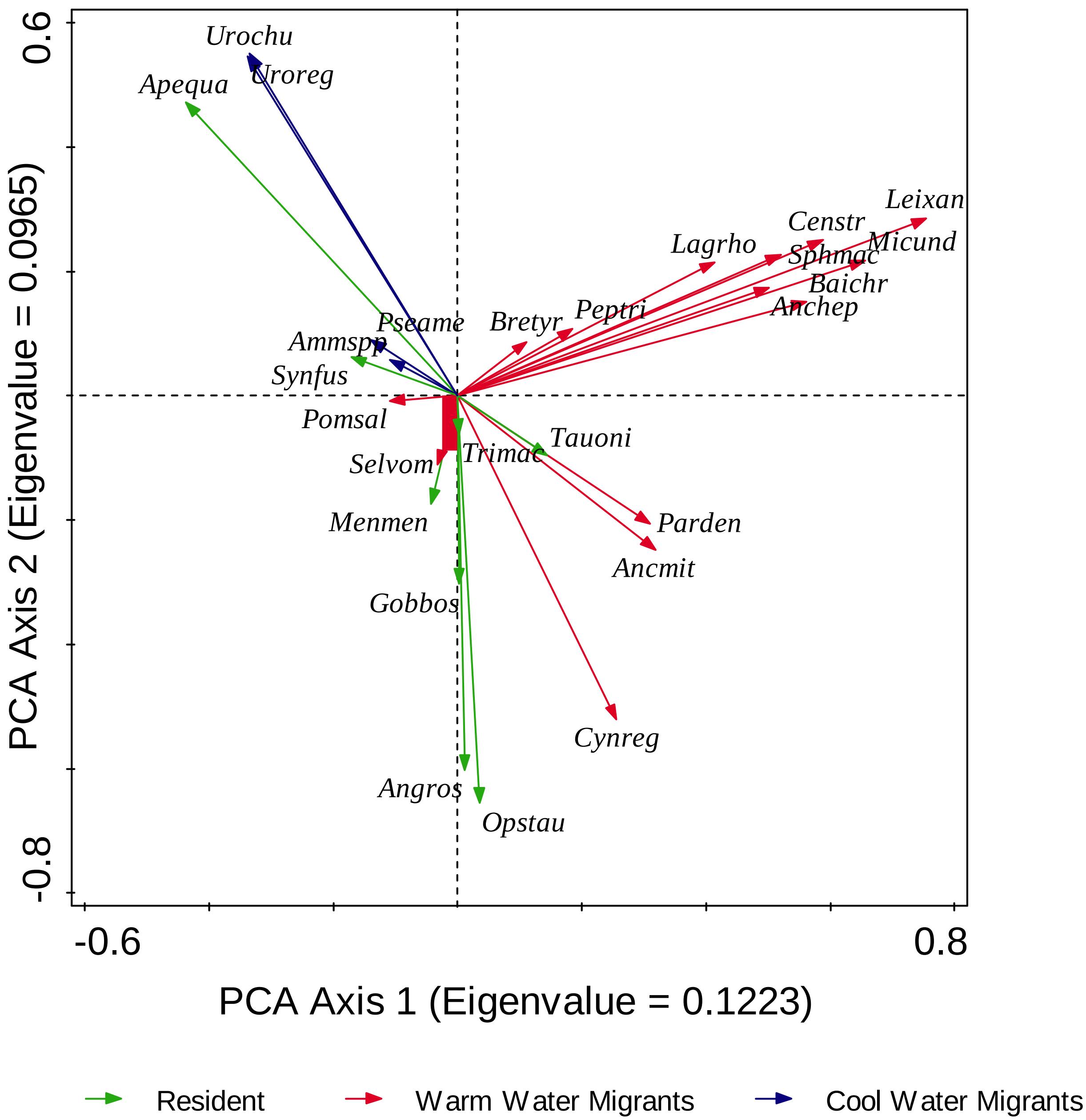


Figure 46. Graphical representation of the first two axes from a principle components analysis on species composition collected at four sites near OCNGS (Fig. 17). Species are categorized as resident, warm-water migrants, and cool-water migrants according to Kennish and Lutz (1984), with the exception of *M. undulatus*, which was reclassified as a warm-water migrant following Miller and Able (2002). Species names are abbreviated using the first three letters of the species and genus name (See Table 7A for full spelling).

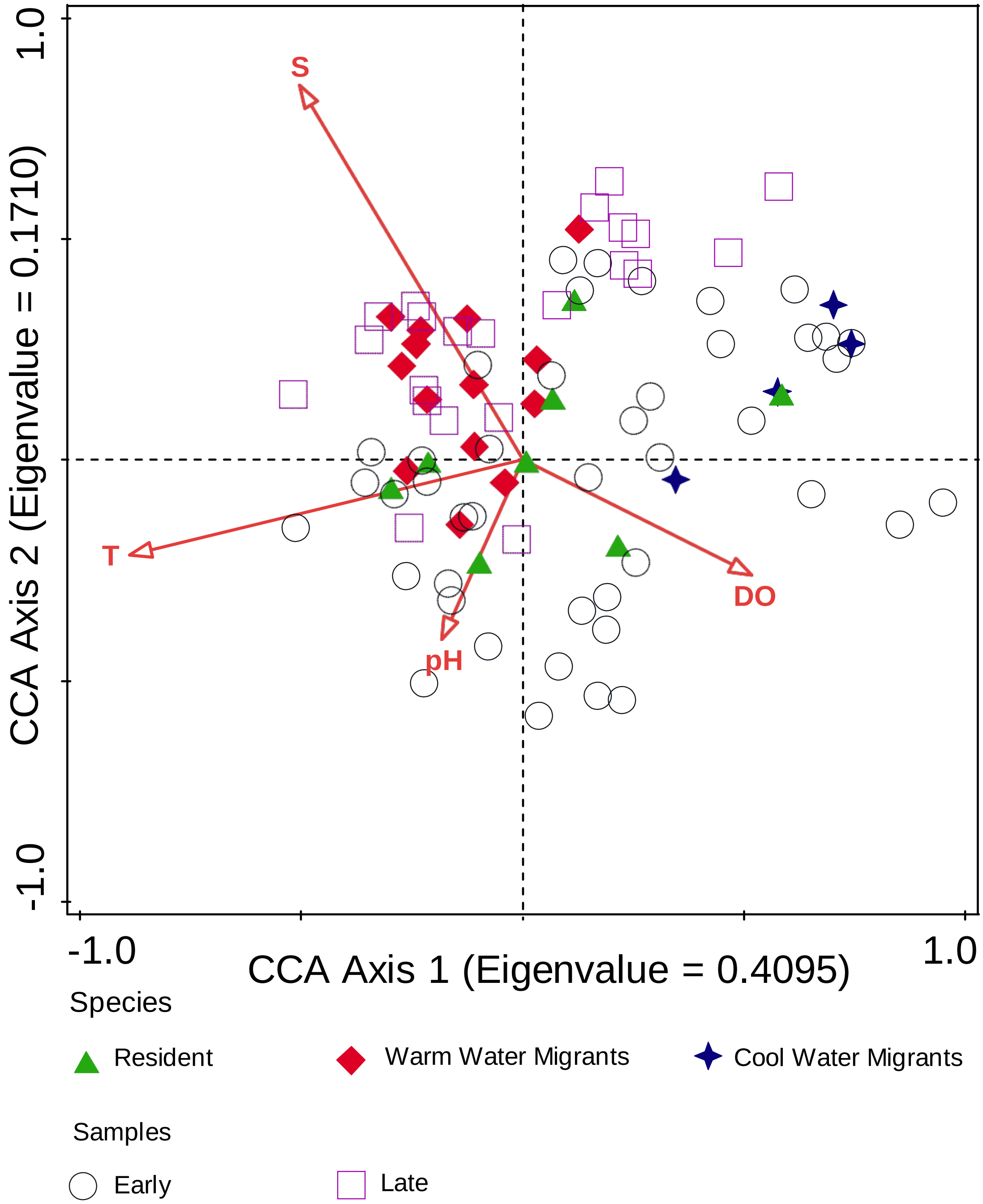


Figure 47. Graphical representation of the first two axes from a canonical correspondence analysis on species composition and environmental data collected at four sites near OCNGS (Fig. 13). Environmental vectors include temperature (T), salinity (S), dissolved oxygen (DO), and pH. Early (late 1970s/early 1980s) and Late (2012/2013) observations are identified by open symbols and individual species loading scores are identified by solid symbols.

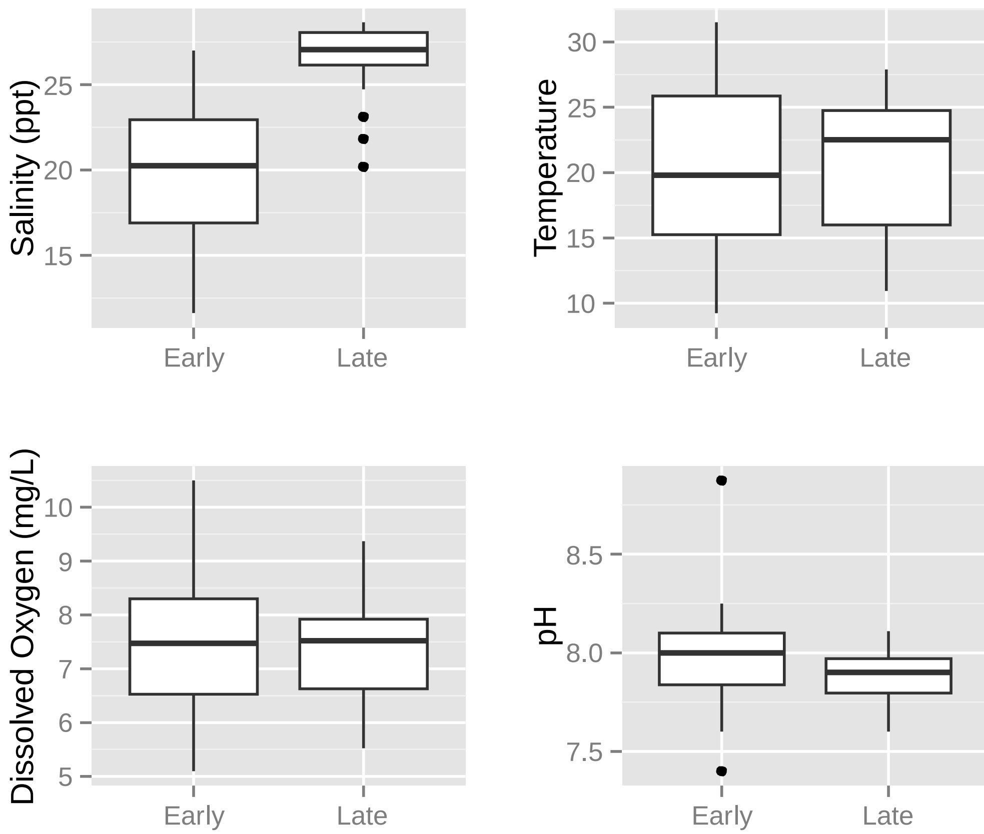


Figure 48. Box-plots of Early (late 1970s/early 1980s) and Late (2012/2013) environmental data collected at four sites near OCNGS (Fig. 13). Median values are represented by thick black lines, interquartile ranges are represented by the upper and lower bounds of the boxes, minimum and maximum values are represented by the upper and lower whiskers, and outliers are represented by dots.

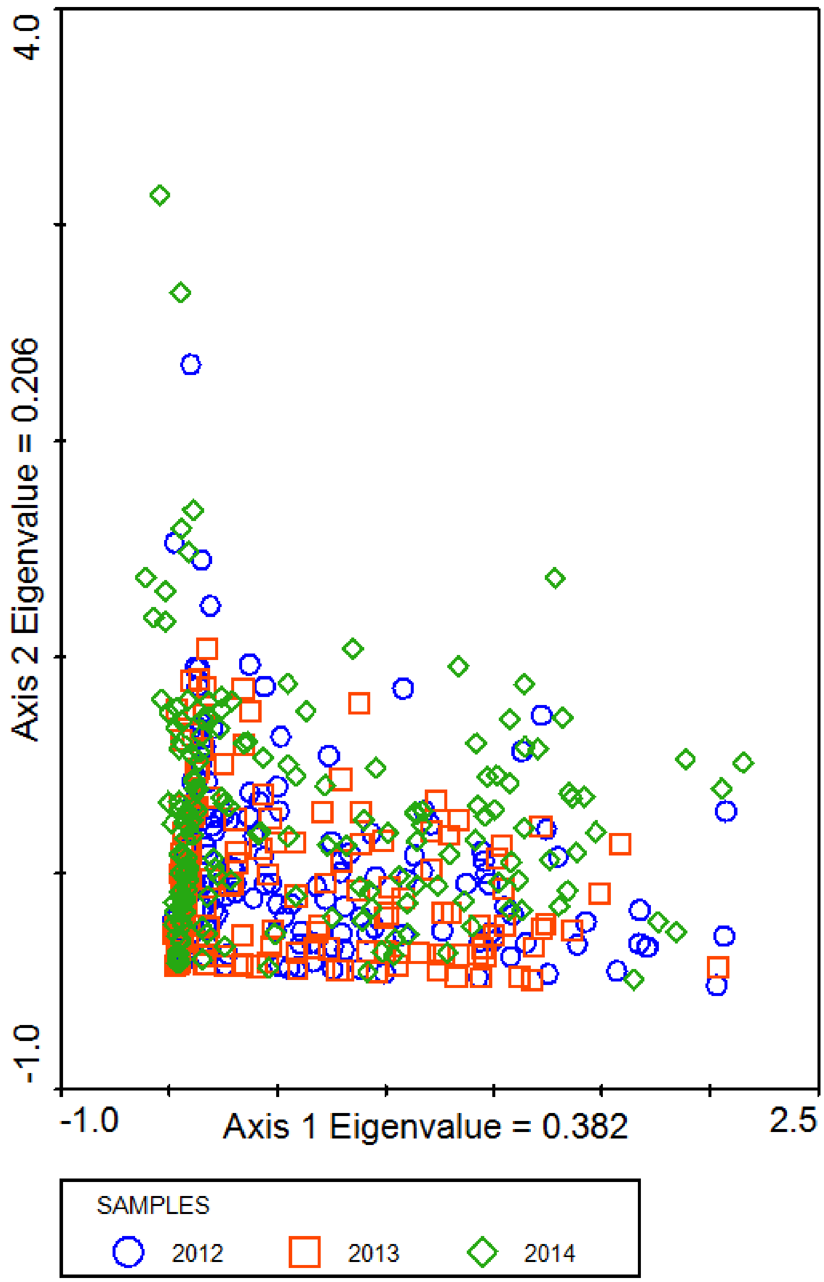


Figure 49. PCA scatterplot of sample score showing similarity on the first two eigenaxes of Barnegat Bay samples from all sites, all years, by sampling event. Samples are color and shape coded by year.

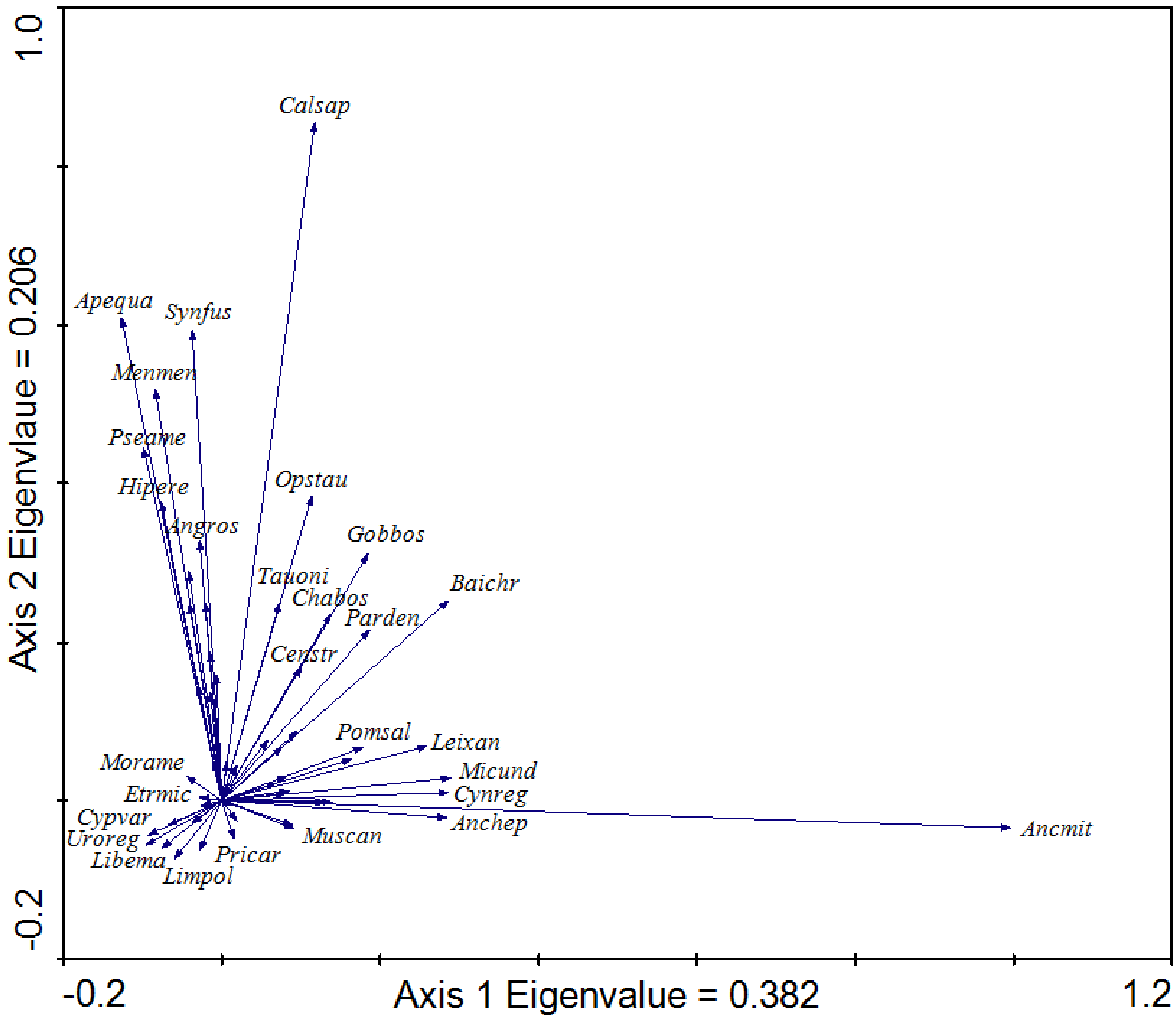


Figure 50. Scatter plot of species score amplitude along the first two eigenaxes of PCA. Vectors point in the direction of increasing abundance, relative to the sample coordinates shown in Figure 40. This scatter plot is in the same coenospace as Figure X1 but is separated for legibility. Species are coded as the first three letters of their Generic name and the first three letters of their specific name. The labeling of species which appear in the center of the plot (and are not important in the differentiation of samples) is suppressed; these are: Bretyr, Canirr, Carhip, Chisch, Cluhar, Dassay, Funhet, Gobgin, Gobstr, Hyphen, Lagrho, Lepgib, Libdub, Lucpar, Menber, Mensax, Mictha, Mugcur, Ovaoce, Peptri, Pogcro, Polvir, Scoaqu, Selset, Selvom, Sphmac, Stechr, Tauads, Trimac. See Table 8 for complete names.

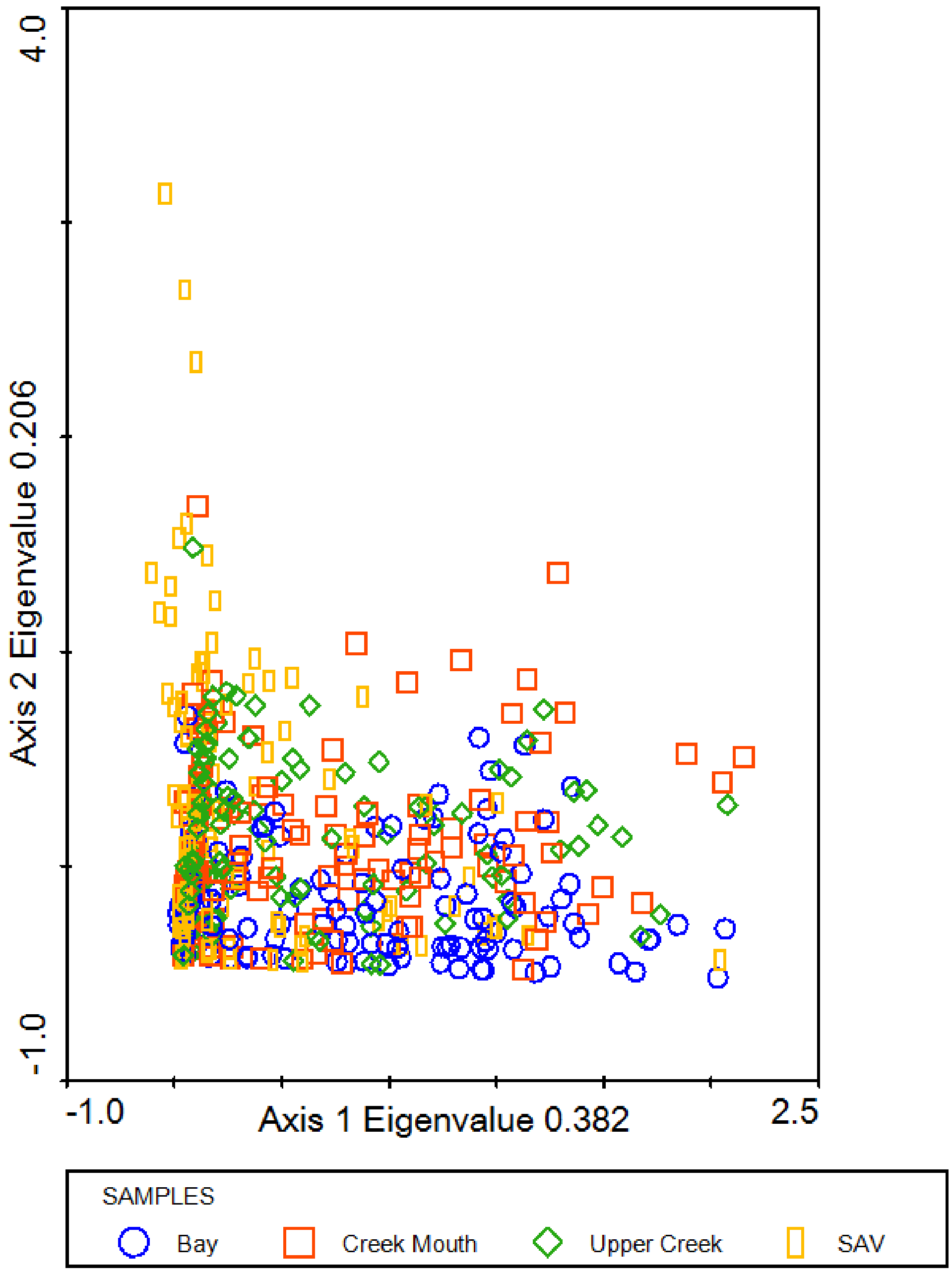


Figure 51. PCA scatterplot of sample score showing similarity on the first two eigenaxes of Barnegat Bay samples from all sites, all years, by sampling event. Samples are color and shape coded by habitat.

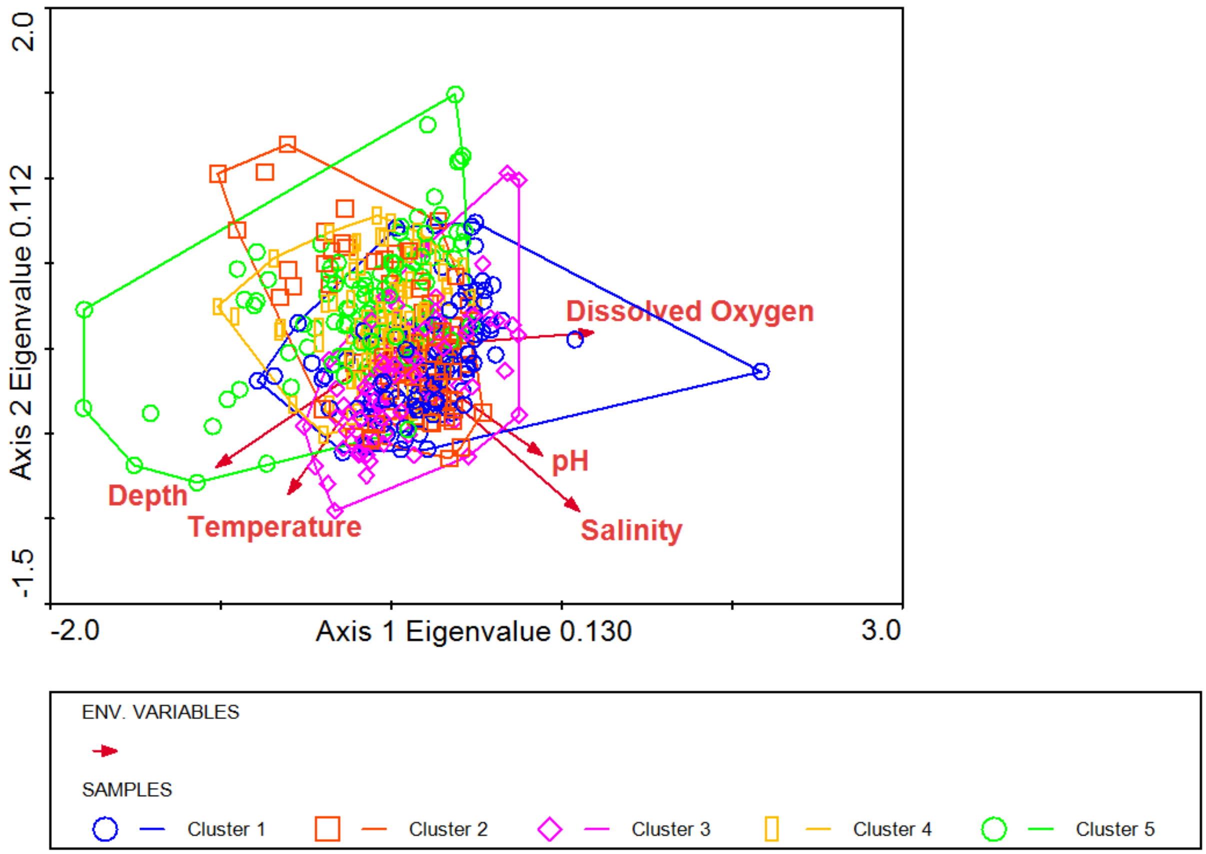


Figure 52. CCA biplot (samples and environmental factors) of fish and crab assemblage from Barnegat Bay, all years. Minimum convex polygons envelop samples based on Urbanization sampling class.

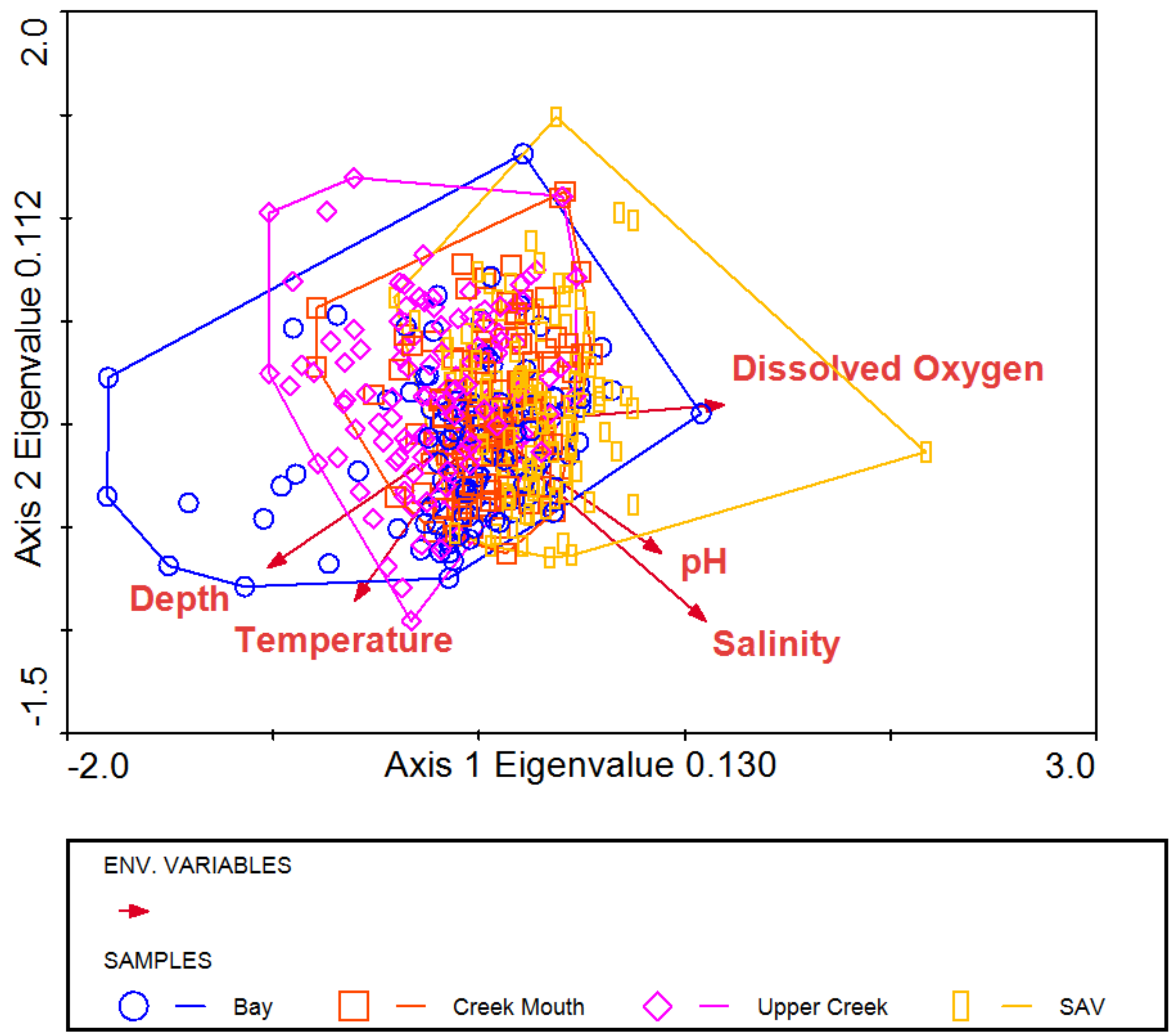


Figure 53. CCA biplot (samples and environmental factors) of fish and crab assemblage from Barnegat Bay, all years. This is same as Figure 43, but samples are encoded by habitat. Minimum convex polygons envelop samples based on habitat.

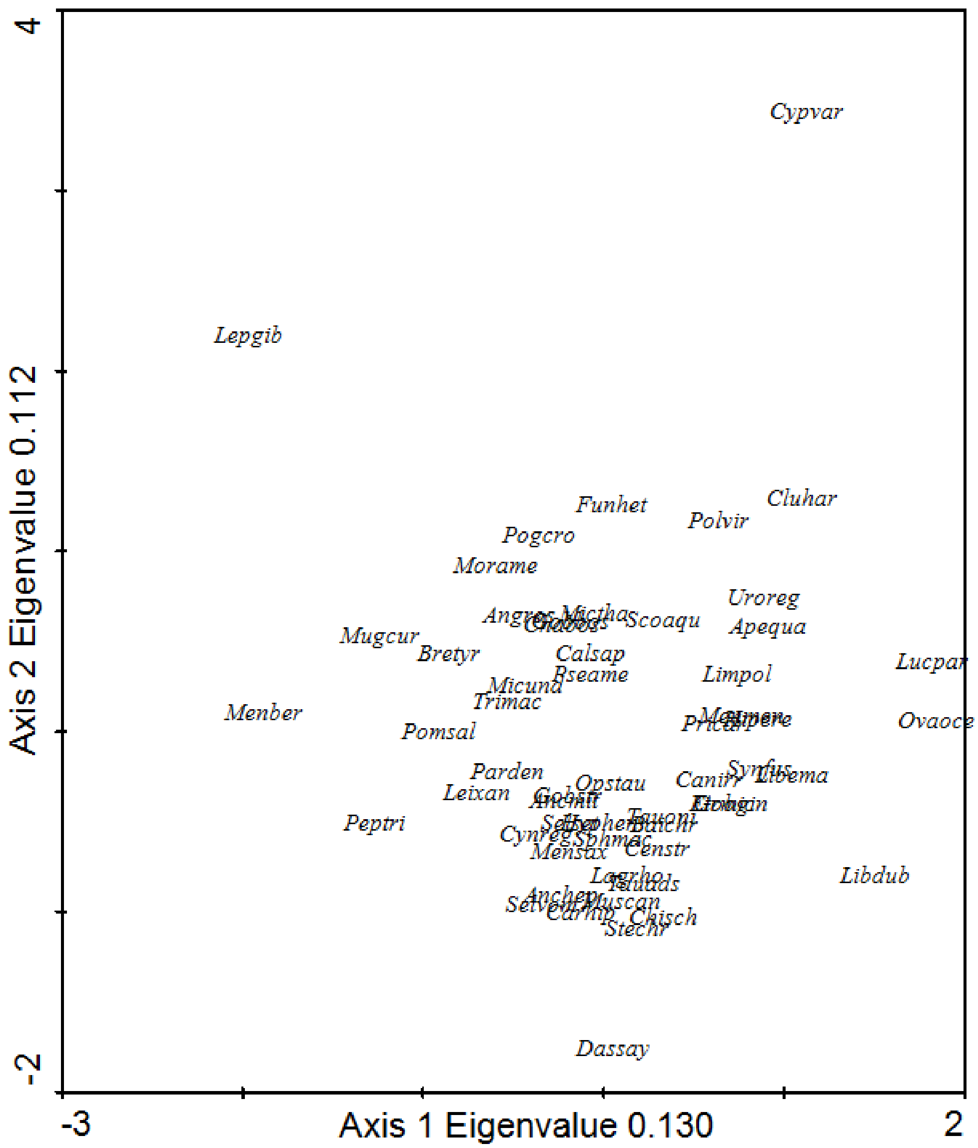


Figure 54. CCA scatter plot of species (fish and crabs) from Barnegat Bay, all years. This plot is in the same coenospace as samples and environmental variables in Figure 44 and 45, but is separated for legibility. Species are coded as the first three letters of their Generic name and the first three letters of their specific name.

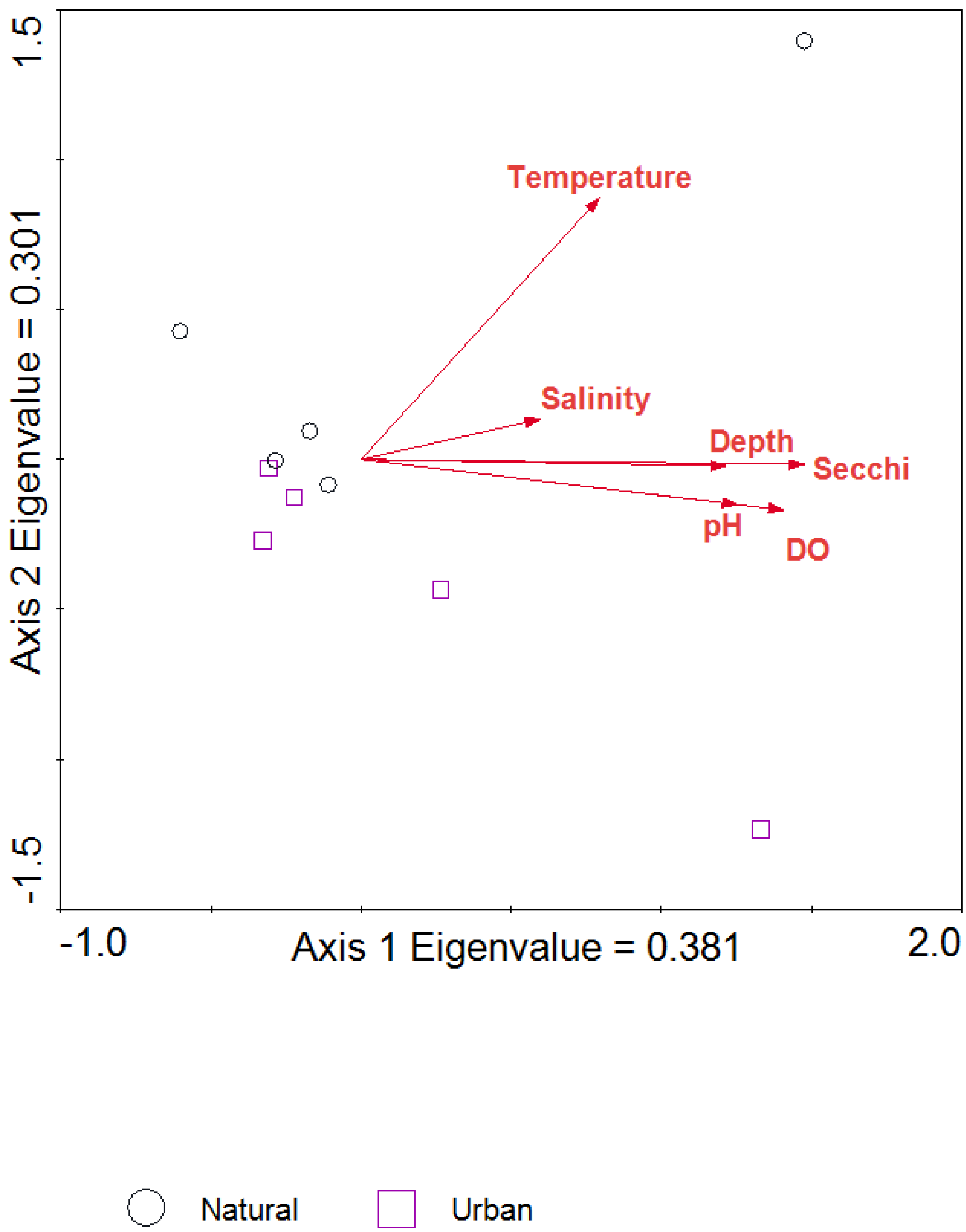


Figure 55. CCA biplot (samples and environmental factors) of fish assemblage from 10 creek sites (two in each duster) from Barnegat Bay, all months, all years amalgamated.

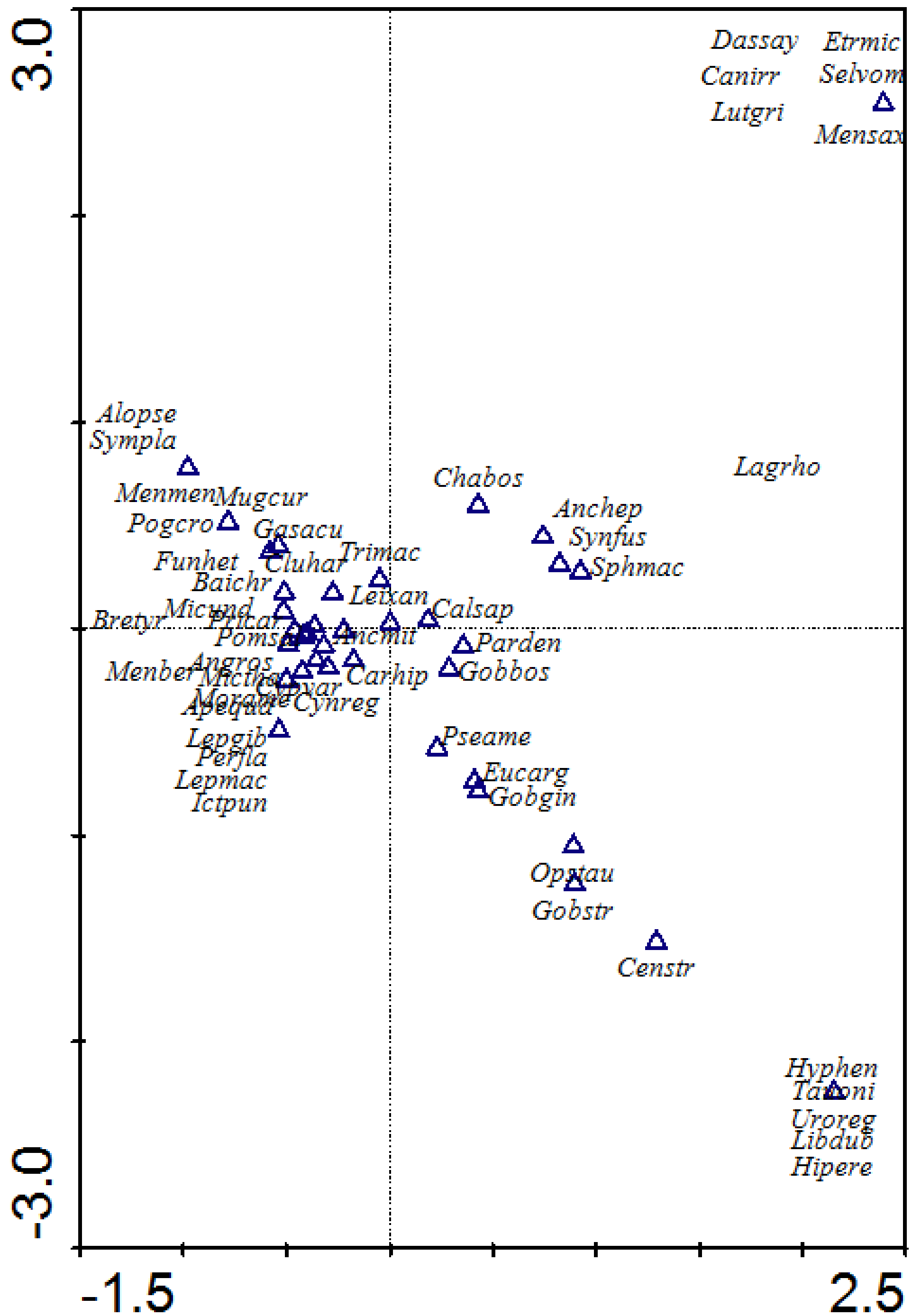


Figure 56. CCA scatter plot of species from 10 creek sites in Barnegat Bay, all months and years amalgamated. This plot is in the same coenospace as samples and environmental variables in Figure 46 and 45, but is separated for legibility. Species are coded as the first three letters of their Generic name and the first three letters of their specific name. Species names are dithered around their centroids (triangles) for legibility.

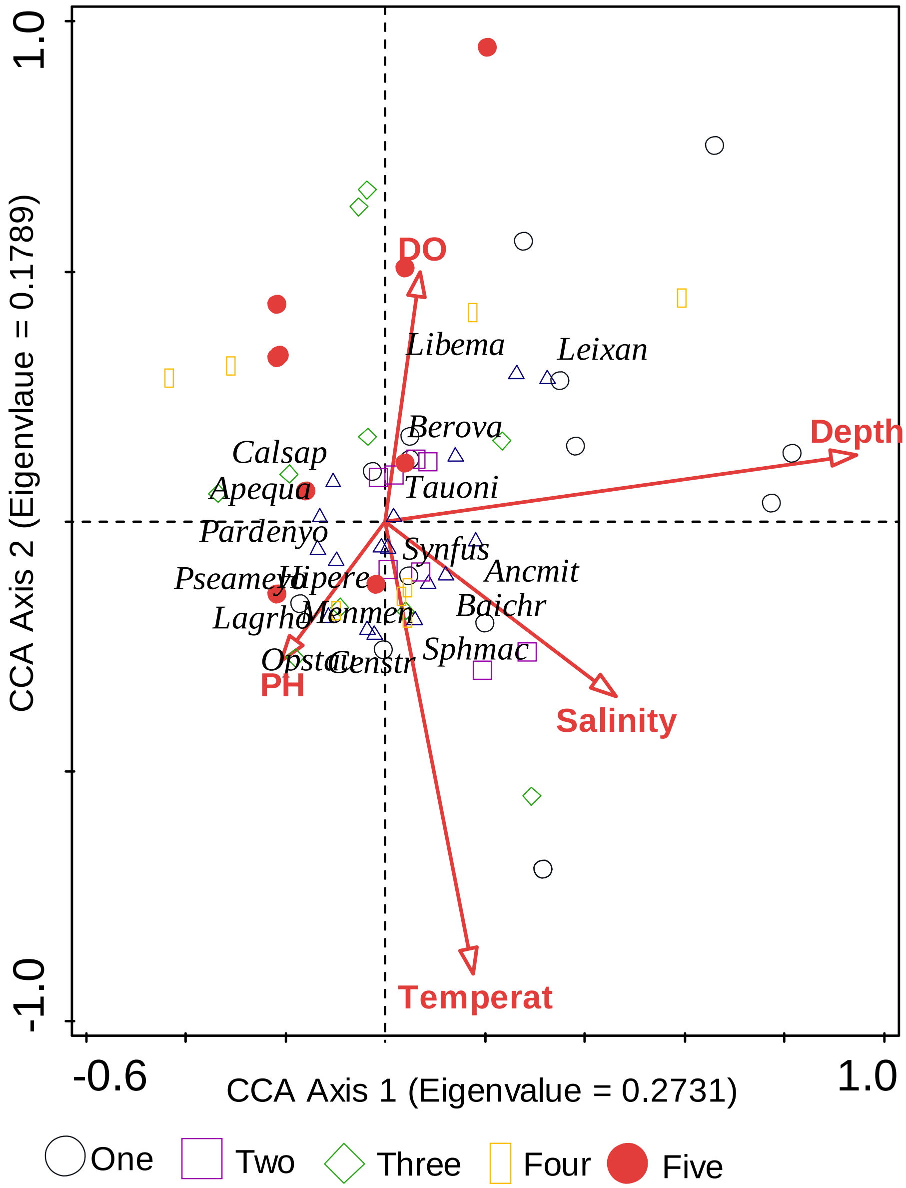


Figure 57. Tri-plot representation of the distribution of samples (geometric symbols) across physical/chemical gradients (arrows pointing in direction of increasing values) and species (text), on the first two axes from a canonical correspondence analysis on species composition and environmental data collected from submerged aquatic vegetation locations in Barnegat Bay in 2012. Environmental vectors include temperature (T), salinity (S), dissolved oxygen (DO), and pH. Samples symbols are categorized by which cluster along the urbanization gradient they belonged to (see Figure 1 for definition of clusters, but 5=most urbanized and 1=least urbanized).

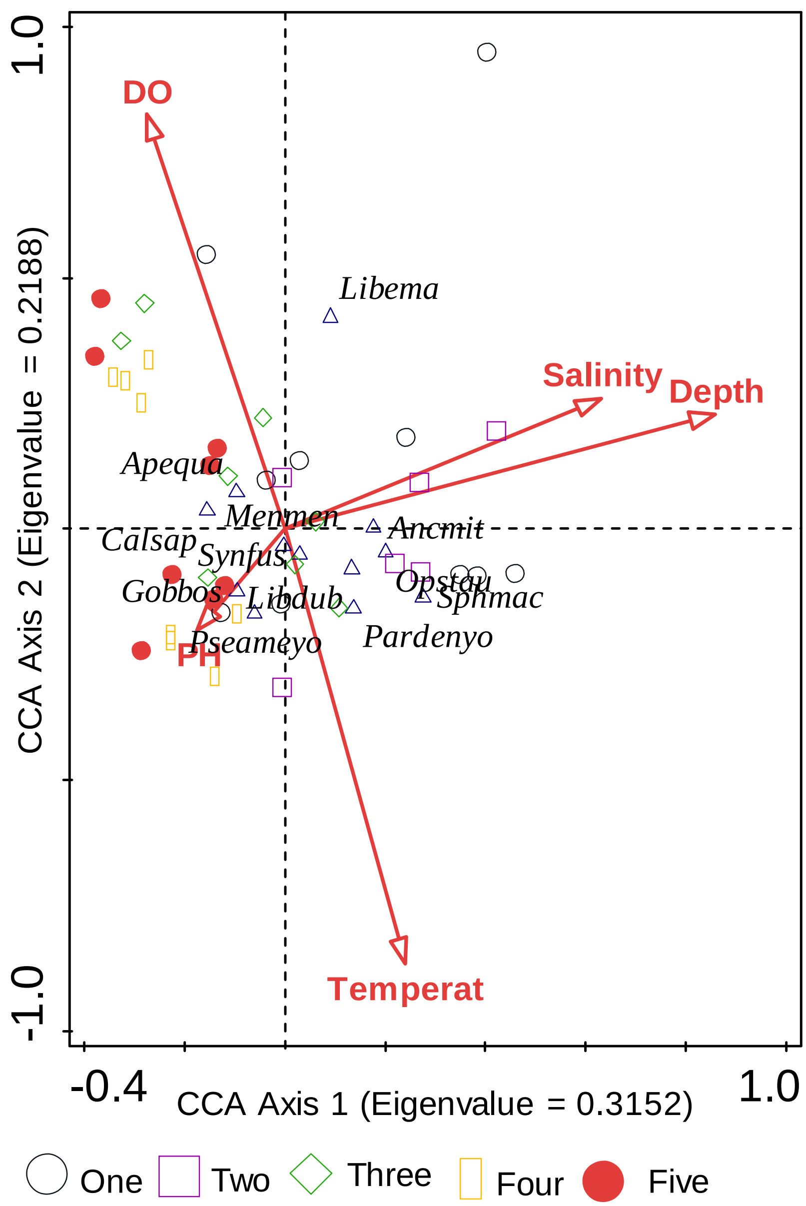


Figure 58. Tri-plot representation of the distribution of samples (geometric symbols) across physical/chemical gradients (arrows pointing in direction of increasing values) and species (text), on the first two axes from a canonical correspondence analysis on species composition and environmental data collected from submerged aquatic vegetation locations in Barnegat Bay in 2013. Environmental vectors include temperature (T), salinity (S), dissolved oxygen (DO), and pH. Samples symbols are categorized by which cluster along the urbanization gradient they belonged to (see Figure 1 for definition of clusters, but 5=most urbanized and 1=least urbanized).

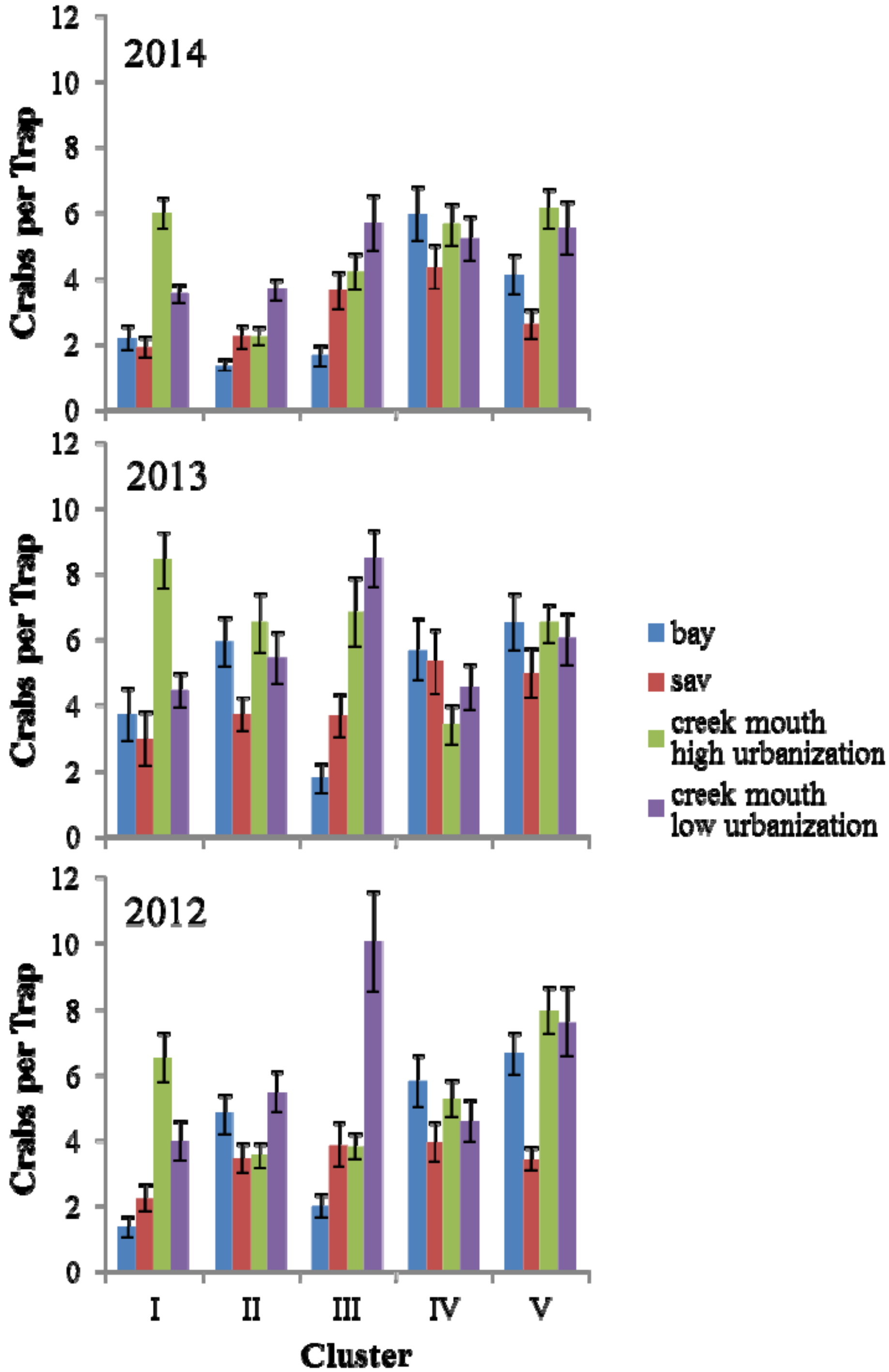


Figure 59. Average (± 1 SE) blue crabs per trap deployed in each of four habitats at each cluster in each year of the study (May-August combined). The numbers above the bars indicate the number of crabs captured per cluster.

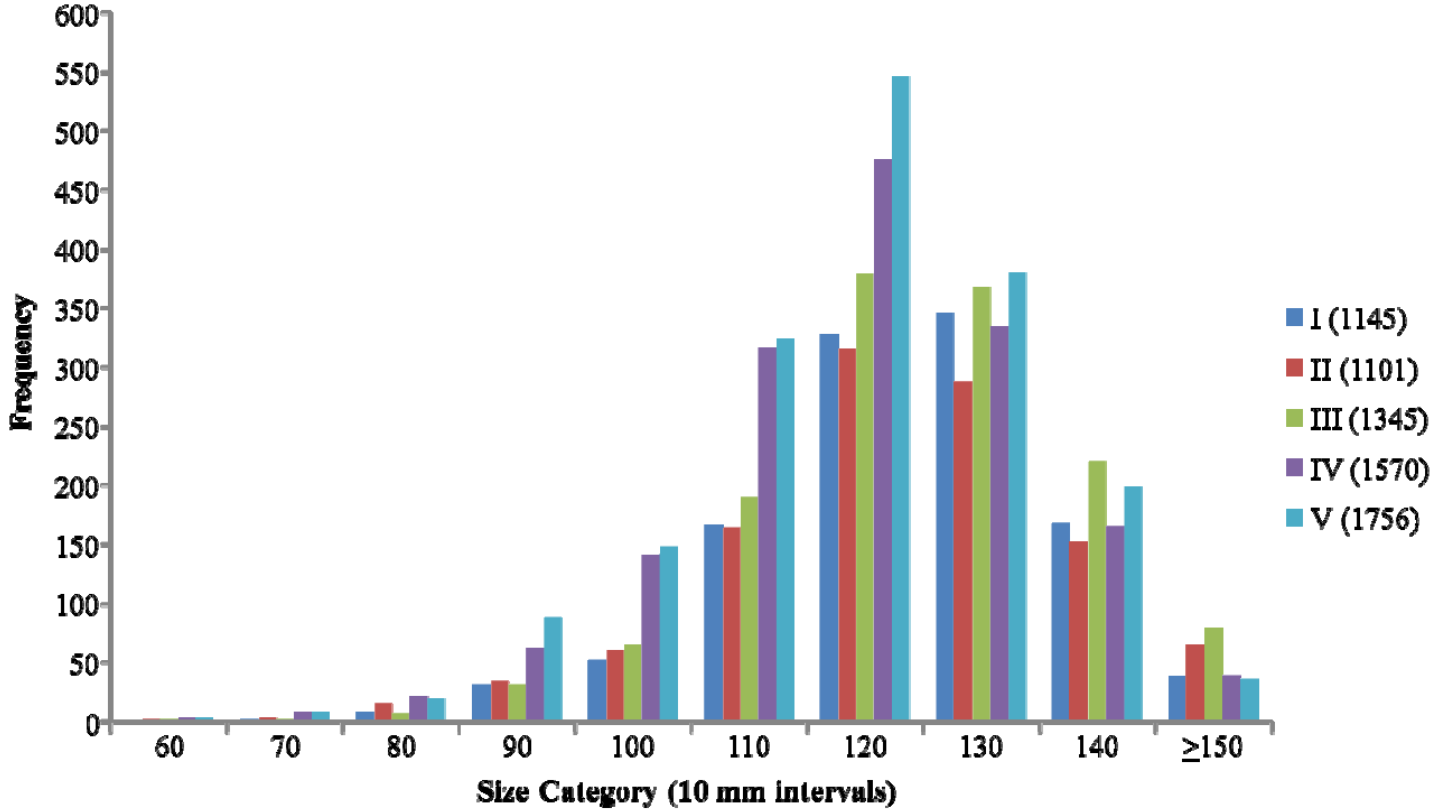


Figure 60. Annual (May-August in each year combined) size frequency distributions of blue crabs from traps deployed in clusters (habitats combined). Sample sizes for each year are included.

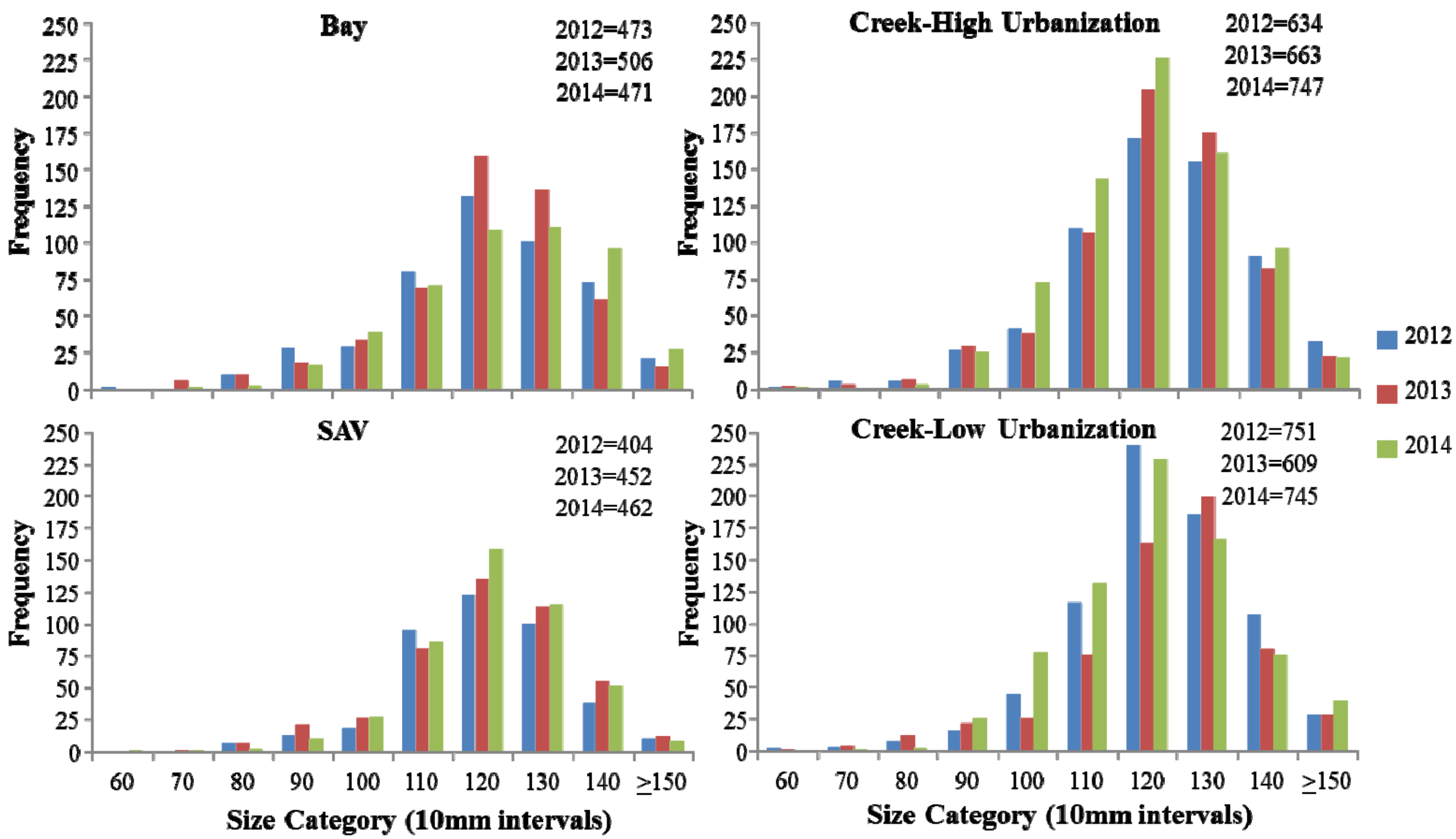


Figure 61. Annual (May-August in each year combined) size frequency distributions of blue crabs from traps deployed in four habitats (clusters combined). Sample sizes for each year are included.

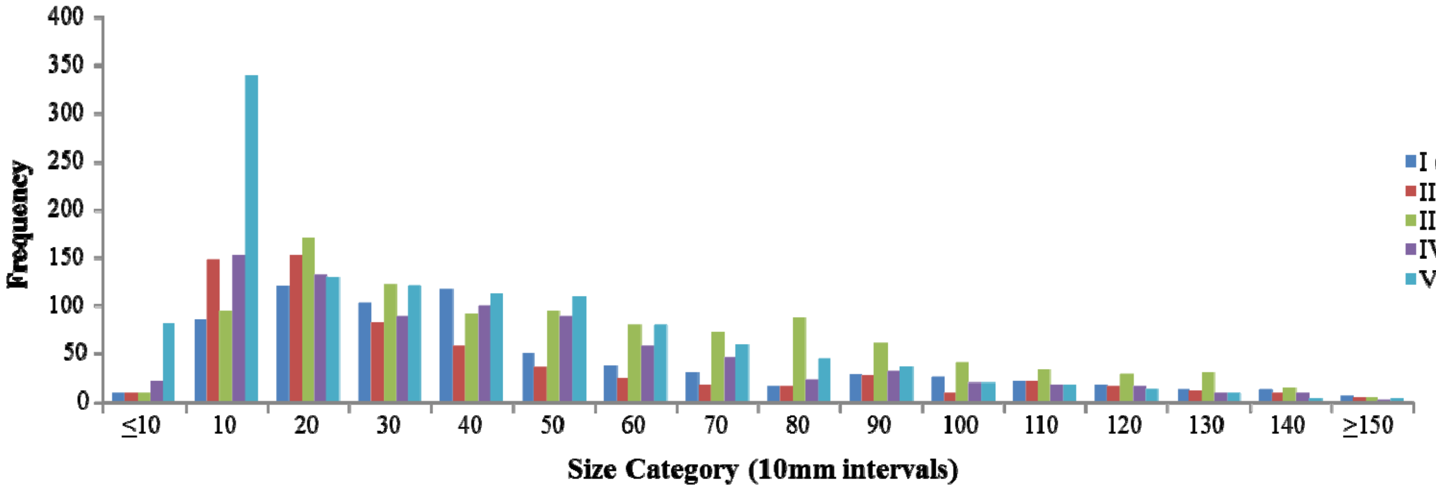


Figure 62. Size frequency distributions of blue crabs captured by trawl in each cluster (June, August and October, 2012-2014), habitats combined. Sample sizes for each cluster are also provided.

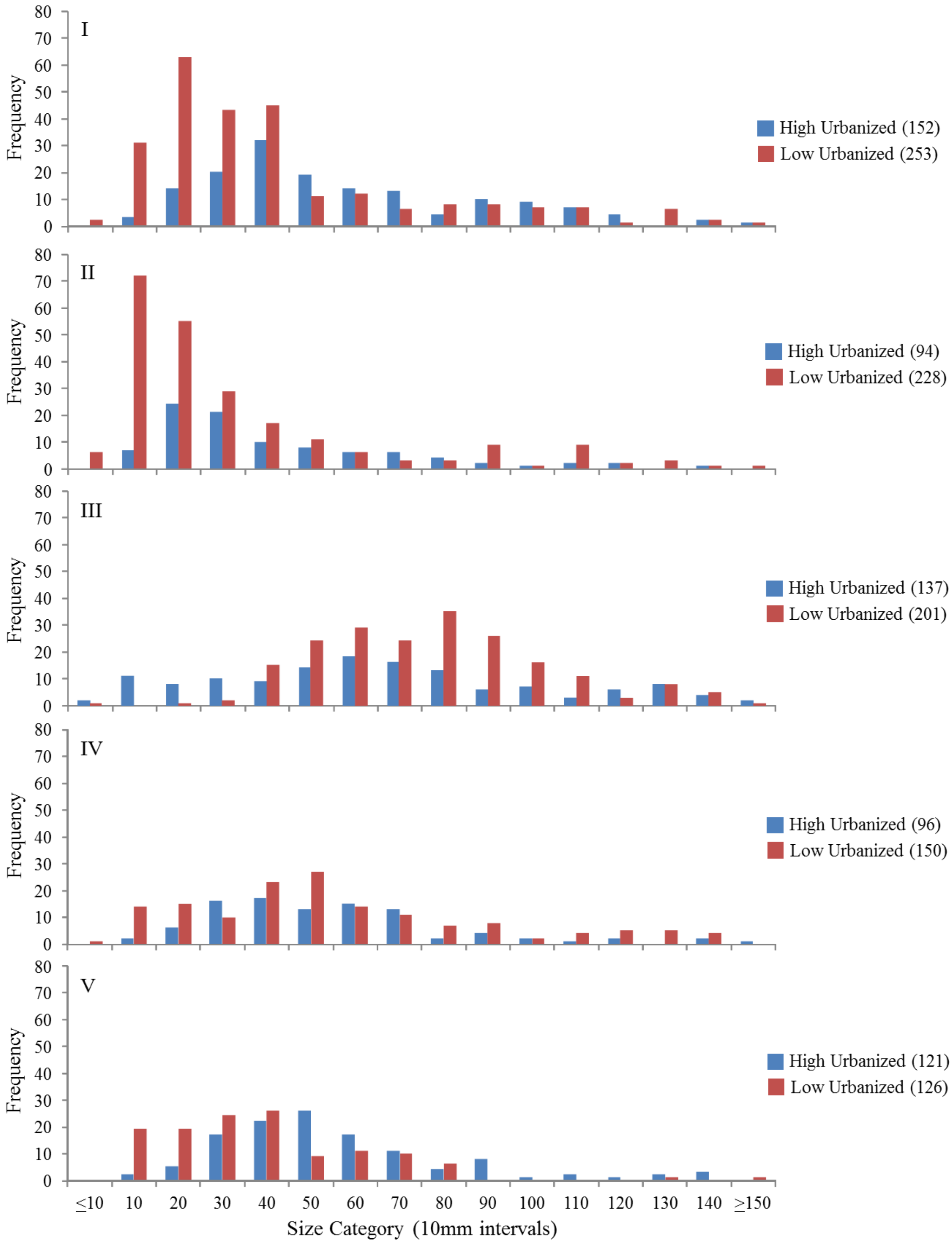


Figure 63. Size frequency distributions of blue crabs captured by trawl in upper creek habitats differing in the extent of urbanization in each cluster (June, August and October, 2012-2014). Sample sizes for each creek are also provided.

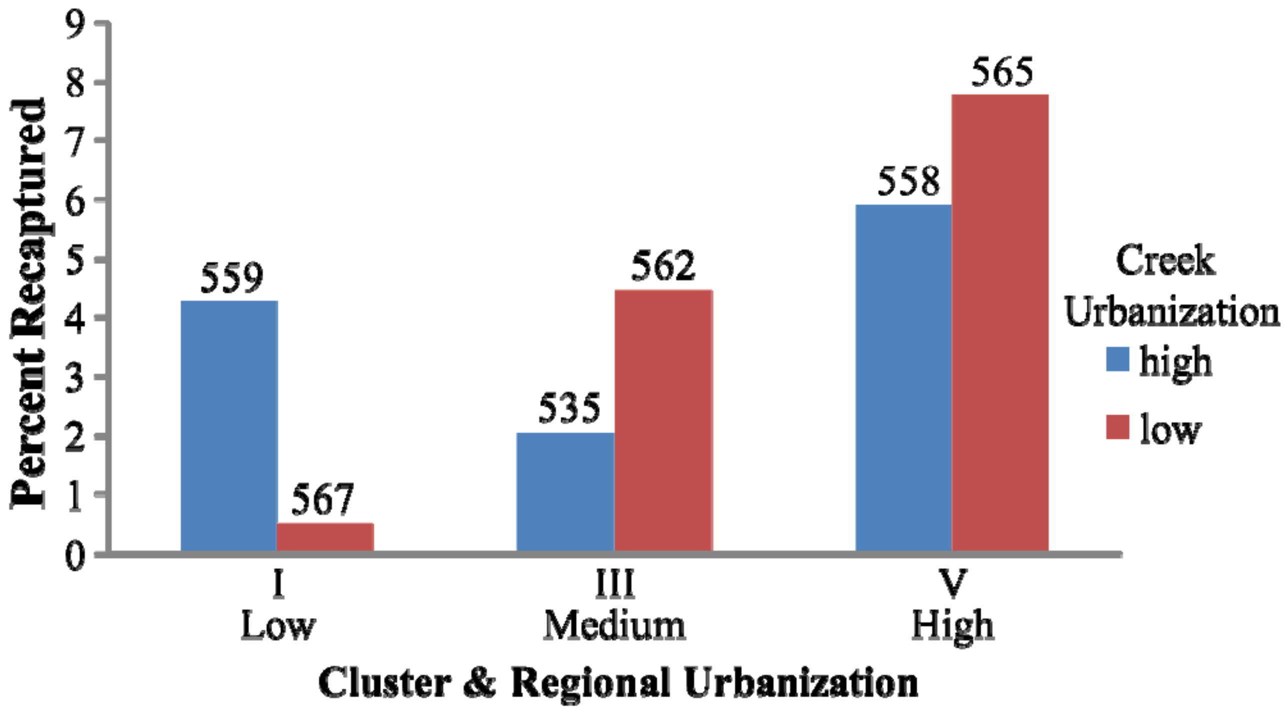


Figure 64. Percent of recaptured crabs according to the cluster (regional urbanization gradient) and creek type (local urbanization) from which they were released (2012-2014 combined). The numbers above each bar indicate the number of crabs tagged at each creek.

Appendix Table 1. Historical data from Barnegat Bay based on review of the available unpublished (grey) literature for both electronic and hardcopy formats. All of these are available at the Rutgers University Marine Field Station. Compiled up to October 2013.

Anonymous. 1997. Final Report: Submitted to the Trust for Public Land for the Habitat Research Component for the Barnegat Bay Initiative. Rutgers University. New Brunswick, New Jersey.

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Blanchard, III, P. P. 1997. Beyond the Century Plan: Biological Studies and Land Conservation of the Barnegat Bay Watershed. Ed. J. Courtmanche. The Trust for Public Land. Morristown, New Jersey.

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Gallagher, PE, M.P. (VP License Renewal Projects, AmerGen, Kennet Square, PA). Letter to: Mr. Mauriello. Letter CC to: Micai, T. (Director, Division of Land Use Regulation, DEP, Trenton, NJ). 2007 October 23. 9 leaves. Electronic copy located at RUMFS, Tuckerton, NJ, T:\! ! ! PROPOSAL FOLDER ! ! !\DEP Barnegat Bay Project\Historical Data.

Gallagher, PE, M.P. (VP License Renewal Projects, AmerGen, Kennet Square, PA). Letter to: Micai, T. (Director, Division of Land Use Regulation, DEP, Trenton, NJ). 2007 October 30. 26 leaves. Electronic copy located at RUMFS, Tuckerton, NJ, T:\! ! ! PROPOSAL FOLDER ! ! !\DEP Barnegat Bay Project\Historical Data.

Hoffman, H. W., R. P. Smith, and P. H. Sandine. May 1977. Passage of Entrained Plankton Down the Discharge Canal. Ichthyological Associates, Inc. Preliminary Final Report of Ecological Studies for the Oyster Creek Generating Station September 1975-August 1976. Volume Two. Part One. Plankton. Ithaca, New York. pp. 27-36.

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Appendix Table 2. Historical sources for larval fish sampling in Barnegat Bay associated with Oyster Creek Nuclear Generating Station (OCNGS) monitoring. See Appendix Table 1 that includes published papers.

Data Sources/Location	See Appendix Figure	Gear	No. of Stations	Duration	Frequency	No. of Samples	Day/ Night	Length Data	Sp. Comp.	Source
Outside Creek Mouth Stations										
01, 02, 03, 18, 19, 20, 21, 23	1	20 cm bongo sampler	8	Sept. - Dec. 1975	Monthly	---	---	N	N	Smith, R. P. et al. February 1976a.
01, 03 ,04 ,17 ,18 ,19 ,21 ,23	1	20 cm bongo sampler	8	Jan. - April 1976	Monthly	---	---	N	N	Smith, R. P. et al. June 1976a.
01, 02 , 03, 18, 19, 20, 21, 23 01, 03 , 04, 17, 18 or 20, 19, 21, 23	1	20 cm bongo sampler	8	Sept. 1975 - Aug. 1976	Monthly Sept, Nov, Dec, Feb; twice monthly Oct, Mar - Aug	---	---	N	N	Smith, R. P., P. H. Sandine, and H. W. Hoffman. October 1977.
01, 02 , 03, 18, 19, 20, 21, 23 01, 03 , 04, 17, 18 or 20, 19, 21, 23	1	20 cm bongo sampler	8	Sept. 1975 - Aug. 1976	Monthly Sept, Nov, Dec, Feb; twice monthly Oct, Mar - Aug	---	---	N	N	Smith, R. P., P. H. Sandine, and H. W. Hoffman. May 1977.
17 and 19, 04 and 03	1	20 cm bongo sampler	4	June - Aug. 1976	3 and 29 June, 28 July, and 23 Aug.	32	---	N	N	Tatham, T. R. October 1977.
17 and 19, 04 and 03	1	20 cm bongo sampler	4	June - Aug. 1976	3 and 29 June, 28 July, and 23 Aug.	32	---	N	N	Tatham, T. R. May 1977.
Inside Oyster Creek and Forked River										
Sta. 50, 30, 15, 45, 46, 6	1, 2	20 cm bongo sampler	6	March 1976 - March 1977	Monthly	178	---	N	N	Sandine, P. H. June 1977a.
Sta. 50, 30, 14, 45, 46, 6	2	20 cm bongo sampler	6	March 1976 -	Once monthly	72*	---	N	N	Smith, R. P. and P. H. Sandine. December 1978.

				March 1977						
Sta. 50, 30, 14, 45, 46, 6	2	20 cm bongo sampler	6	March 1976 - March 1977	Once monthly	72*	---	N	N	Smith, R. P. and P. H. Sandine. November 1978.
Oyster Creek Nuclear Generating Station										
condenser intake/discharge (sta.07/11) , discharge canal (sta.14-17), thermal plume (sta.19)	1, 3	36 and 20cm bongo samplers	6	Sept. - Dec. 1975	Monthly	48*	---	N	N	Smith, R. P. et al. February 1976c.
condenser intake/discharge (sta.07/11) , discharge canal (sta.14-17), thermal plume (sta.19)	1, 3	36 and 20cm bongo samplers	6	11, 18, 25 March 1976	Weekly	36*	---	N	N	Smith, R. P. et al. June 1976c.
condenser intake/discharge (sta.07/11) , discharge canal (sta.14-17), thermal plume (sta.19)	1, 3	20 cm bongo sampler	7	Sept. - Dec. 1975; 11 March - 2 Sept. 1976	Monthly; Weekly	---	Both	N	N	Hoffman, H. W., R. P. Smith, and P. H. Sandine. October 1977.
condenser intake/discharge (sta.07/11) , discharge canal (sta.14-17), thermal plume (sta.19)	1, 3	20 cm bongo sampler	7	Sept. - Dec. 1975; 11 March - 2 Sept. 1976	Monthly; Weekly	---	Both	N	N	Hoffman, H. W., R. P. Smith, and P. H. Sandine. May 1977.
condenser intake/discharge (sta.07/11) and discharge intake/ discharge (sta.12/13)	3	36 cm bongo sampler	4	Sept. - Dec. 1975	Sept. twice weekly and 24 hr biweekly; Oct.-Dec. biweekly and 24hr monthly	---	Both	N	N	Smith, R. P. et al. February 1976b.
condenser intake/discharge	3	36 cm bongo sampler	4	Jan - 8 March	Jan/Feb biweekly and	---	Both	N	N	Smith, R. P. et al. June 1976b.

(sta.07/11) and discharge intake/ discharge (sta.12/13)				1976	24hr monthly; March/April twice weekly and 24hr biweekly					
condenser intake/discharge (sta.07/11) and discharge intake/ discharge (sta.12/13)	3	36 cm bongo sampler	4	Sept. 1975 - Aug. 1976	Twice weekly, then once bi-weekly and 24 hr monthly	---	Both	N	N	Sandine, P. H., K. A. Tighe, and H. W. Hoffman. October 1977.
condenser intake/discharge (sta.07/11) and discharge intake/ discharge (sta.12/13)	3	36 cm bongo sampler	4	Sept 1975. - Aug. 1976	Sept. twice weekly and 24 hr biweekly; Oct.-Feb. biweekly and 24hr monthly	---	Both	N	N	Sandine, P. H., K. A. Tighe, and H. W. Hoffman. May 1977.
condenser intake/discharge (sta.07/11) and discharge intake/ discharge (sta.12/13)	3	36 cm bongo sampler	4	Sept. 1976 - Feb. 1977	Sept/Oct twice weekly and 24hr biweekly, Nov-Feb biweekly and 24hr monthly	212	Both	N	N	Sandine, P. H. et al. June 1977.
condenser intake/discharge (sta.07/11)	3	36 cm bongo sampler	2	Sept. 1976 - Aug. 1977	Sept, Oct, March-Aug twice weekly and 24 hr bi-weekly; Nov-Feb biweekly and 24hr monthly	483	Both	N	N	Sandine, P. H., R. P. Smith, and F. A. Swiecicki. December 1978.
condenser intake/discharge (sta.07/11)	3	36 cm bongo sampler	2	Sept. 1976 - Aug. 1977	Sept, Oct, March-Aug twice weekly and 24 hr bi-weekly; Nov-	483	Both	N	N	Sandine, P. H., R. P. Smith, and F. A. Swiecicki. November 1978.

					Feb biweekly and 24hr monthly					
condenser intake/discharge (sta.07/11)	3	36 cm bongo sampler	2	Sept. 1977 - Aug. 1978	Weekly, 24 hr monthly	352	Both	N	Y	Miller, F. C. and K. A. Tighe. April 1979.
condenser intake/discharge (sta.07/11)	3	36 cm bongo sampler	2	Sept. 1977 - Aug. 1978	Weekly, 24 hr monthly	352	Both	N	Y	Miller, F. C. and K. A. Tighe. March 1979.
condenser intake/discharge (sta.07/11)	3	36 cm bongo sampler	2	1 Sept. 1977 - 29 March 1978	Weekly, 24 hr monthly	208	Both	N	N	Smith, R. P. and F. A. Swiecicki. January 1979.
condenser intake/discharge (sta.07/11)	3	36 cm bongo sampler	2	5 Sept. - 26 March 1979	Weekly, 24 hr monthly	108*	Both	N	N	Ichthyological Associates, Inc. January 1979.
condenser intake/discharge (sta.07/11)	3	36 cm bongo sampler	2	4 Sept. - 29 Oct. 1979, 28 May - 27 Aug. 1980; Nov./Dec. 1979	Weekly; Biweekly, 24hr monthly	172*	Both	N	Y	Ecological Analysts, Inc. 1981
condenser intake/discharge (sta.07/11)	3	36 cm bongo sampler	2	1 Sept. 1980 - 31 Aug. 1981	weekly and 24 hr monthly; bi-weekly Nov/Dec	258	Both	N	Y	Ecological Analysts, Inc. 1982
condenser intake/discharge (sta.07/11)	3	barrel sampler	2	May - Aug. 1985	21 tows of 10 minutes	42*	---	N	N	EA Engineering, Science, and Technology, Inc. 1986
Open Bay										
Cedar Beach to Gulf Point:4 strata - North, Central, South, East 60	4 5	20 cm bongo sampler	12 random	March - April 1976	Twice in March, once	---	Day	N	N	Tighe, K. A., P. H. Sandine, and H. W. Hoffman. October 1977.

quadrates (0.4 x 0.4 km)			25 random	May - Aug. 1976	in April Monthly					
Cedar Beach to Gulf Point:4 strata - North, Central, South, East; 60 quadrates (0.4 x 0.4 km)	4 5	20 cm bongo sampler	12 random ; 25 random	March - April 1976; May - Aug. 1976	Twice in March, once in April; Monthly	---	Day	N	N	Tighe, K. A., P. H. Sandine, and H. W. Hoffman. October 1977.
Goodluck Point to Gulf Point 87 quadrates (0.4 x 0.4 km)	6	20 cm bongo sampler	50 random	March 1976 - March 1977	Once monthly	600*	---	N	N	Sandine, P. H. June 1977b.
Berkely Shores to Gulf Point 87 quadrates (0.4 x 0.4 km)	6	20 cm bongo sampler	50 random	March 1976 - March 1977	Once monthly	600*	---	N	N	Tighe, K. A. and P. H. Sandine. December 1978.
Berkely Shores to Gulf Point 87 quadrates (0.4 x 0.4 km)	6	20 cm bongo sampler	50 random	March 1976 - March 1977	Once monthly	600*	---	N	N	Tighe, K. A. and P. H. Sandine. November 1978.
Miscellaneous										
Based on previous data collections	---	---	---	Sept. 1975 - March 1977	---	---	---	N	N	Ichthyological Associates, Inc. January 1978.
Based on previous data collections	---	---	---	Sept. 1975 - Aug. 1981	---	---	Both	N	N	EA Engineering, Science, and Technology, Inc. 1986
						*Estimated numbers				

Notes:

- 24 hr sampling frequency is sampling every 6 hours over a period of 24 hours.
- All bongo samplers have 505 micron mesh size.

Appendix Table 3. Barnegat Bay/Little Egg Harbor historical list of publications on fishes from the Rutgers University Marine Field Station.

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Wilson, K.A, K.L. Heck, Jr. and K.W. Able. 1987. Juvenile blue crab, Callinectes sapidus, survival: an evaluation of eelgrass, Zostera marina, as refuge. Fish. Bull. 85(1):53-58.

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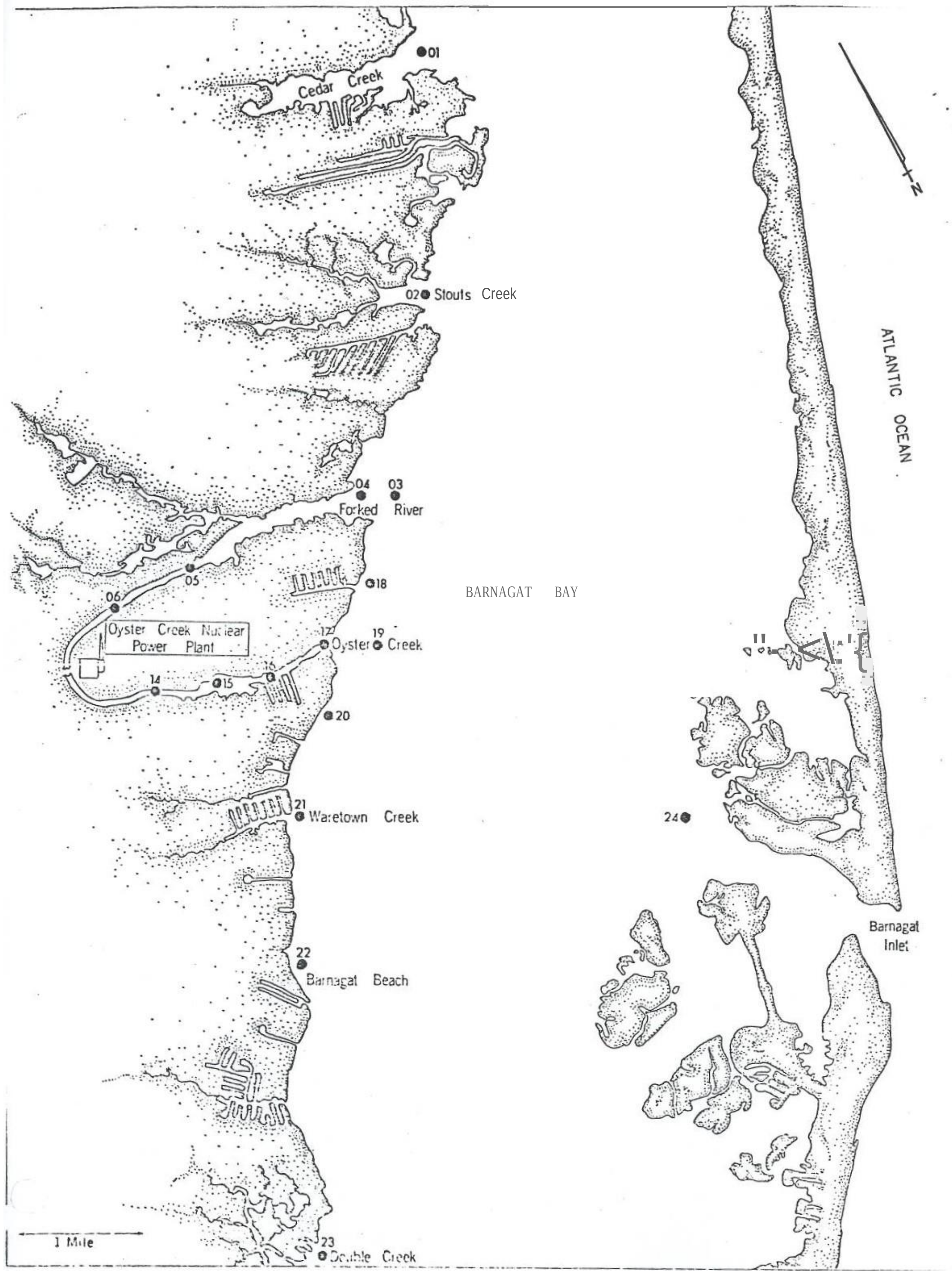
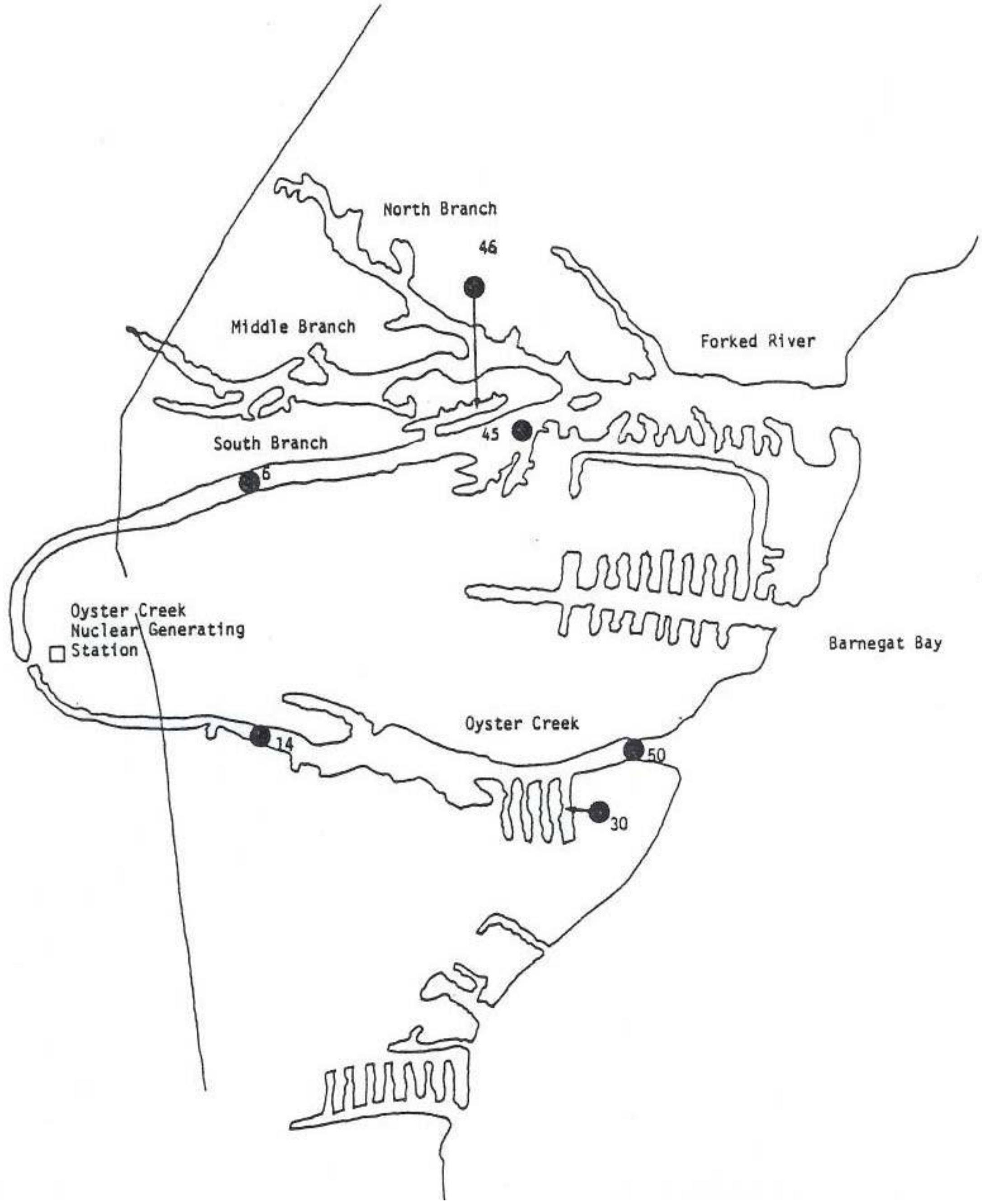
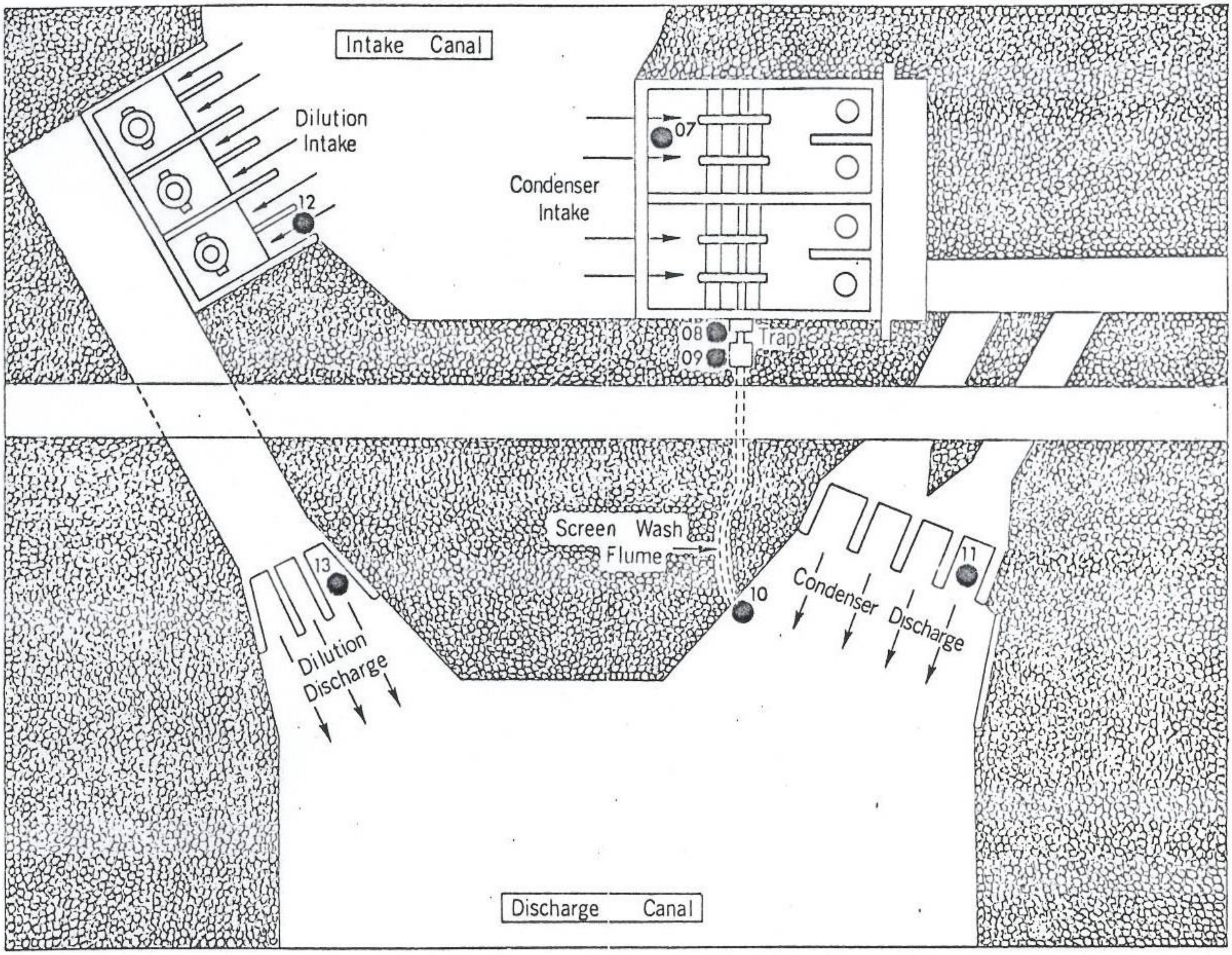


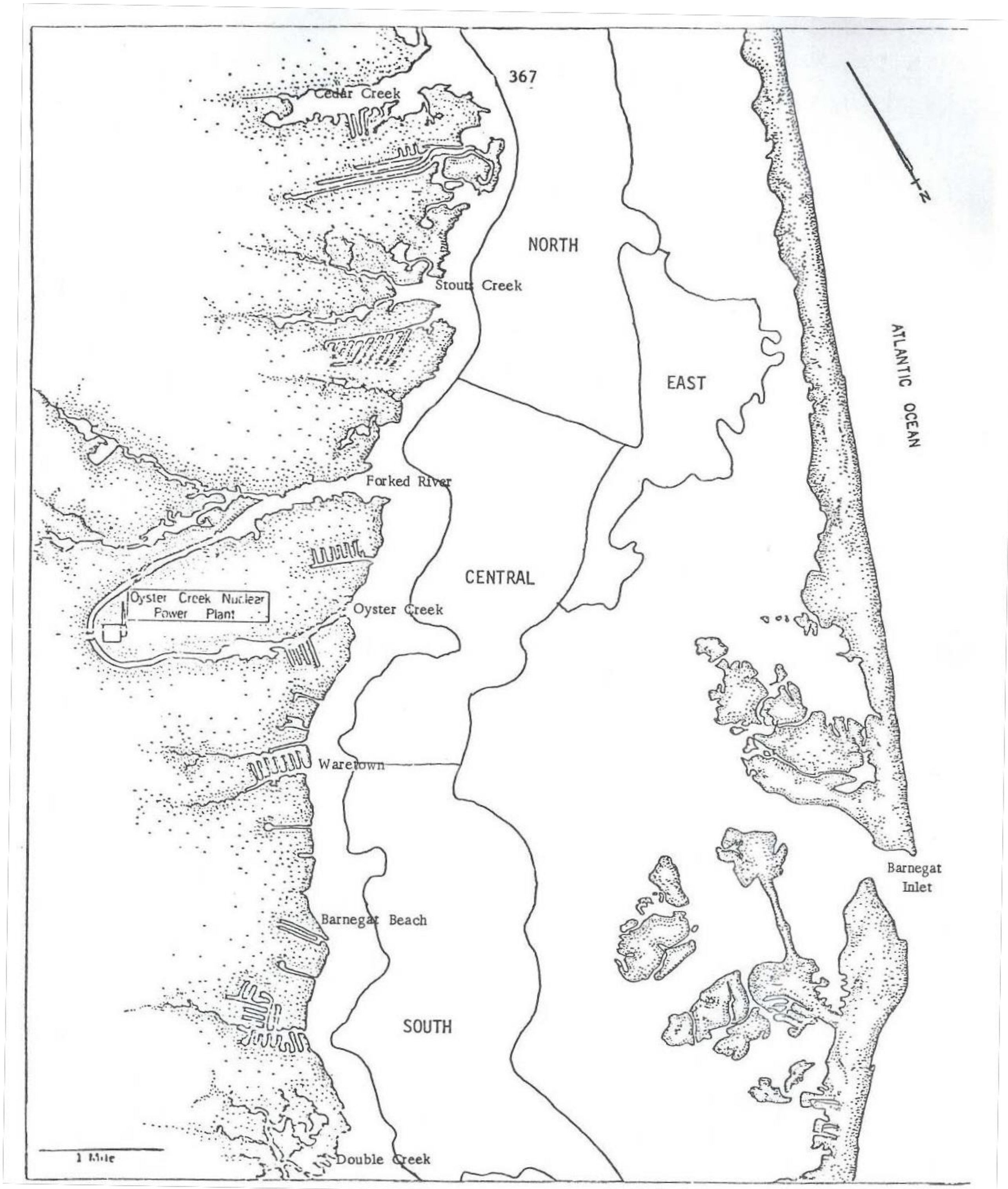
Appendix Figure 1. Sampling locations for biological collections taken for the Oyster Creek Nuclear Generating Station



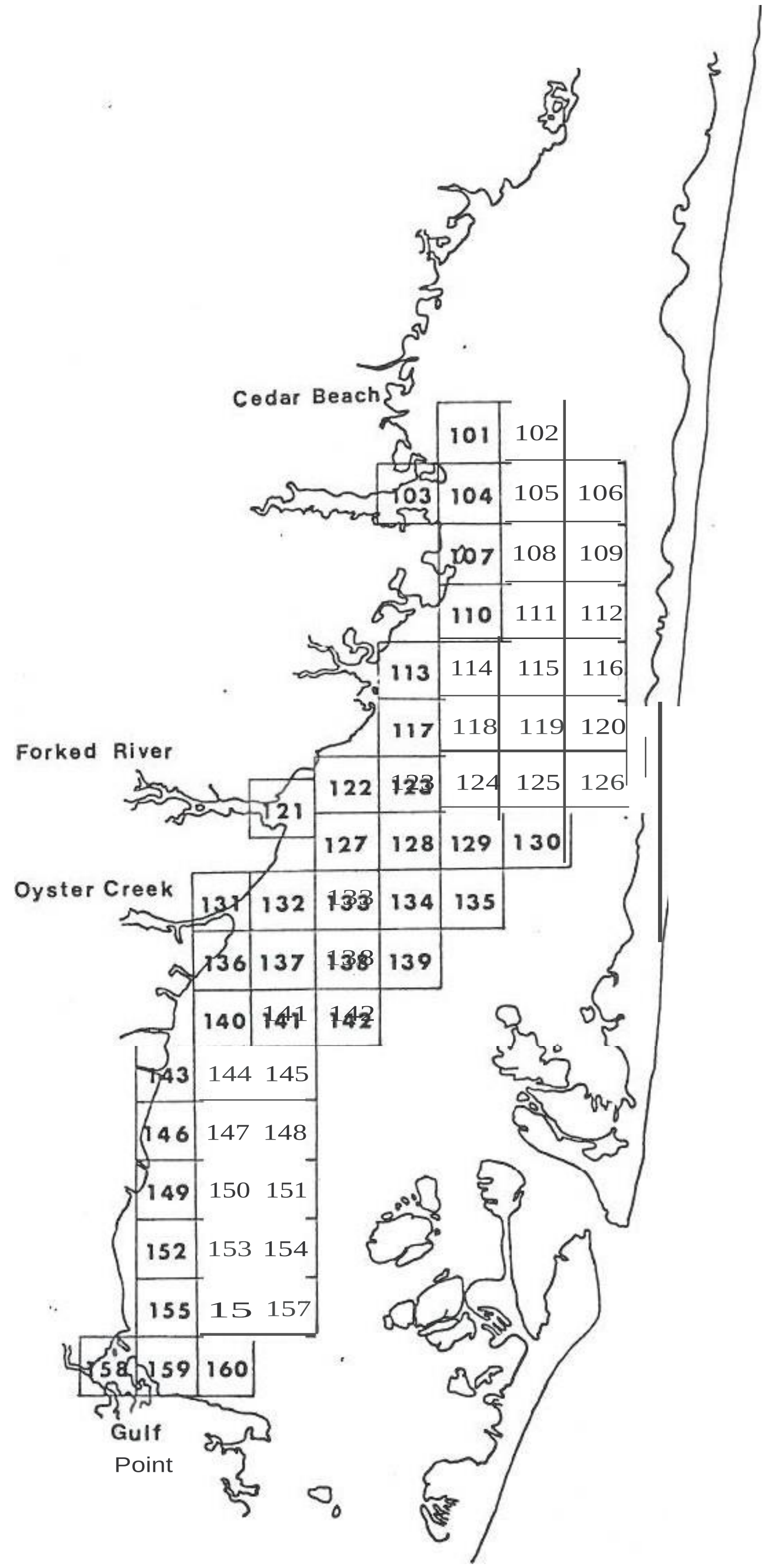
Appendix Figure 2. Sampling locations for ichthyoplankton collections for Oyster Creek Nuclear Generating Station thermal effects studies.



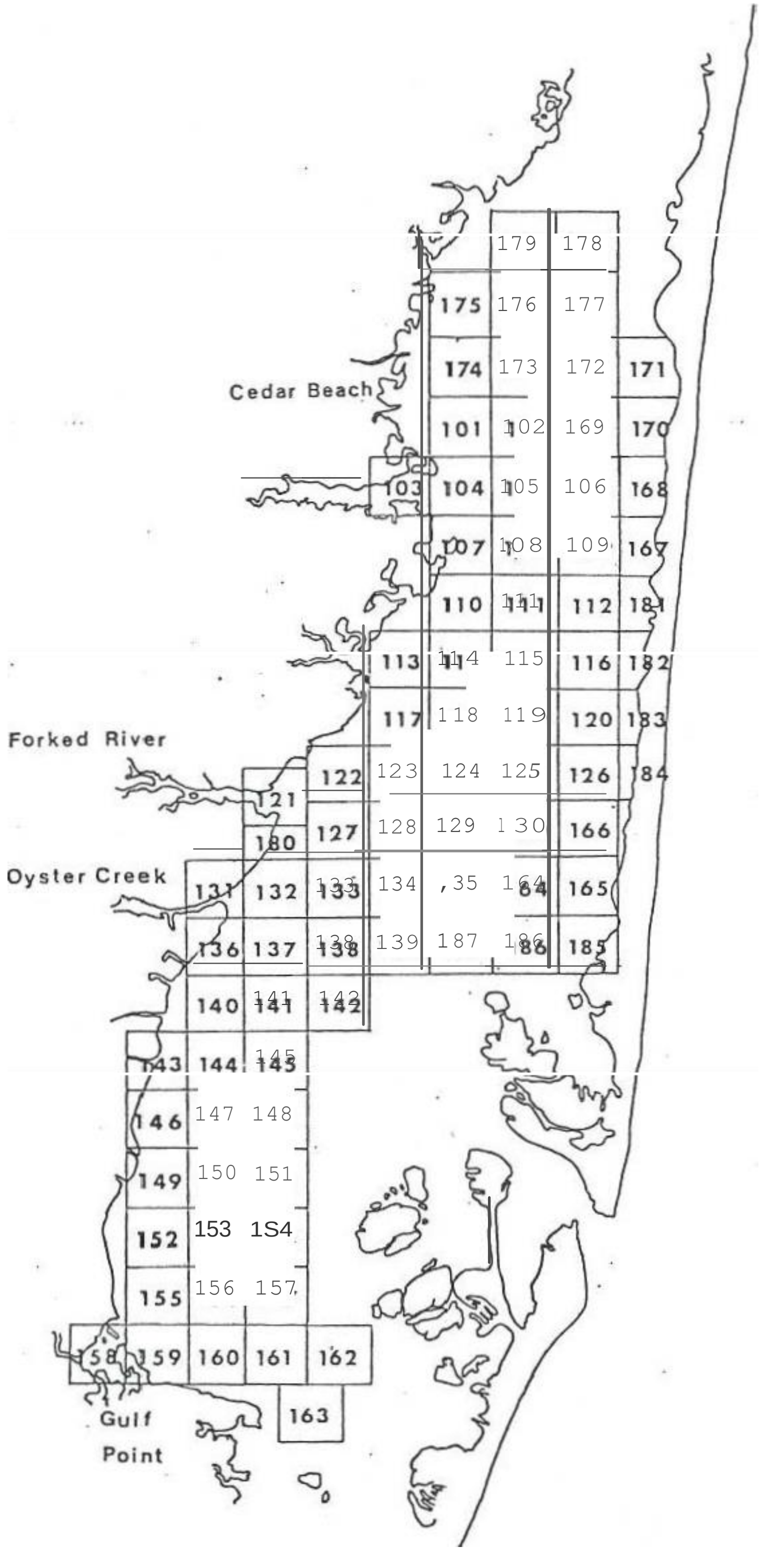
Appendix Figure 3. Sampling locations (●) for biological collections at Oyster Creek Nuclear Generating Station.



Appendix Figure 4. Sampling strata for ichthyoplankton population studies in Barnegat Bay.



Appendix Figure 5. Quadrates sampled for ichthyoplankton population studies in Barnegat Bay.



Appendi x Figure 6. Quadrates used for ichthyoplankton population studies i n Barnegat Bay.