Barnegat Bay—Year 2

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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 Year One and Two 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 both 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. 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. 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faunal response over these decades suggest that some resident and cool-water migrant species are less abundant and have been replaced by warm-water migrants.

There were no obvious, consistent responses among locations along the urbanization gradient perhaps because this gradient co-varied with a salinity gradient. There was also no evident response at the small scale of urbanized vs. non-urbanized marsh creeks. These studies are continuing.

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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. 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 subestuary/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. *Morone saxatilis, Morone americana, Centropristis striata, Tautoga onitis*) and ecological (e.g. *Menidia menidia, Anchoa mitchilli, Brevoortia tyrannus* and other Clupeids, *Ammodytes sp*.) importance. This sampling also included species known to be in decline (e.g. *Pseudopleuronectes americanus, Clupiedae, Anguilla rostrata* and *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 2010) 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 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

The Barnegat Bay watershed (≈ 1,730 km^2) is dominated by shallow (< 2 m average depth), lagoon-type estuary (279 km^2) that stretches north-south for nearly 70 km (Kennish 2001). Exchange with the ocean takes place through Little Egg and Barnegat inlets and Pt. Pleasant Canal through the Manasquan River. Tidal flows are restricted by the shallow waters, extensive shoals and marsh islands near the inlets. The largest tidal exchange occurs through the larger (≈2.5 km wide) Little Egg Inlet. The smallest tidal exchange occurs through the Pt. Pleasant Canal.

Salinities in the bay range from ≈ 8-32 with the highest salinities at Little Egg and Barnegat inlets and the lowest at the western side of the bay near Tom's River and north (< 15) where the surface freshwater inflow is greatest. Water temperature ranges from ≈ -1.4 - 30°C with the highest temperature at the mouth of Oyster Creek due to the thermal discharge from the Oyster Creek Nuclear Generating Station (OCNGS). The circulation of the bay is largely (70% of subtidal motion) the result of coastal pumping (Chant 2001) while wind velocity and direction strongly influence the complex circulation.

To evaluate the impacts of urbanization within the bay, we selected five spatially discreet sample clusters (Table 1) along the north-south axis of the bay. The location of each cluster (Fig. 1) 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 Fig. 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 2). 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 2).

In order to evaluate the potential impact of urbanization, we first needed to understand the sources of larval, juvenile and adult fishes and crabs 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. These sampling locations occurred behind Little Egg Inlet in southern Barnegat Bay, Barnegat Inlet and Oyster Creek/Forked River (at the inflow and outflow sites of the power plant) in the central portion of the Bay, and the Pt. Pleasant Canal in the northern portion of the Bay.

Sampling Techniques

To determine the species composition and seasonal and annual variation in abundance and size of larval fish, these were sampled seasonally (spring, summer and fall) on night flood tides using plankton nets (1 m diameter mouth, 1.0 mm mesh, 3 tows on each date) (Table 3). For each plankton net sample, the water depth, surface water temperature, salinity, and dissolved oxygen content were recorded using a hand-held YSI meter.

To determine the temporal response of juvenile and adult fishes and blue crabs, each habitat/location was sampled seasonally (spring, summer and fall) during the daytime using otter trawl sampling techniques (Table 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 = *Zostera marina* and *Ruppia maritima*) and macroalgae (includes several species groups by tow and volume), was determined for each sample.

In order to determine spatial and temporal distribution of larger juvenile and adult fishes, 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.

Trap sampling for *Callinectes sapidus* occurred for three successive days in each month (May-August). Trap sampling effort mirrored the trawl sampling locations. Crab traps (2 per habitat, except upper creek habitats) were placed at the collecting sites 24 hours prior to sampling (to insure equal soak times among the sites) and baited daily (e.g., *Brevoortia tyrannus*). As part of a mark-recapture study during trap sampling, a day was designated for tagging crabs from each location. Once per month (June-August), a sample (66 crabs) of adult crabs was tagged and released at each creek mouth in the upper, central and southern areas of the Bay along the urban gradient (clusters V, III, and I). 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 (via increased human population size) 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 human urbanization gradient.

Sampling Effort

Data collection of larval (Table 3), juvenile and adult fishes, and blue crabs (Table 4 and 5) proceeded as planned during 2013. Collections (including otter trawl, gill net, and plankton net samplings) from 54 total sites were gathered during April, June, August and October sampling of fishes. This resulted in 492 otter trawl tows during the year that collected 4,676 fishes and 1,364 crabs (Table 4). Over the same period there were 146 gill net collections with 433 fishes and 81 crabs (Table 5). Larval fishes were collected and enumerated during April, June, August and October in 60 collections overall (Table 3). The three sampling gears comprehensively covered the size range of fish in a complementary fashion (Fig. 2).

Statistical Analysis of Species Composition Data

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 both the 2012 and 2013 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. 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. *Cynoscion regalis, 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 (2010) as shown in Table 6. 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 (eg. *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 *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. Ordinations 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 2013. There were no deviations from the approved QUAP.

Results and Discussion

Characterization of Habitats

The dominant structural habitat types in Barnegat Bay include beds of submerged aquatic vegetation (SAV) consisting of eelgrass (*Zostera marina*) and widgeongrass (*Ruppia maritima*) combined, or macroalgae of various types and marsh creeks (Table 2). 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.

SAV habitats, within otter trawl sampling locations, are most evident in the eastern portion of the bay (Fig. 3). 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 *Ulva lactuca* but (Fig. 4). 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 in Cluster 1 and in the upper bay in Cluster 5 in both years.

Characterization of Fishes and Crabs

The fish species composition from otter trawl tows in April, June, August and October was diverse and crabs varied by habitat in 2013 (Table 7). 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. Particular attention is focused on marsh creek habitats along the urbanization gradient (Fig. 1).

Larval Supply

The sources of larvae vary seasonally, in this temperate estuary (Able and Fahay 2010) and thus the fish supply may vary from year to year. 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. 5). While the flow rates at the OCNGS (In and Out) were high, due to the pumps that provided cooling water to the power plant, the larval fish densities had overlapping denisty values relative to the inlets and thoroughfares (Fig. 6). The species collected included residents, i.e. those that remain in the bay or come back into the bay to spawn (e.g. *Anchoa mitchilli, Gobiosoma bosc, Menidia menidia, Pseudopleuronectes americanus, Syngnathus fucsus*). Transient species included those spawned in the ocean and come into the bay from the ocean or adjacent estuaries were also frequently collected (e.g. *Anguilla rostrata, Bairdiella chrysoura, Clupea harengus, Paralichthys dentatus*) (Table 7). The source of larval supply varied between years and for some representative species (Fig. 7, 8). Some species are known to spawn in both the estuary and the ocean. The density for several species varied between years as for *A. mitchilli* (greater in 2013 at Barnegat Light, but greater in 2012 in remaining sites) and *P. americanus* (greater in 2013 at all sites). For *B. tyrannus* and *A. rostrata*, the year of greater abundance varied with each site. Some species were common at most sites (*A. mitchilli*).

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 entrance to the OCNGS. Some species had peak abundance at the OCNGS (*B. tyrannus*, *A. rostrata* which spawn in the ocean) or the lowest (*P. americanus*) which spawns in the estuary) values (Fig. 7,8). Those species which consistently occurred at the OCNGS included residents (e.g. *Gobiosoma bosc, Syngnathus fuscus, Menidia menidia*), which is not surprising. It is interesting that a number of species originating from spawning in the ocean also occurred consistently at OCNGS (e.g. *Anguilla rostrata, Brevoortia 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.

Juvenile and Adult Distribution

The juvenile fishes and *Callinectes sapidus* collected by otter trawl during 2013 (Table 8) 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. 9, 10). These general patterns, for these dominant species, also indicate that they occur across the major habitat types (Table 9). Species with higher abundances in the open bay, relative to other habitats, include *Anchoa* mitchilli and *Menidia* menidia. Those with highest abundances in SAV include *Apeltes quadracus, Pseudopleuronectes americanus, Syngnathus fuscus,* and *Callinectes sapidus* (also marsh creek – upper). Species with high values in marsh creeks include *Bairdiella chrysoura* (upper and mouth), *Brevoortia tyrannus* (upper), and *Gobiosoma bosc* (upper and mouth).

The abundance and distribution of *Paralichthys dentatus* had a clear seasonal pattern during 2013 (Fig. 11). 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 were dominated by *Brevoortia tyrannus*, *Mustelus canis*, and *Leiostomus xanthurus* and the crab *Callinectes sapidus* (Table 10). The spatial pattern of distribution of juveniles and adults varied between species (Fig. 12, 13). *Brevoortia tyrannus* were fairly evenly distributed across the clusters of sampling sites in the upper (Cluster 5), middle (Cluster 3), and lower (Cluster 1) bay. *Cynoscion regalis* occurred most consistently in the lower (Cluster 1), and middle (Cluster 3) and was least abundant in the upper (Cluster 5) bay. *Leiostomus 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 *Mustelus canis* which were found in proximity to the major inlets (Cluster 1 and 3) but not in the upper bay (Cluster 5). *Libinia emarginatum* was found primarily near Little Egg Inlet as was *Limulus polyphemus*. The species composition for crabs was relatively diverse and representative of Barnegat Bay with five species collected to date by otter trawl (Table 8).

During twelve days of trap sampling (3 days each in month May- August), 4,171 crabs were captured: 2,301 blue crabs (*Callinectes sapidus*), 1,269 spider crabs (*Libinia emarginata*), 552 long-nosed spider crabs (*Libinia dubia*), 40 green crabs (*Carcinus maenas*), and 9 rock crabs (*Cancer irroratus*). Blue crabs were fairly evenly distributed among the clusters (percent representation among clusters 17.6%-25.1%), both species of spider crabs predominated in cluster I (*L. dubia*-71.9%; *L. emarginata*-65.6%), green crabs were only captured in Cluster III and rock crabs were evenly distributed among Clusters I, III and IV (33% in each). These six species of crabs also showed relatively distinct distribution patterns among habitats. Blue crabs were evenly distributed among the habitats (percent representation among habitats 19.8%-30.6%), both species of spider crabs were predominantly in the bay habitat (*L. dubia*-45.3%; *L. emarginata*-61.5%), green crabs were primarily captured in SAV (90%), and rock crabs were primarily captured in the bay habitat (89.9%).

Response to Superstorm Sandy

The preliminary examination of fish abundance from 2012 and 2013, which largely corresponds to before and after Superstorm Sandy, suggests that the response varies with the index. 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 (Table 8). 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. 14). 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 (*Anchoa hepsetus, Anchoa mitchilli, Apeltes quadracus, Bairdiella chrysoura, Brevoortia tyrannus, Hippocampus erectus, Lagodon rhomboides, Leiostomus xanthurus,* and *Syngnathus fuscus*) were more abundant in 2012 than in 2013. Three other species (*Clupea harengus, Menidia menidia,* and *Pseudopleuronectes americanus*) were more abundant in 2013 than in 2012.

In analysis with PCA of the combined 2012 and 2013 trawl data set, the first and second principle components of the explained just 7% and 5% of the variation, respectively, in species composition. This indicates that no single species or group of species set a strong gradient in time or space. However, along the stronger of the two most important axes, crabs and cool water migrant fishes tended to separate from residents and warm water migrants, while the later further differentiated along the second eigenaxis (Figure 15). Samples from 2012 were commonly characterized by higher principle component scores for axes one and two, indicating that the species loading heavily on these two axes were found in higher abundance in 2012 than in 2013 (Figure 16). It is difficult to determine if these differences are due to Superstorm Sandy effect, or annual variation or some combination of both.

Trap sampling for blue crabs in 2012 occurred prior to Sandy whereas in 2013 trap sampling occurred after Sandy thus comparing these years represents one way of estimating the potential effects of Sandy. On average, 90% of blue crabs captured by trap are adults. The number of blue crabs captured by trap (2,301) in 2013 is very similar to the number captured by trap over the same time-period and sampling sites as 2012 (2,295) suggesting no obvious negative effects of hurricane Sandy on adult blue crab abundance. In contrast, the number of blue crabs captured in June and August by trawl in 2013 (701) is a 52% reduction over the same time-period and sampling sites as 2012 (1,473). On average, 90% of blue crabs captured by trawl are sub-adults (juveniles and pre-pubertal females), thus the trawl data suggest a potential negative effect of hurricane Sandy on juvenile blue crabs. Reductions in the number of juvenile blue crabs captured in 2013 were essentially bay-wide occurring in all clusters (63% in Cluster I, 56% in Cluster III, 46% in Cluster IV and 76% in Cluster V), except Cluster II (Manahawkin Bay) which experienced a 21% gain in juvenile blue crabs. Reductions in the number of juvenile blue crabs captured in 2013 occurred in all habitats (52% in bay, 71% in SAV, and 55% in creek mouths) except upper creeks which experienced an 8% gain in juvenile blue crabs. Those habitats experiencing reductions in the number of juvenile blue crabs in 2013, show a distinct lack of 10-30mm blue crabs (Fig. 16) particularly in June (rather than August). This suggests that Sandy had a negative impact on the over-wintering survival of blue crabs that recruited to the estuary in the late summer-early fall of 2012.

<u>Historical Comparison</u>

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 OCNGS. 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 11, Figure 17). Among resident species there were a similar number of species (20 early vs. 21 later). For Cool Water Migrants, there were also a similar number of species (10 vs. 11) with some decidedly less abundant in late collections (*Merluccius bilinearis*) and others which may have been common previously but not frequently collected in late collections (*Pollachius virens*, *Myoxocephalus aenaeus*, and *Ammodytes americanus*). Others may have become more abundant (*Morone saxatilis, Clupea harengus*). The most striking change is in the fishes that are Warm-Water Migrants. These include a large number of species which may have been present but not been documented while others may be the result of expanded occurrence (Table 7) with warmer temperatures in recent years (Able and Fahay 2010).

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. 21). 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 11) loaded heavily on the first axis and warm-water migrants loaded heavily on the second axis (Figure 19).

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. 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 11) separated out along the first canonical axis, which was defined by temperature and to a lesser extent dissolved oxygen (Fig. 20). 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. 21). 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. 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 2010).

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 course in the early reports (Table 12). 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 Atherinopsidae, Blennidae, and Gobiidae. Second, the difference in sampling gear between the early and later collections likely account for these and other differences (Table 12).

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 12). In almost every instance where a taxa is represented in both years of both the early and late collections, abundance is greater in the early collections. This is true for *Anchoa mitchilli*, *Atherinopsidae* (if we include all species), *Syngnathus fuscus*, *Tautoga onitis*, *Blennidae*, *Gobiidae*, *Trinectes maculatus* and *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

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. 22). 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, 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. 23). 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. 24). *Callinectes sapidus* and *Apeltes quadraticus* were more closely associated with the urban clusters while *Opsanus tau*, *Paralichthys dentatus*, and *Spheoroides maculatus* were more associated with the natural end of the gradient.

Species gradients in creek habitats were weaker than in SAV beds. There were no strong species drivers in 2012 along either of the first two canonical eigenaxes (Fig. 25). Of the physical/chemical variables, salinity varied most strongly and inversely with temperature on the first canonical axes while pH but also temperature and salinity covaried along the second canonical axis. Dissolved oxygen co-varied inversely with temperature and low oxygen samples, which could occur in any cluster, were typified by *Apeltes quadracus* and *Gobiosoma bosc*, while warm high oxygen samples were typified by *Lagodon rhomboides* and *Paralichthys dentatus. Pseudopleuronectes americanus* YOY were centrally distributed with respect to temperature but were found primarily in low salinity water along with *Micropogonius undulatus.* There was no recognizable difference in the spread or distribution of urban cluster categories, nor in the difference of “urbanized” or “non-urbanized” within the clusters.

There was also a lack of assemblage differentiation in 2013 in creeks, with no strong species drivers on either of the first two axes (Fig. 26). These axes were similar in their eigenvalue strengths near 15%. Temperature was strongly but inversely correlated with dissolved oxygen on the first canonical axis suggesting the threat of hypoxia development in summer, while salinity described an orthogonal gradient on axis 2. There was very weak separation of “urbanized’ and “un-urbanized” creeks within a cluster mostly along the first axis. For the most samples throughout the year, there was no separation of sites by urban cluster, but 3 samples from Cluster 5, the most urbanized, were distinctly different from all others along the first axis. These 3 were cold and high in dissolved oxygen.

Blue crab abundance varied among clusters and especially among habitats both within and among clusters (Fig. 27). The sex ratio of crabs was consistently male-biased and similar among the higher salinity clusters (2.6M:F, 3.5M:F, 2.5M:F in clusters I, II, and III respectively). However, as in 2012 and our other blue crab population studies in Barnegat Bay, the sex ratio becomes even more male-biased in lower salinity areas (6.0M:F and 5.1M:F in clusters IV and V respectively) (Fig. 28). Overall the size frequency distribution of blue crabs captured in traps was similar among the habitats: the mode at the low urbanized creek mouth was 130mm and 120mm at the other three habitats (Fig. 29). During four days of tagging crabs (1 day each in June and July; 2 days in August), a total of 1,188 crabs were tagged and released. To date, we have information on 40 recaptured crabs. There is a distinct regional urbanization effect on the number of recaptured crabs with an increasing number of recaptured crabs as the level of urbanization increases but only at low urbanized creeks (Fig. 30). In 2012, we also observed a greater effect of the regional urbanization gradient on recaptured crabs from the low urbanized creeks. This consistent pattern suggests that the fishing pressure in low urbanized creeks may better reflect the regional urbanization gradient unlike high urbanized creeks which may not vary in fishing pressure along the regional urbanization gradient. While overall recapture rates per cluster do not show a direct correlation with the regional urbanization gradient, the greatest recapture rates occur in the high urbanization zone of the bay (i.e., Cluster V).

Collaborations

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*). During 2013, abundance of sea nettles and ctenophores was measured during this 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 relatively undisturbed creeks in northern Barnegat Bay to further compare the effect of creek development on sea nettle abundance. In addition, comparison of three gears (trawl, seine and plankton net) was also conducted in the hopes of combining trawl, seine and plankton net data to provide a better understanding of sampling biases associated with these gears on gelatinous zooplankton in the bay.

This study is being advanced by RIOS summer intern project which is developing the techniques to determine the sex of adult *Chrysaora quinercirrha* (Jessica Gezymalla, Hiram College). During June, July and August of 2013 we continued to conduct histological analysis of sea nettle (19-109 mm in diameter) gonads (n = 140) towards two ends: (1) to determine if the historical technique for determining sex (gonad color) is accurate, and (2) to assess whether sea nettles are reproducing sexually or asexually in Barnegat Bay. The analysis thus far suggests that the ratio of males to females is close to 50:50, with slightly more males than females. All of the females we have analyzed are sexually mature, but very few of the males are. No fertilized eggs or planulae have been detected in any jellyfish. These preliminary results suggest that sea nettle reproduction in Barnegat Bay is primarily asexual (by budding ephyrae) rather than sexual.

We are attempting to enhance our understanding of larval fish sources and distribution in the Bay in collaboration with Monmouth University personnel (Ursula Howson and Jim Nickels). They have agreed to provide the fish larvae from their bongo net sample (500µ mesh only) from three standard sites in the upper, middle and lower Bay. In return, 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 in prep.). 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 *Pseudopleuronectes americanus* (Able et al. in review a) and predator-prey interactions between juvenile *Conger oceanicus* and *Anguilla rostrata* (Musumeci et al. in press). 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. in review b, Appendix Table 4). In addition, we compared larval winter flounder abundance at our Little Egg Inlet (Little Sheepshead Creek) over the period from 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. in review, Appendix Table 5).

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Table 1. 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 2. Habitat characteristics by cluster and sampling site up to October 2013. 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	0.01-1.0	28.5-31.1	11.2-21.9	5.8-10.0
		B110	Spartina, Phragmites	Macroalgae, Seagrass	0.01-0.51, 0.01-0.01	28.7-30.2	8.8-23.2	5.3-9.7
	SAV	STA 3	Spartina, Phragmites	Macroalgae, Seagrass	0.01-16.5, 0.01-1.0	28.0-29.9	9.7-24.4	6.0-9.0
		STA 52	Spartina, Phragmites	Macroalgae, Seagrass	0.01-3.5, 0.33-0.50	28.2-30.7	8.9-23.9	5.8-9.7
	Creek Mouth	STA 15	Spartina, Phragmites	Macroalgae	0.01-460.0	22.2-28.3	11.3-24.7	5.1-10.1
		STA 50	Spartina	Macroalgae	0.01-80.0	27.7-28.8	10.3-24.8	5.0-10.8
	Upper Creek	STA 14	Upland	Macroalgae	0.01-2.0	24.3-27.1	12.0-24.9	3.5-10.1
		STA 51	Spartina	Macroalgae	0.01-0.58	26.3-28.2	10.2-24.4	3.6-10.4
II	Bay	STA 60	-	Macroalgae, Seagrass	1.0-3.0, 0.01-0.01	23.5-28.1	12.7-25.4	5.8-9.3
		STA 61	-	Macroalgae	0.01-0.25	26.0-29.3	12.6-24.9	6.2-9.3
	SAV	STA 66	Spartina, Phragmites	Macroalgae, Seagrass	0.01-10.0, 3.0-12.0	26.0-29.8	10.0-24.9	6.1-9.4
		STA 67	Spartina, Phragmites	Macroalgae, Seagrass	0.01-0.20, 7.0-7.5	27.7-30.2	10.0-24.6	6.4-9.2
	Creek Mouth	STA 62	Spartina	Macroalgae	0.01-10.0	26.0-28.3	14.2-25.1	5.8-9.6
		STA 63	Spartina, Phragmites	Macroalgae, Seagrass	0.01-4.0, 0.01-0.01	22.4-28.3	12.6-25.7	6.0-9.0
	Creek	STA 64	Spartina	Seagrass	1.0-1.0	11.8-25.3	10.0-25.0	2.6-8.1

	Upper	STA 65	Upland	Macroalgae	0.01-0.01	9.7-22.2	13.9-25.2	1.2-8.5
III	Bay	STA 70	-	Macroalgae, Seagrass	0.01-12.0, 0.01-0.01	27.2-28.3	11.8-25.1	6.1-8.3
		STA 71	-	Macroalgae, Seagrass	0.01-2.5, 0.01-0.01	27.1-29.3	10.9-23.8	5.9-8.8
	SAV	STA 76	Spartina, Phragmites	Macroalgae, Seagrass	0.01-39.0, 0.01-5.0	27.3-29.1	11.8-23.9	6.4-8.5
		STA 77	Spartina, Phragmites	Macroalgae, Seagrass	0.01-28.0, 0.01-2.0	27.6-28.8	17.0-24.2	6.2-7.9
	Creek Mouth	STA 72	Spartina, Phragmites	Macroalgae, Seagrass	1.0-60.0, 0.01-0.01	22.0-28.9	15.9-27.4	5.5-8.2
		STA 73	Spartina, Phragmites	Macroalgae, Seagrass	0.01-45.0, 0.01-0.01	23.3-27.9	10.9-24.4	5.1-8.5
	Creek Upper	STA 74	Upland	Macroalgae, Seagrass	0.01-2.0, 0.01-0.01	22.1-27.1	17.7-30.6	5.8-8.5
		STA 75	Upland	Macroalgae	0.01-12.0	22.7-26.8	12.0-24.6	5.8-8.2
IV	Bay	STA 80	-	Macroalgae	0.01-0.25	9.5-24.6	13.6-23.3	7.2-8.6
		STA 81	-	Macroalgae, Seagrass	0.01-0.01, 0.01-0.01	18.1-24.0	13.7-24.1	7.0-9.0
	SAV	STA 86	Upland	Macroalgae, Seagrass	0.01-5.0, 0.01-4.0	19.4-24.2	23.1-23.7	6.7-9.0
		STA 87	-	Macroalgae, Seagrass	0.01-0.25, 0.01-2.5	17.9-24.7	13.9-23.7	5.9-9.5
	Creek Mouth	STA 82	Spartina, Phragmites	Macroalgae	0.01-4.0	17.4-24.5	14.2-26.7	4.4-8.5
		STA 83	Spartina, Phragmites	Macroalgae	3.0-46.0	18.1-22.6	13.9-24.2	4.9-9.2
	Creek Upper	STA 84	Spartina, Phragmites	Macroalgae, Seagrass	0.03-27.0	18.1-24.0	22.8-25.8	2.4-6.5
		STA 85	Upland	Macroalgae	0.01-2.5	19.5-22.2	14.8-26.1	0.2-6.9
V	Bay	STA 90	-	Macroalgae	0.01-8.0	14.4-26.4	12.3-22.6	0.16-11.0
		STA 91	-	Macroalgae	0.01-1.0	17.2-26.1	14.4-24.4	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	2.0-60.0	17.1-27.9	14.4-26.0	5.5-8.0
		STA 93	Spartina, Phragmites	Macroalgae, Seagrass	2.0-108.0, 0.01-0.01	16.8-28.9	14.5-25.0	1.1-8.5
	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 3. Sampling effort and number of larval fishes and crabs in Barnegat Bay during 2013. See Fig. 1 for locations of clusters.

Cluster	Location	Number of Tows	Number of Fishes	Number of Crabs	Total Fish Density (ind/1000 m)
I	Little Egg Inlet	April: 3	542	1	318.30
		June: 3	164	3	114.97
		August: 3	279	1	195.98
		October: 3	257	3	138.59
III	Barnegat Inlet	April: 3	76	0	64.26
		June: 3	69	25	64.68
		August: 3	1,063	19	752.05
		October: 3	35	2	20.06
	Forked River	April: 3	146	1	113.748
		June: 3	204	5	146.50
		August: 3	458	2	267.79
		October: 3	275	0	153.73
	Oyster Creek	April: 3	99	0	69.54
		June: 3	181	3	113.61
		August: 3	294	4	206.52
		October: 3	95	0	66.73
V	Pt. Pleasant Canal	April: 3	293	0	259.67
		June: 3	13	149	7.69
		August: 3	56	3	63.02
		October: 3	6	1	5.80
TOTAL		60	4,605	222	204.01

Table 4. Sampling effort with otter trawl in Barnegat Bay during 2013. 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	Number of Tows	Number of Fishes	Number of Crabs
I	Bay	April: 6	3	36
		June: 6	4	0
		Aug: 6	279	7
		Oct: 6	145	8
	SAV	April: 9	0	30
		June: 9	21	14
		Aug: 9	75	5
		Oct: 9	12	1
	Creek Mouth	April: 6	27	4
		June: 6	10	13
		Aug: 6	150	7
		Oct: 6	14	0
	Upper Creek	April: 6	0	9
		June: 6	35	66
		Aug: 6	100	8
		Oct: 6	75	6
II	Bay	April: 6	0	1
		June: 6	20	8
		Aug: 6	220	1
		Oct: 6	12	8
	SAV	April: 6	0	0
		June: 6	95	36
		Aug: 6	99	1
		Oct: 6	1,059	1
	Creek Mouth	April: 6	5	10
		June: 6	25	22
		Aug: 6	152	3
		Oct: 6	42	5
	Creek Upper	April: 6	0	21
		June: 6	5	69
		Aug: 6	53	28
		Oct: 6	0	5
III	Bay	April: 6	2	1
		June: 6	6	4
		Aug: 6	202	22
		Oct: 6	74	0
	SAV	April: 6	8	8
		June: 6	40	73
		Aug: 6	30	4
		Oct: 6	7	1
	Creek Mouth	April: 6	6	2
		June: 6	23	37
		Aug: 6	149	13
		Oct: 6	13	3
	Creek Upper	April: 6	6	9
		June: 6	3	21
		Aug: 6	5	92
		Oct: 6	2	6
IV	Bay	April: 6	0	1
		June: 6	12	2
		Aug: 6	1	0
		Oct: 6	5	1
	SAV	April: 6	0	89
		June: 6	22	90
		Aug: 6	63	4

		Oct: 6	17	182
	Creek Mouth	April: 6	0	6
		June: 6	46	8
		Aug: 6	272	14
		Oct: 6	104	18
	Creek Upper	April: 6	19	34
		June: 6	21	12
		Aug: 6	311	12
		Oct: 6	36	13
V	Bay	April: 6	4	11
		June: 6	22	5
		Aug: 6	155	1
		Oct: 6	54	9
	SAV	April: 6	2	4
		June: 6	13	17
		Aug: 6	57	21
		Oct: 6	7	8
	Creek Mouth	April: 6	0	7
		June: 6	37	49
		Aug: 6	42	8
		Oct: 6	0	4
	Creek Upper	April: 6	2	39
		June: 6	3	10
		Aug: 6	34	29
		Oct: 6	53	20
Total		492	4,734	1,457

Table 5. Sampling effort with gill nets in Barnegat Bay during 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
I	Bay	June Day: 4	0	2
		June Night: 4	2	5
		Aug: 4	8	3
		Oct: 4	7	0
	Creek Mouth	June Day: 4	8	2
		June Night: 4	20	4
		Aug: 4	30	3
		Oct: 4	8	1
	Creek Upper	June Day: 4	11	3
		June Night: 4	39	1
		Aug: 4	49	0
		Oct: 4	1	0
	SAV	June Day: 6	11	3
		June Night: 4	17	5
		Aug: 4	21	6
		Oct: 4	5	3
III	Bay	June: 2	0	2
		Aug: 4	38	0
		Oct: 4	2	0
	Creek Mouth	June: 2	1	0
		Aug: 4	19	3
		Oct: 4	15	0
	Creek Upper	June: 2	0	0
		Aug: 4	1	0
		Oct: 4	3	1
	SAV	June: 2	2	0
		Aug: 4	30	3
		Oct: 4	1	0
V	Bay	June: 2	1	4
		Aug: 4	28	7
		Oct: 4	1	2
	Creek Mouth	June: 2	1	3
		Aug: 4	19	5
		Oct: 4	0	0
	Creek Upper	June: 2	0	0
		Aug: 4	7	1
		Oct: 4	1	1
	SAV	June: 2	0	4
		Aug: 4	24	3
		Oct: 4	2	1
Total		146	433	81

Table 6. 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 7. Larval fish density and total number of fish collected from inlets (Barnegat Inlet, Little Egg Inlet), thoroughfares (Pt. Pleasant Canal) and at the Oyster Creek Nuclear Generating Station (OCNGS) intake and discharge canals in February, April, June, August and October of 2012 and 2013. 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. Fish per 1000m^3. Den = density, No = number

	Little Egg Inlet				Barnegat Inlet				Pt. Pleasant Canal				OCNGS Intake				OCNGS Discharge			
	2012		2013		2012		2013		2012		2013		2012		2013		2012		2013	
Scientific Name	**Den**	**No**	**Den**	**No**	**Den**	**No**	**Den**	**No**	**Den**	**No**	**Den**	**No**	**Den**	**No**	**Den**	**No**	**Den**	**No**	**Den**	**No**
Ammodytes americanus																				
Ammodytes sp.	0.204	1	0.302	2	1.544	2	0.297	1	3.601	5			39.993	317	0.85	6	0.669	8	0.301	3
Anchoa hepsetus	4.482	22	0.151	1	33.192	43			0.72	1			8.453	67	0.142	1	8.78	105		
Anchoa mitchilli	189.7	931	72.14	477	32.42	42	228.24	768	14.403	20	4.28	23	130.83	1037	65.764	464	71.577	856	21.086	210
Anchoa sp.	45.84	225	0.454	3	64.069	83	44.281	149	15.123	21	0.186	1	17.663	140	0.567	4	18.563	222	2.51	25
Anguilla rostrata	3.463	17	3.781	25	2.316	3			12.243	17	0.93	5	40.372	320	12.898	91	9.449	113	26.91	268
Apeltes quadracus					24.701	32	0.297	1	2.16	3			0.126	1						
Bairdiella chrysoura	0.407	2			5.403	7	0.892	3	0.72	1	0.744	4	1.892	15	0.142	1	0.92	11	0.1	1
Blenniidae sp.													0.126	1						
Brevoortia tyrannus	12.22	60	57.17	378	2.316	3	5.944	20			1.116	6	111.02	880	73.135	516	35.789	428	23.396	233
Centropristis striata	0.815	4			33.192	43														
Chilomycterus schoepfi													0.252	2	0.142	1			0.201	2
Clupea harengus	1.019	5	1.664	11									12.742	101	5.102	36	13.379	160	1.506	15
Clupeidae sp.			0.302	2	10.035	13	0.297	1									0.084	1	0.1	1
Clupeiformes sp.	0.407	2	0.302	2	40.911	53	18.129	61					8.327	66	2.551	18	3.846	46	0.502	5
Conger oceanicus	0.204	1									0.186	1	0.126	1						
Ctenogobius boleosoma	0.204	1	0.151	1	3.86	5	0.594	2							0.142	1	0.753	9		
Cynoscion regalis	2.037	10	0.302	2	2.316	3	0.297	1												
Elops saurus			0.151	1																

Enchelyopus cimbrius					1.544	2			3.601	5			0.252	2			0.836	10		
Engraulidae sp.	2.037	10	0.302	2			2.378	8					6.813	54					0.1	1
Engraulis eurystole	0.611	3											0.126	1						
Etropus microstomus					23.157	30			0.72	1										
Fundulus heteroclitus	0.407	2	0.302	2					0.72	1			0.378	3						
Fundulus luciae			0.151	1																
Fundulus majalis																				
Gasterosteus aculeatus																				
Gerreidae sp.																				
Gobiesox strumosus							0.297	1			0.186	1			0.283	2				
Gobiidae sp.			0.151	1	0.772	1	0.297	1	1.44	2			3.659	29	3.969	28	6.439	77	0.502	5
Gobiosoma bosc	40.75	200	0.454	3	1.544	2	0.297	1	12.243	17	2.233	12	7.317	58	10.772	76	4.432	53	5.723	57
Gobiosoma ginsburgi	11.82	58	0.756	5	27.017	35	16.048	54	0.72	1	2.419	13	1.388	11	5.386	38	0.167	2	2.711	27
Gobiosoma sp.	26.49	130	0.151	1			2.675	9			0.744	4	8.705	69	9.354	66	4.515	54	8.234	82
Hippocampus erectus	1.222	6	0.151	1	0.772	1			0.72	1	0.186	1	0.378	3			0.334	4		
Hyporhamphus meeki													0.126	1						
Hypsoblennius hentz							0.297	1					0.378	3	0.142	1				
Lagodon rhomboides	0.407	2	0.151	1	0.772	1							2.019	16			1.087	13		
Leiostomus xanthurus	2.037	10											60.306	478	0.142	1	29.016	347	0.1	1
Lucania parva			0.151	1																
Menidia beryllina													0.126	1	0.283	2			0.201	2
Menidia menidia	2.037	10	2.722	18			0.594	2			0.372	2	6.056	48	0.142	1	2.509	30	0.803	8
Menidia sp.	1.019	5	1.966	13	0.772	1	0.297	1					1.64	13	0.283	2	1.087	13	0.201	2
Menticirrhus saxatilis	0.815	4					0.297	1					0.126	1						
Microgobius thalassinus							1.486	5			0.186	1	5.803	46	2.268	16	6.188	74	1.908	19
Micropogonias undulatus			0.302	2							0.186	1	0.252	2	0.142	1	0.084	1		
Mugil cephalus													0.126	1						
Mugil curema			0.151	1											0.283	2				
Myrophis punctatus	0.204	1											0.126	1			0.084	1		

Ophidion marginatum																				
Opisthonema oglinum	0.407	2											2.019	16	0.567	4	0.585	7	0.502	5
Opsanus tau			0.151	1					0.72	1	0.186	1	0.126	1					0.1	1
Paralichthys dentatus	3.056	15	0.605	4	1.544	2					0.372	2	56.647	449	8.929	63	19.734	236	8.736	87
Peprilus sp.			0.302	2																
Peprilus triacanthus	1.426	7																		
Pholis gunnellus																				
Pleuronectes sp.											0.186	1								
Pogonias cromis									0.72	1							0.084	1		
Pomatomus saltatrix																			0.1	1
Prionotus carolinus	0.407	2			1.544	2	1.189	4	0.72	1	0.186	1								
Prionotus evolans	0.204	1			2.316	3													0.1	1
Pseudopleuronectes americanus	7.538	37	77.28	511	3.088	4	22.289	75	2.881	4	53.78	289	0.252	2	7.795	55			4.82	48
Sciaenidae sp.	15.28	75			3.86	5			1.44	2			0.631	5			1.087	13		
Scophthalmus aquosus	0.204	1	4.84	32			14.859	50			0.186	1								
Sphoeroides maculatus											0.372	2								
Strongylura marina													0.757	6			0.167	2		
Symphurus plagiusa					0.772	1														
Syngnathus fuscus	31.17	153	14.07	93	8.491	11	4.161	14	5.041	7	1.116	6	11.102	88	4.394	31	6.021	72	3.816	38
Tautoga onitis	0.815	4			6.175	8					0.186	1								
Tautogolabrus adspersus					60.209	78	3.269	11			0.186	1								
Tylosurus acus																	0.084	1		
Unidentified fish					0.772	1							0.126	1					0.1	1
Urophycis regia	0.407	2											0.252	2						

Table 8. Fish and crab species composition and abundance (CPUE = number per tow) by otter trawl sample and month across all clusters in Barnegat Bay during 2013. Individuals caught in April (n= 470 individuals), June (n= 1117 individuals), August (n= 3274 individuals), and October (n= 2287) varied by month.

Scientific Name	Common Name	April	June	August	October	Total CPUE for 2013
Fishes						
Anchoa hepsetus	Striped Anchovy	0	0	0.05	0.01	0.06
Anchoa mitchilli	Bay Anchovy	0.04	1.44	22.08	13.71	37.27
Anchoa sp.	Anchovy	0	0	0.10	0.02	0.11
Anguilla rostrata	American Eel	0.01	0.05	0.03	0	0.09
Apeltes quadracus	Four spine Stickleback	0.07	0.08	0	0	0.15
Astroscopus guttatus	Northern stargazer	0	0	0.01	0	0.01
Bairdiella chrysoura	Silver perch	0	0	0.15	0.17	0.32
Brevoortia tyrannus	Atlantic menhaden	0.03	0.41	0.15	0.11	0.70
Caranx hippos	Crevalle jack	0	0	0	0.01	0.01
Centropristis striata	Black sea bass	0	0.04	0.02	0	0.07
Chasmodes bosquianus	Striped blenny	0	0	0.01	0.01	0.02
Chilomycterus schoepfii	Striped burrfish	0	0.01	0	0	0.01
Clupea harengus	Atlantic herring	0.20	0	0	0	0.20
Clupeidae sp.	Herring/Shad/Menhaden	0	0	0.01	0	0.01
Cynoscion regalis	Weakfish	0	0	0.04	0	0.04
Dactylopterus volitans	Flying gurnard	0	0	0.01	0	0.01
Dasyatus sayi	Bluntnose stingray	0	0	0.01	0	0.01
Etropus microstomus	Smallmouth flounder	0.01	0	0	0	0.01
Fundulus heteroclitus	Mummichog	0.07	0.01	0	0	0.07
Fundulus luciae	Spotfin Killifish	0	0.01	0	0	0.01
Gobiosoma bosc	Naked goby	0.04	0.01	0.32	0.06	0.42
Gobiosoma ginsburgi	Seaboard goby	0	0	0.02	0	0.02
Hippocampus erectus	Lined seahorse	0	0.01	0	0	0.01
Ictalurus punctatus	Channel catfish	0	0	0.01	0	0.01
Lagodon rhomboides	Pinfish	0	0.02	0.03	0	0.05
Leiostomus xanthurus	Spot croaker	0	0.15	0.08	0.02	0.26
Menidia beryllina	Inland silverside	0.02	0	0	0	0.02
Menidia menidia	Atlantic silverside	0.01	0.15	0.25	1.06	1.47
Menidia sp.	Silverside	0	0.04	0	0	0.04
Menticirrhus saxatilis	Northern kingfish	0.01	0	0.02	0	0.03
Microgobius thalassinus	Green goby	0.01	0	0.02	0.01	0.03
Micropogonias undulatus	Atlantic croaker	0.02	0.04	0.01	0.02	0.09
Morone americana	Silver perch	0.03	0	0	0	0.03
Morone sp.	Bass	0	0.01	0.01	0	0.02

Mustelus canis	Smooth dogfish	0	0.01	0.02	0	0.02
Mycteroperca microlepis	Gag grouper	0	0	0.01	0	0.01
Opsanus tau	Oyster toadfish	0.04	0.06	0.11	0	0.21
Paralichthys dentatus	Summer flounder	0.02	0.15	0.05	0.02	0.25
Peprilus triacanthus	Atlantic butterfish	0	0.01	0.01	0.02	0.03
Pollachius virens	Pollock	0.02	0	0	0	0.02
Pomatomus saltatrix	Bluefish	0	0.08	0.07	0.01	0.16
Pseudopluronectes americanus	Winter Flounder	0.02	1.22	0.01	0	1.24
Sciaenidae sp.	Drum/croaker	0	0	0.01	0	0.01
Selene setapinnis	Atlantic moonfish	0	0	0	0.01	0.01
Selene vomer	Lookdown	0	0	0	0.02	0.02
Sphoeroides maculatus	Northern puffer	0	0.07	0.04	0	0.11
Stenotomus chrysops	Scup	0	0	0.01	0	0.01
Syngnathus fuscus	Northern pipefish	0.07	0.29	0.24	0.13	0.73
Tautoga onitis	Tautog	0.02	0.02	0.02	0.01	0.07
Tautogolabrus adspersus	Cunner	0	0.01	0.02	0	0.02
Trinectes maculatus	Hogchoker	0	0.02	0.02	0.02	0.05
Urophycis regia	Spotted hake	0.05	0	0	0.01	0.06
Crabs *Callinectes sapidus*	Blue crab	2.42	4.52	2.48	3.10	12.52
Cancer irroratus	Rock crab	0.05	0.01	0	0	0.06
Libinia dubia	Longnose spider crab	0	0.02	0.02	0.03	0.07
Libinia emarginatum	Common Spider crab	0.49	0.11	0.01	0.01	0.62
Libinia sp.	Spider crab	0	0	0.01	0	0.01
Ovalipes ocellatus	Lady crab	0.01	0	0.01	0.02	0.04
Terrapins *Malachemys terrapin*	Diamondback terrapin	0.07	0	0.03	0	0.10
Horseshoe crab *Limulus polyphemus*	Horseshoe crab	0	0.01	0	0	0.01

Table 9. Species composition and abundance (CPUE) by habitat (otter trawl) from sampling in 2013.

Species	Bay	Marsh Creek (mouth)	Marsh Creek (upper)	SAV
Fishes				
Anchoa hepsetus	0.02		0.03	0.01
Anchoa mitchilli	13.90	8.20	4.79	10.28
Anchoa sp.	0.01	0.03	0.08	
Anguilla rostrata	0.02	0.03	0.04	0.01
Apeltes quadracus		0.01	0.01	0.12
Astroscopus guttatus	0.01			
Bairdiella chrysoura		0.15	0.15	0.02
Brevoortia tyrannus	0.03	0.12	0.57	
Caranx hippos			0.01	
Centropristis striata	0.02	0.03		0.02
Chasmodes bosquianus		0.02		
Chilomycterus schoepfi		0.01		
Clupea harengus		0.20		
Clupeidae			0.01	
Cynoscion regalis	0.04			
Dactylopterus volitans				0.01
Dasyatis say				0.01
Etropus microstomus			0.01	
Fundulus heteroclitus		0.01	0.07	
Fundulus luciae				0.01
Gobiosoma bosc	0.01	0.22	0.16	0.05
Gobiosoma ginsburgi			0.03	
Hippocampus erectus				0.01
Ictalurus punctatus			0.01	
Lagodon rhomboides		0.02	0.02	0.02
Leiostomus xanthurus	0.11	0.08	0.07	0.02
Menidia beryllina			0.03	
Menidia menidia	0.95	0.07	0.13	0.33
Menidia sp.				0.04
Menticirrhus saxatilis	0.03	0.01		
Microgobius thalassinus		0.02	0.02	
Micropogonias undulatus	0.02	0.03	0.04	
Morone americana	0.01	0.02	0.01	
Morone sp.			0.02	

Mustelus canis		0.01		0.02
Mycteroperca microlepis		0.01		
Opsanus tau	0.01	0.10	0.06	0.05
Paralichtys dentatus	0.07	0.08	0.06	0.05
Peprilus triacanthus	0.03			
Pollachius virens	0.02			
Pomatomus saltatrix	0.06	0.03	0.07	0.01
Pseudopleuronectes americanus	0.22	0.23	0.05	0.71
Sciaenidae		0.01		
Selene setapinnis			0.01	
Selene vomer		0.01	0.01	
Sphoeroides maculatus	0.03	0.02	0.03	0.04
Stenotomus chrysops				0.01
Syngnathus fuscus	0.04	0.17		0.49
Tautoga onitis	0.02	0.03	0.01	0.01
Tautogolabrus adspersus		0.01		0.02
Trinectes maculatus	0.02	0.02	0.02	
Urophycis regia	0.04	0.02		
Crabs *Callinectes sapidus*	1.09	2.98	4.25	4.11
Cancer irroratus	0.03		0.03	0.01
Libinia dubia	0.01	0.03		0.04
Libinia emarginata	0.29			0.23
Libinia sp.		0.01		
Limulus polyphemus	0.01			
Malaclemys terrapin			0.10	
Ovalipes ocellatus	0.04			

Table 10. Total CPUE and abundance of fish species caught for 2012 (day) and 2013 (day-June, night-other months) in gillnet sampling.

		1				3				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 11. 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 - 2013 and Able and Fahay (2010).

Categories and Species	1970-1980s			2012-2013		
	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 12. 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) and 2013. The 1979-1981 and 2012-2013 samples were based on Bongo (36 cm diameter, 0.5 mm mesh) and plankton (1 m diameter, 1 mm mesh) nets, respectively.

Scientific Name	**Common Name**	**1979-1980**	**1980-1981**	**2012**	**2013**
Anguillidae					
Anguilla rostrata	American eel	0.14	0.87	2.36	2.29
Ophichthidae					
Myrophis punctatus	Speckled worm eel	---	---	0.02	---
Congridae					
Conger oceanicus	American conger	---	---	0.01	0.01
Clupeiformes		---	---	0.84	0.51
Clupeidae		---	---	0.07	0.02
Brevoortia tyrannus	Atlantic menhaden	---	0.05	6.89	6.78
Clupea harengus	Clupea harengus	---	---	1.34	0.36
Opisthonema oglinum	Atlantic thread herring	---	---	0.13	0.05
Engraulidae		---	---	0.32	0.06
Anchoa hepsetus	Striped anchovy	---	---	1.20	0.01
Anchoa mitchilli	Bay anchovy	39.77	60.47	14.51	11.41
Anchoa sp.	Anchovy	---	---	3.47	1.07
Engraulis eurystole	Silver anchovy	---	---	0.02	---
Lotidae					
Enchelyopus cimbrius	Fourbeard rockling	---	---	0.10	---
Phycidae					
Urophycis regia	Spotted hake	---	---	0.02	---
Batrachoididae					
Opsanus tau	Oyster toadfish	---	---	0.01	0.02
Belonidae					
Strongylura marina	Atlantic needlefish	---	0.05	0.04	---
Tylosurus acus	Agujon needlefish	0.06	---	0.01	---
Hemiramphidae					
Hyporhamphus meeki	American halfbeak	---	---	0.01	---
Fundulidae					
Fundulus heteroclitus	Mummichog	---	---	0.03	0.01
Fundulus luciae	Spotfin killifish	---	---	---	0.01
Atherinopsidae		1.63	6.40	---	---
Menidia beryllina	Inland silverside	---	---	0.01	0.02

Menidia menidia	Atlantic silverside	0.06	1.42	0.44	0.18
Menidia sp.	Silverside	---	---	0.16	0.11
Gasterosteidae					
Apeltes quadracus	Four spine stickleback	---	---	0.18	0.01
Syngnathidae					
Hippocampus erectus	Lined seahorse	---	0.11	0.08	0.01
Syngnathus fuscus	Northern pipefish	5.48	6.55	1.66	1.07
Triglidae					
Prionotus carolinus	Northern searobin	---	---	0.03	0.03
Prionotus evolans	Striped searobin	---	---	0.02	0.01
Cottidae					
Myoxocephalus aenaeus	Grubby	---	0.48	---	---
Pomatomidae					
Pomatomus saltatrix	Bluefish	---	---	---	0.01
Sparidae					
Lagodon rhomboides	Pinfish	---	---	0.16	0.01
Sciaenidae		---	---	0.50	---
Bairdiella chrysoura	Silver perch	---	---	0.18	0.05
Cynoscion regalis	Weakfish	---	0.19	0.07	0.02
Leiostomus xanthurus	Spot croaker	---	---	4.20	0.01
Menticirrhus saxatilis	Northern kingfish	---	---	0.03	0.01
Micropogonius undulatus	Altantic croaker	0.08	---	0.02	0.02
Pogonias cromis	Black drum	---	---	0.01	---
Mugilidae					
Mugil cephalus	Flathead mullet	---	---	0.01	---
Mugil curema	Silver mullet	---	---	---	0.02
Labridae					
Tautoga onitis	Tautog	0.12	0.03	0.06	0.01
Ammodytidae					
Ammodytes americanus	Sand lance	---	21.93	---	---
Ammodytes sp.		---	---	1.67	0.07
Blenniidae		3.55	0.63	0.01	---
Chasmodes bosquianus	Striped blenny	---	0.03	---	---
Hypsoblennius hentz	Feather blenny	---	---	0.02	0.01
Gobiesocidae					
Gobiesox strumosus	Skilletfish	---	---	---	0.02
Gobiidae		48.36	27.35	0.55	0.21
Ctenogobius boleosoma	Darter goby	---	---	0.08	0.02
Gobiosoma bosc	Naked goby	0.36	0.16	1.66	0.88

Gobiosoma ginsburgi	Seaboard goby	---	---	0.54	0.81
Gobiosoma sp.	Goby	---	---	1.27	0.95
Microgobius thalassinus	Green goby	---	---	0.60	0.24
Scophthalmidae					
Scophthalmus aquosus	Windowpane flounder	---	0.22	0.01	0.49
Paralichthyidae					
Paralichthys dentatus	Summer flounder	---	0.12	3.53	0.92
Pleuronectidae					
Pleuronectes sp.					0.01
Pseduopleuronectes americanus	Winter flounder	---	17.89	0.24	5.75
Achiridae					
Trinectes maculatus	Hogchoker	0.20	0.06	---	---
Tetradontidae					
Chilomycterus schoepfi	Striped burrfish	---	---	0.01	0.02
Sphoeroides maculatus	Northern puffer	0.31	0.27	---	0.01
	Unidentified larvae	0.18	0.11	0.01	0.01
Total Taxa		14	23	52	47

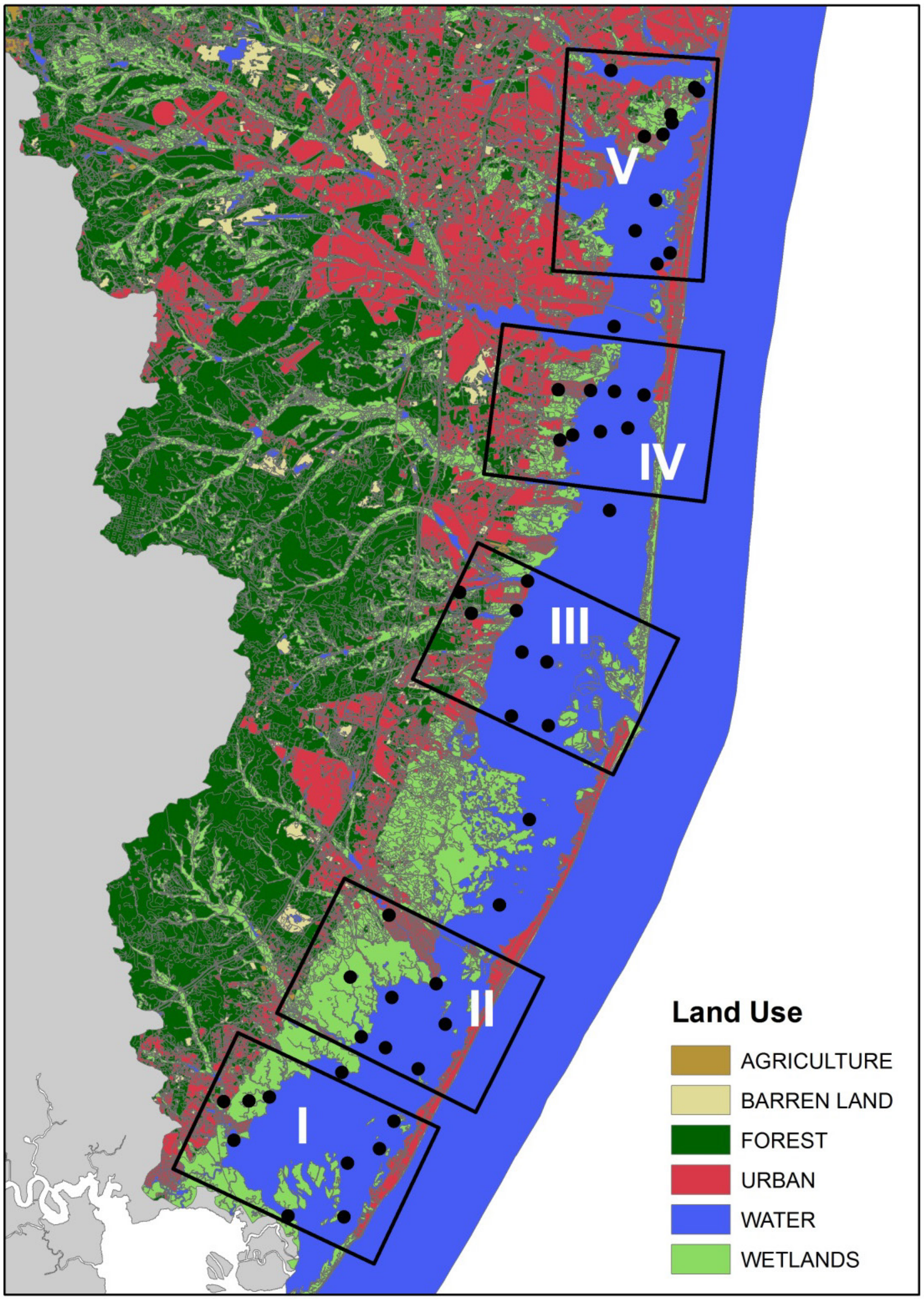


Figure 1. Location of individual sampling sites (clusters I-V) in Barnegat Bay along the urbanization gradient. See Table 1 for characteristics of each cluster.

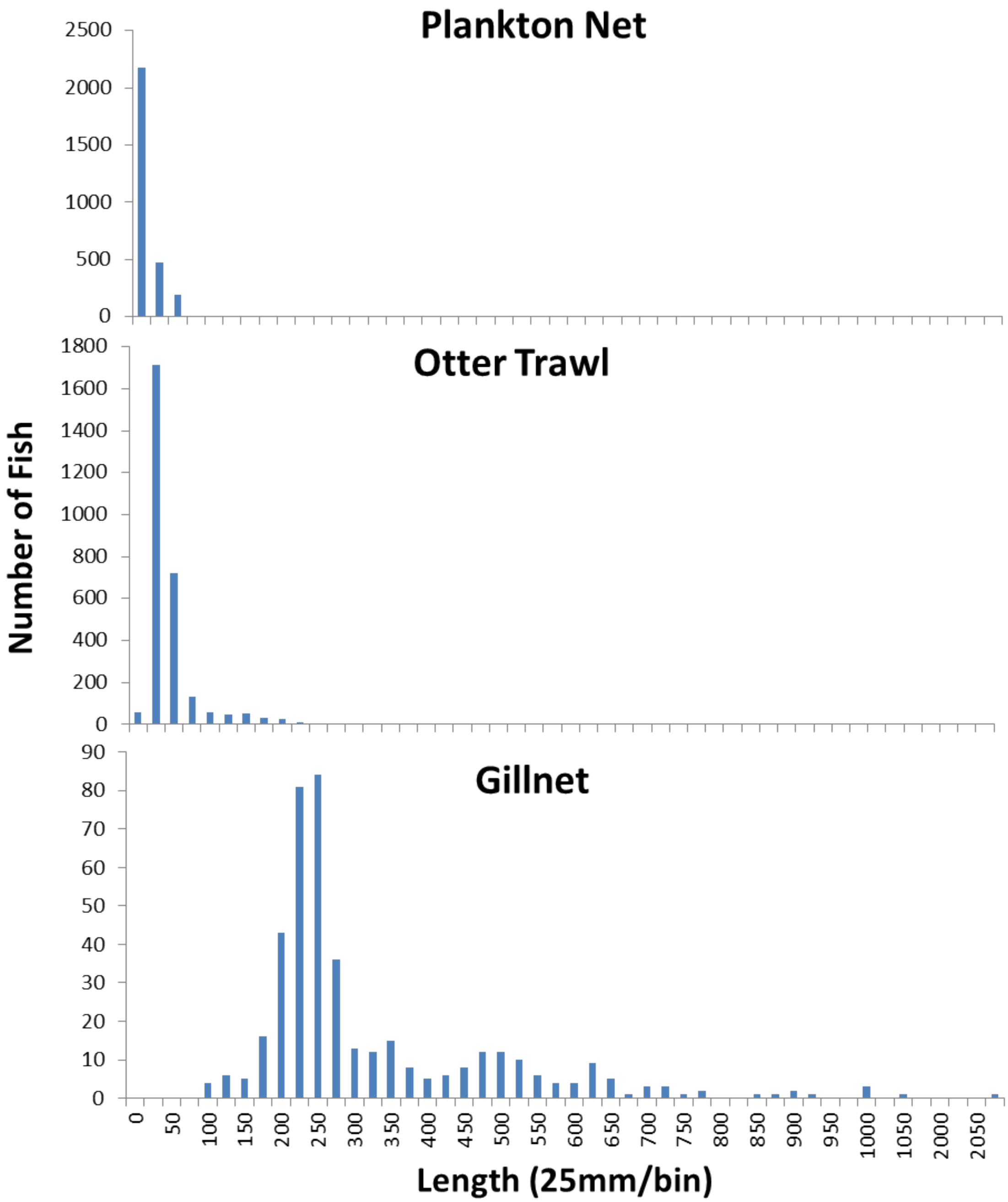


Figure 2. Composition of lengths by sampling gear during 2013.

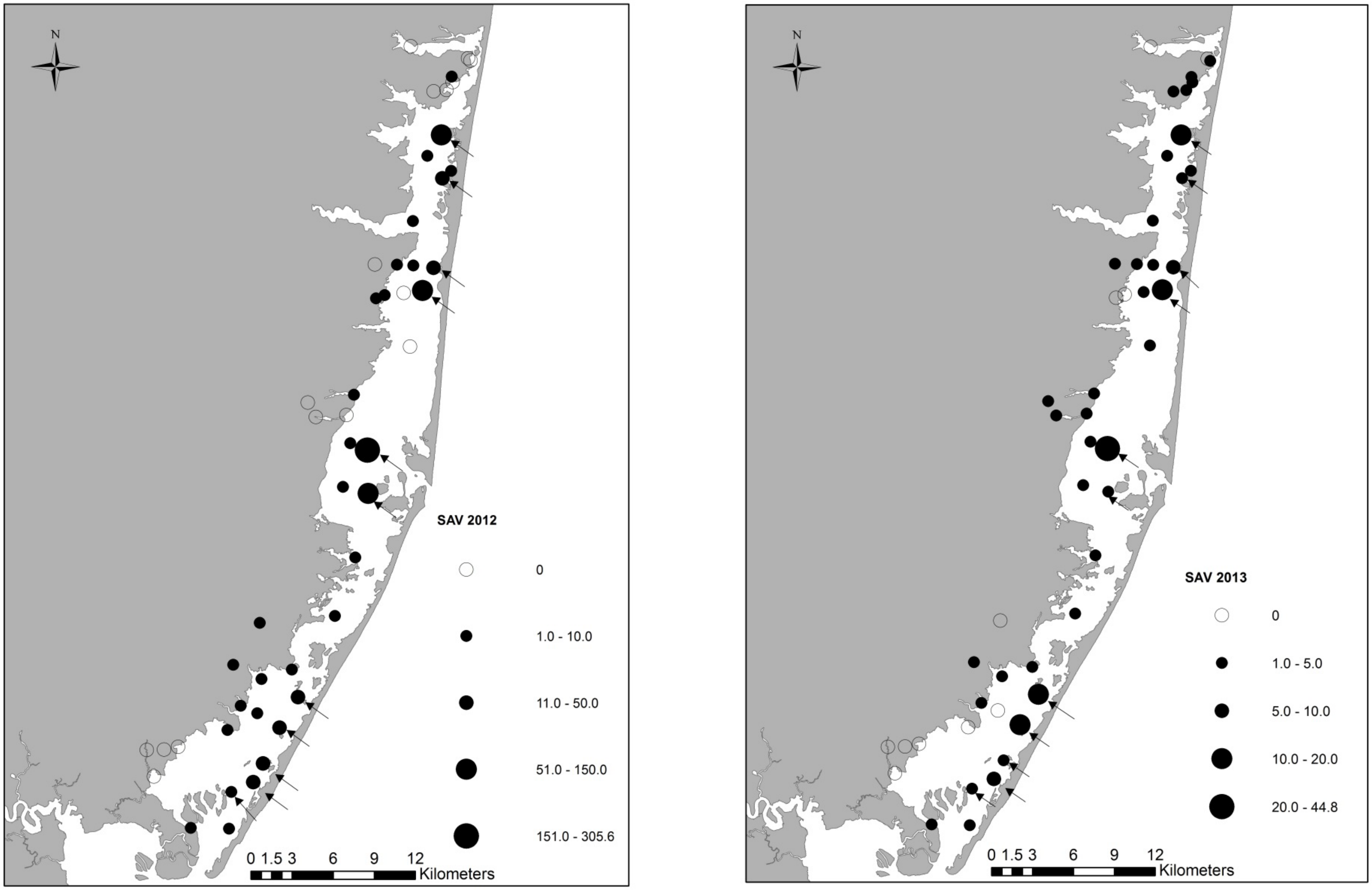


Figure 3. Distribution of SAV in composite samples during 2012 and 2013 sampling. Closed circles with arrows indicate SAV beds. Closed circles without arrows indicate where SAV blades were detected in other locations. Values indicated in liters. Open circles indicate where no SAV was collected.

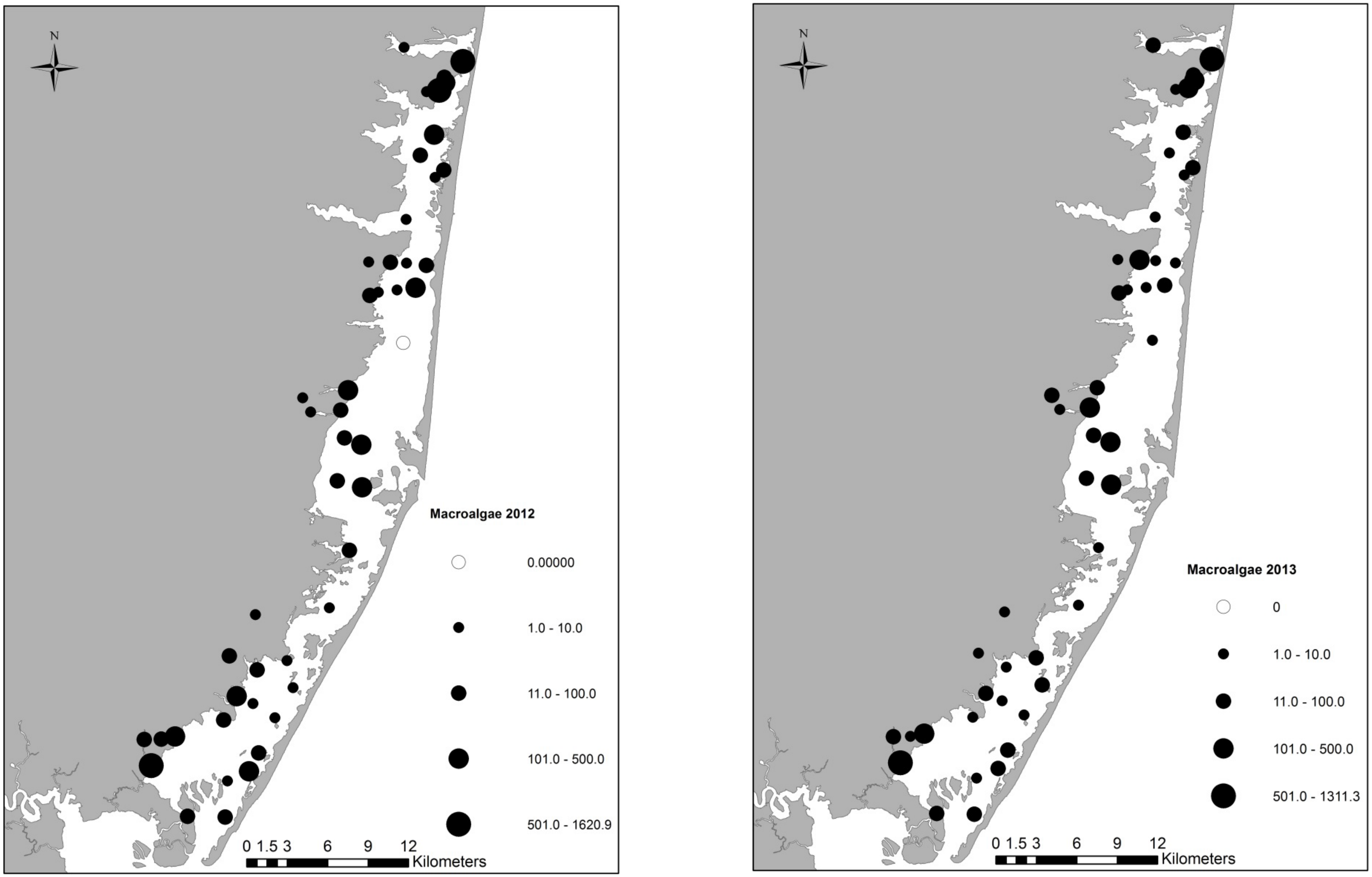


Figure 4. Distribution of macroalgae (closed circles) in composite otter trawl samples during 2012 and 2013 sampling. Open circles indicate where macroalgae was not collected. Values indicated in liters.

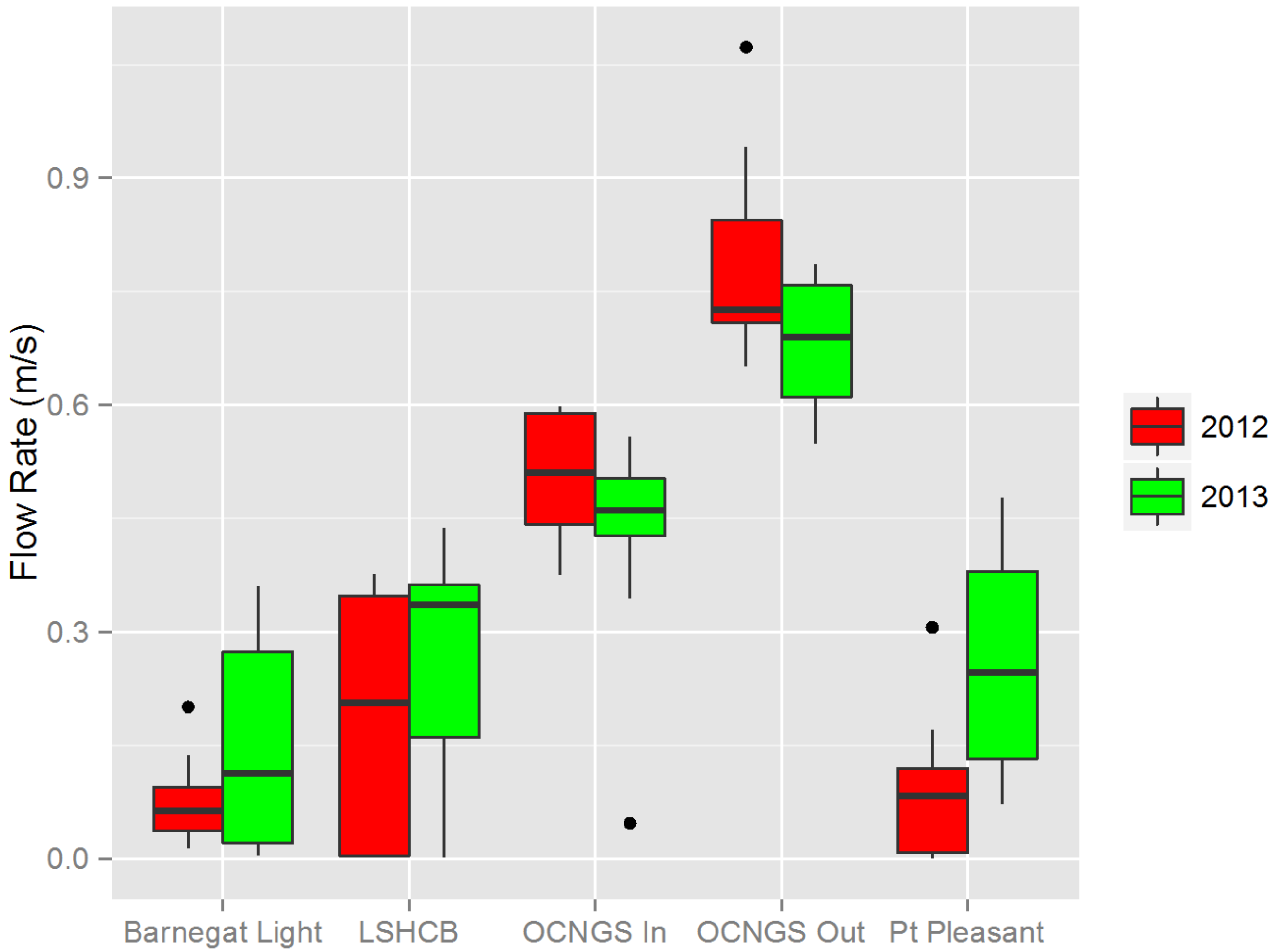


Figure 5. Box plot display of the distribution of flow rates measured during bridge net sampling in 2012 (February, April, June, and August) and 2013 (February, April, June, August, and October).

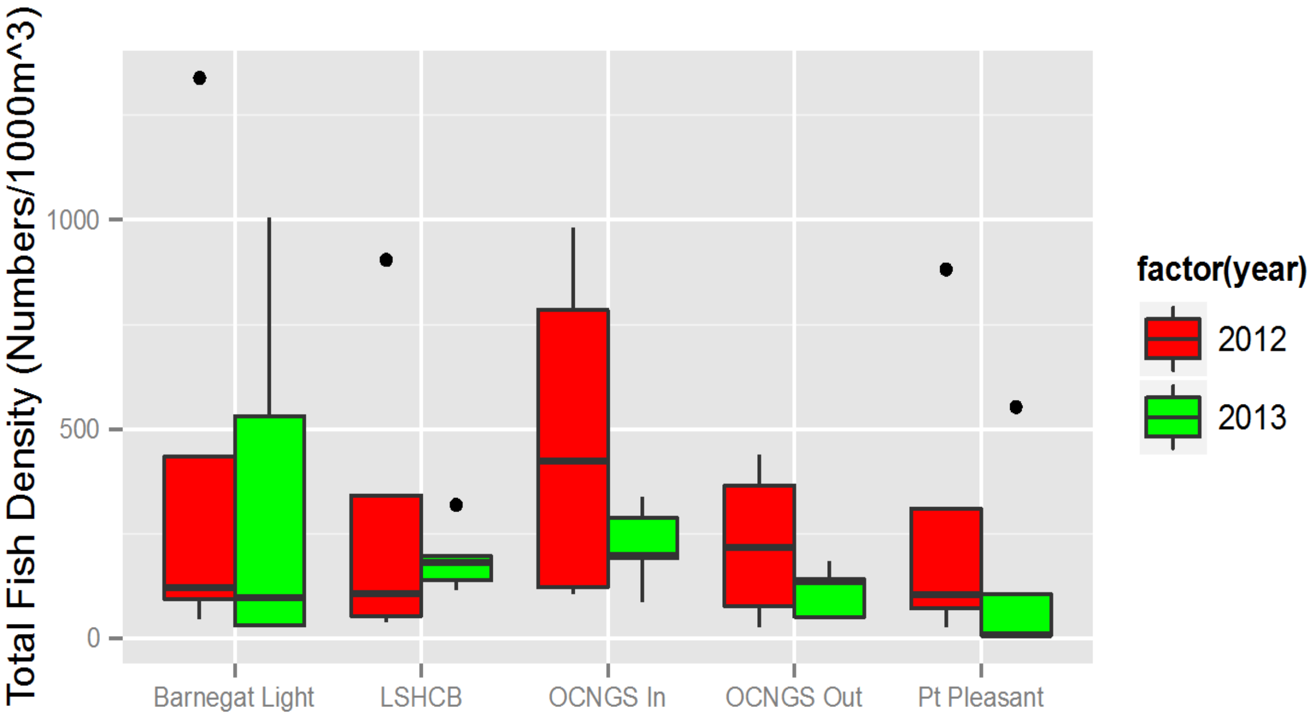


Figure 6. Box plot display of the distribution of bi-monthly total fish density collected from bridge net sampling in 2012 (February, April, June, and August) and 2013 (February, April, June, August, and October). Fish density was calculated as the total number of fish per $1000m^3$ for each sampling location and month.

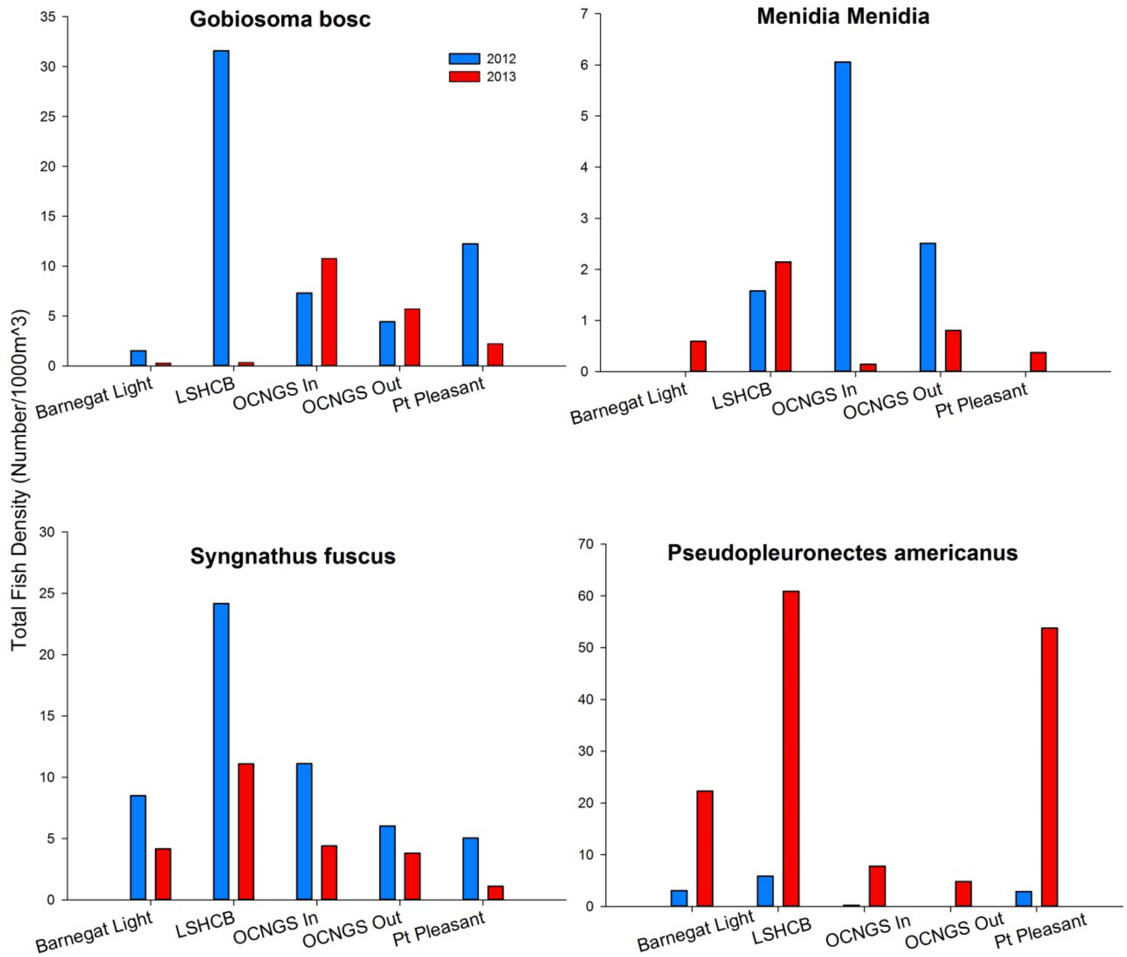


Figure 7. Total larval fish density (numbers of fish per 1000m^3) of some commonly collected resident species fish sampling in 2012 (February, April, June, and August) and 2013 (February, April, June, August, and October. Total number of fish and total volume were summed across all tows for a given year and location.

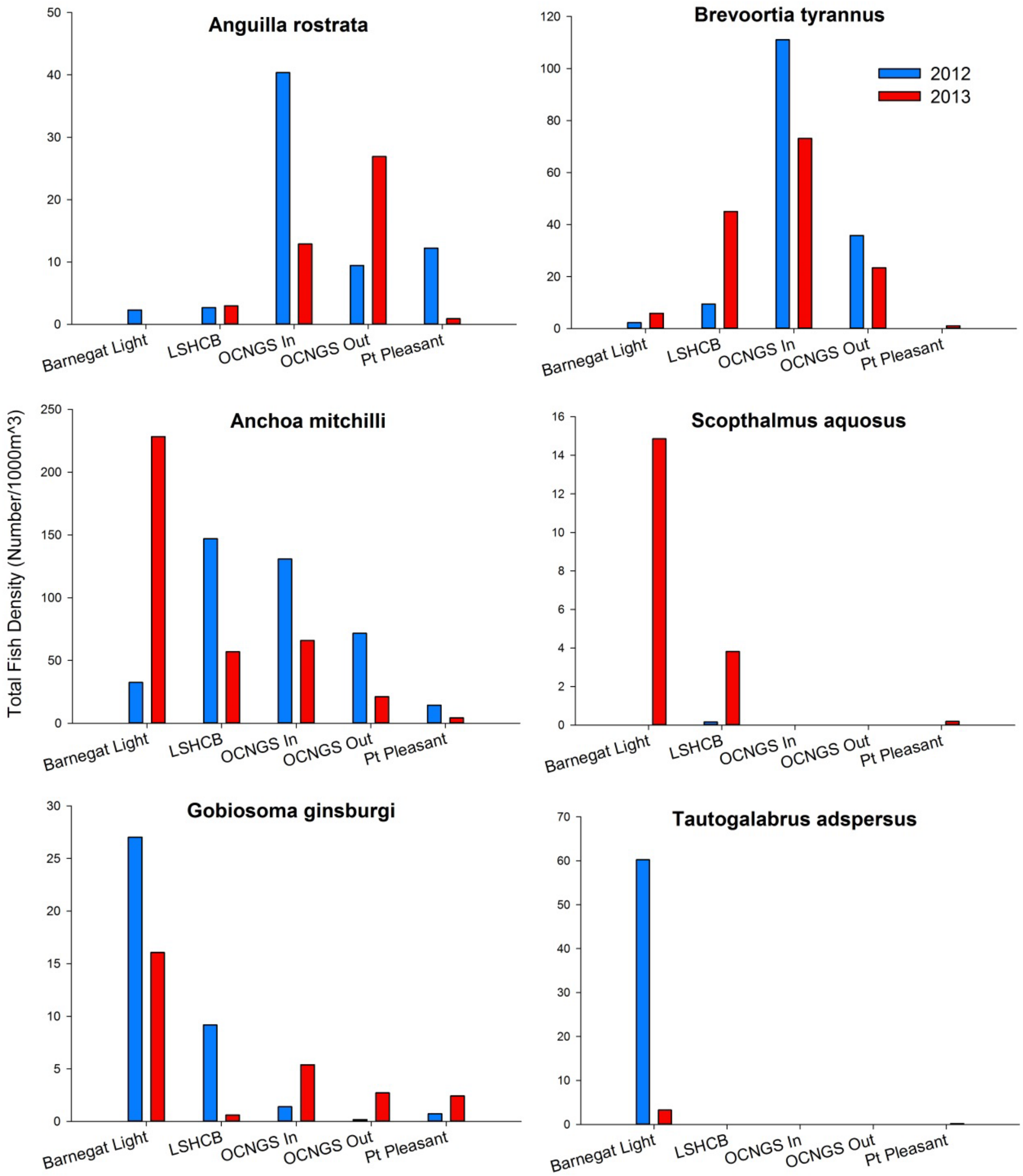


Figure 8. Total larval fish density (numbers of fish per 1000m^3) of some commonly collected transient species from larval fish sampling in 2012 (February, April, June, and August) and 2013 (February, April, June, August, and October). All of these species spawn in the ocean with the exception of *A. 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.

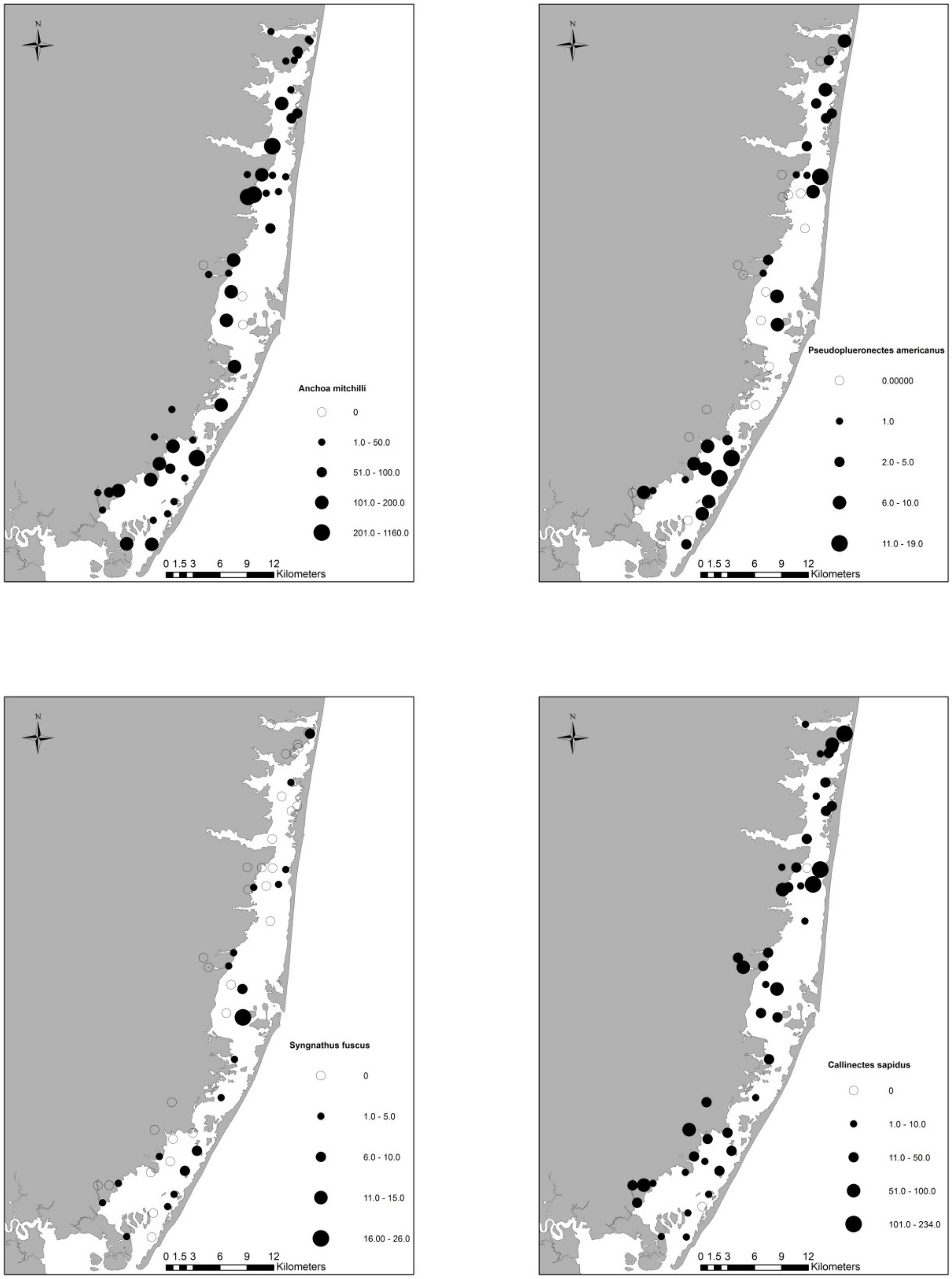


Figure 9. Spatial distribution of selected species during all otter trawl samples collected in 2013. Anchoa mitchilli (upper left), Pseudopleuronectes americanus (upper right), Syngnathus fuscus (lower left), and Callinectes sapidus (lower right) were found evenly distributed across the entire bay, although Callinectes and Anchoa were also found in creeks.

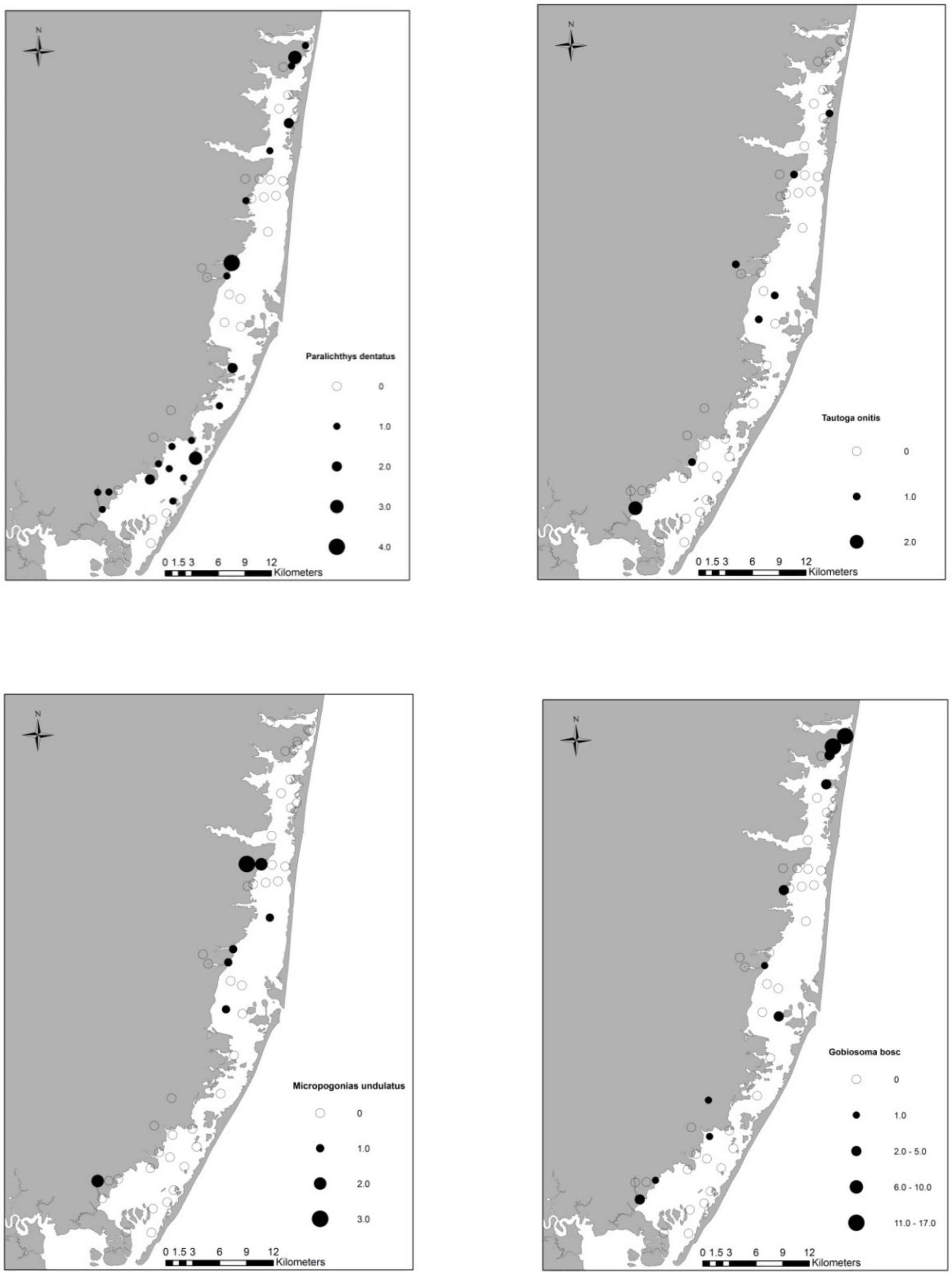


Figure 10. Spatial distribution of selected species during all otter trawl samples collected in 2013. Paralichthys dentatus (upper left) and Tautoga onitis (upper right) were evenly distributed, although the latter was less abundant. Micropogonias undulatus (lower left) was most frequently collected in the western portion of the bay. Gobiosoma bosc (lower right) was found in most portions of the bay, but was most abundant in upper bay collections.

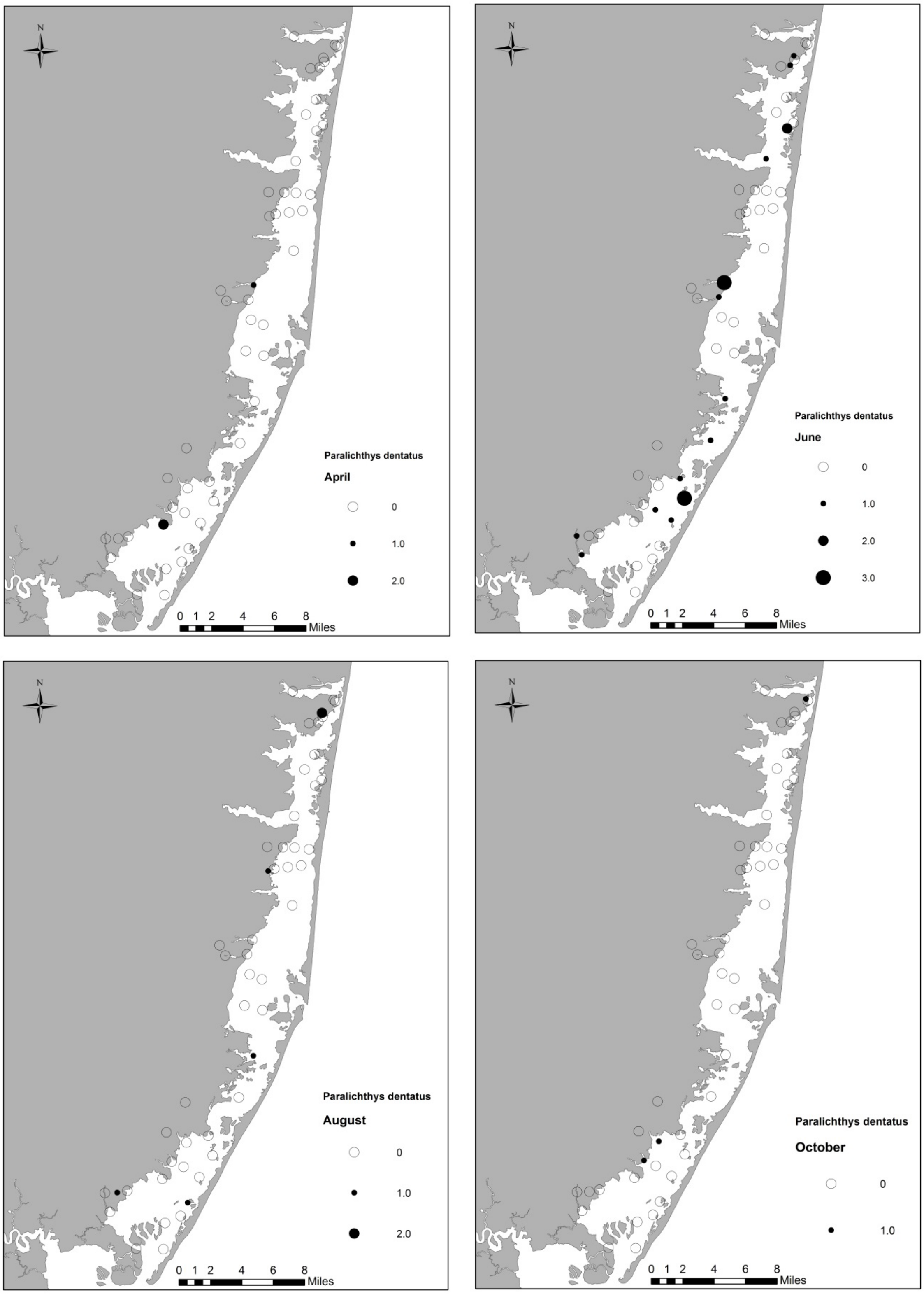


Figure 11. Spatial distribution of *Paralichthys dentatus* from otter trawl samples by sampling month during 2013.

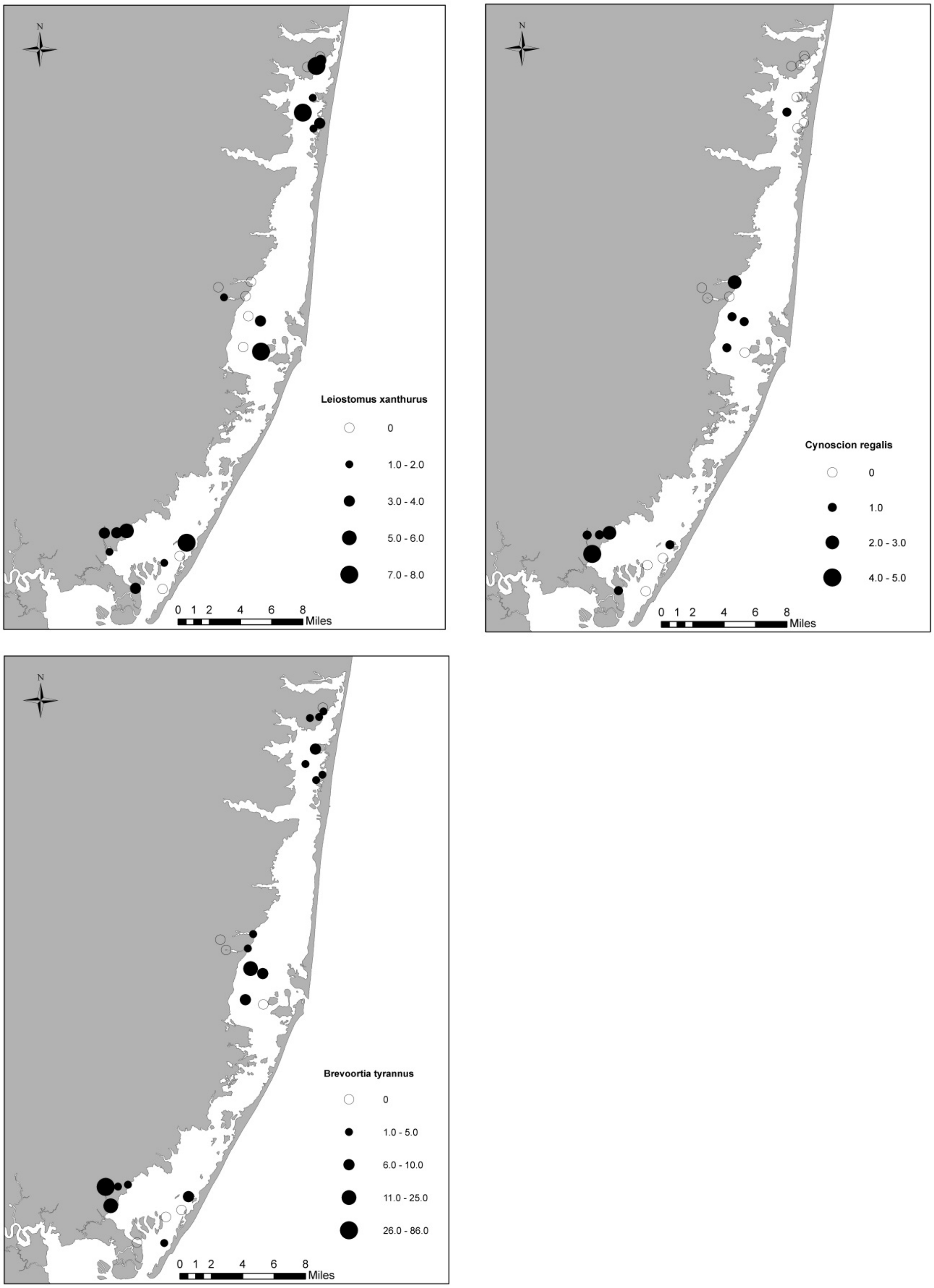


Figure 12. Spatial distribution of dominant species from gill net sampling in 2013 including *Leiostomus xanthurus* (upper left), *Cynoscion regalis* (upper right), and *Brevoortia tyrannus* (lower left).

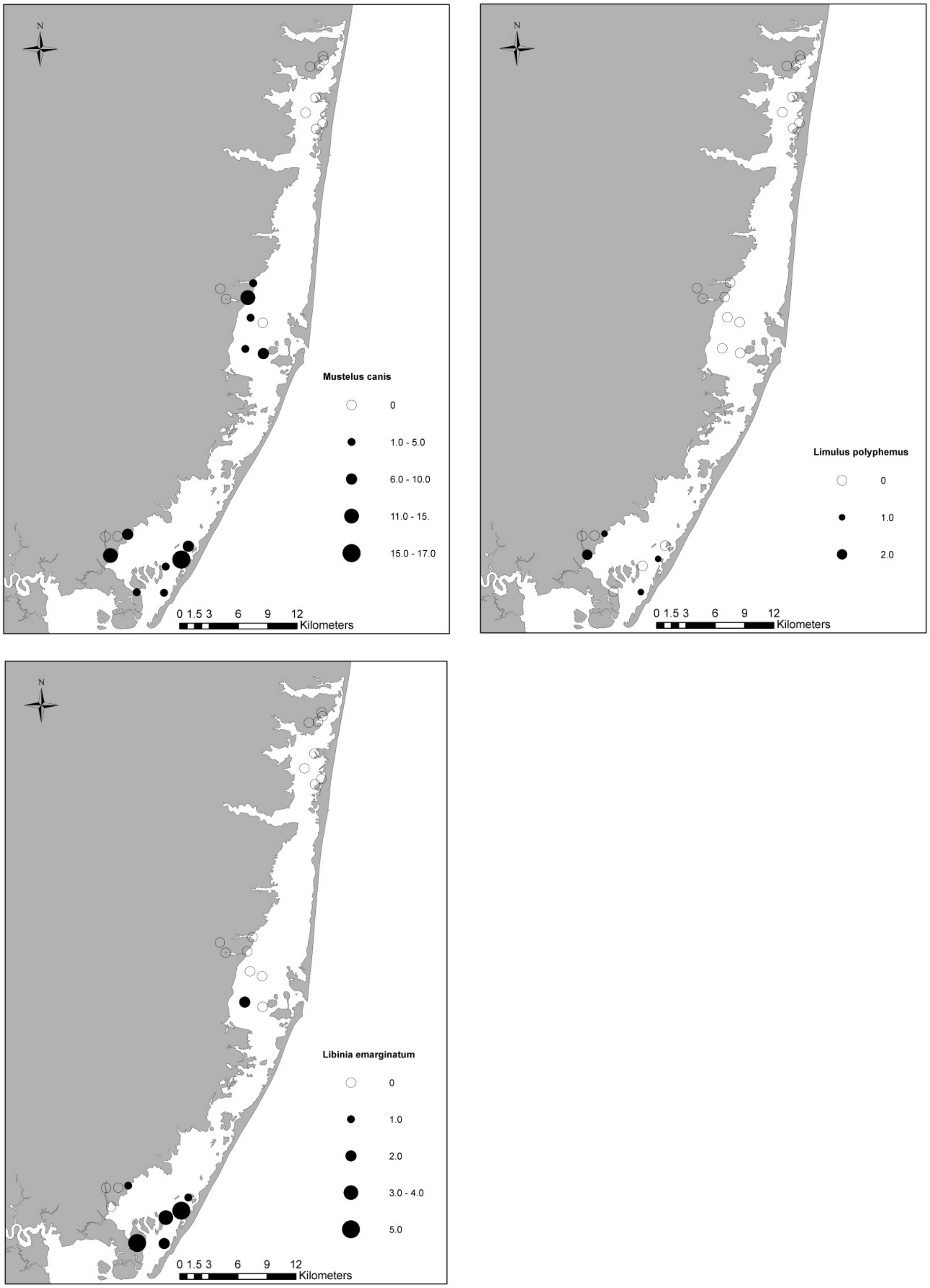


Figure 13. Spatial distribution of dominant species from gill net sampling in 2013 including *Mustelus canis* (upper left), *Limulus polyphemus* (upper right), and *Libinia emarginatum* (lower left).

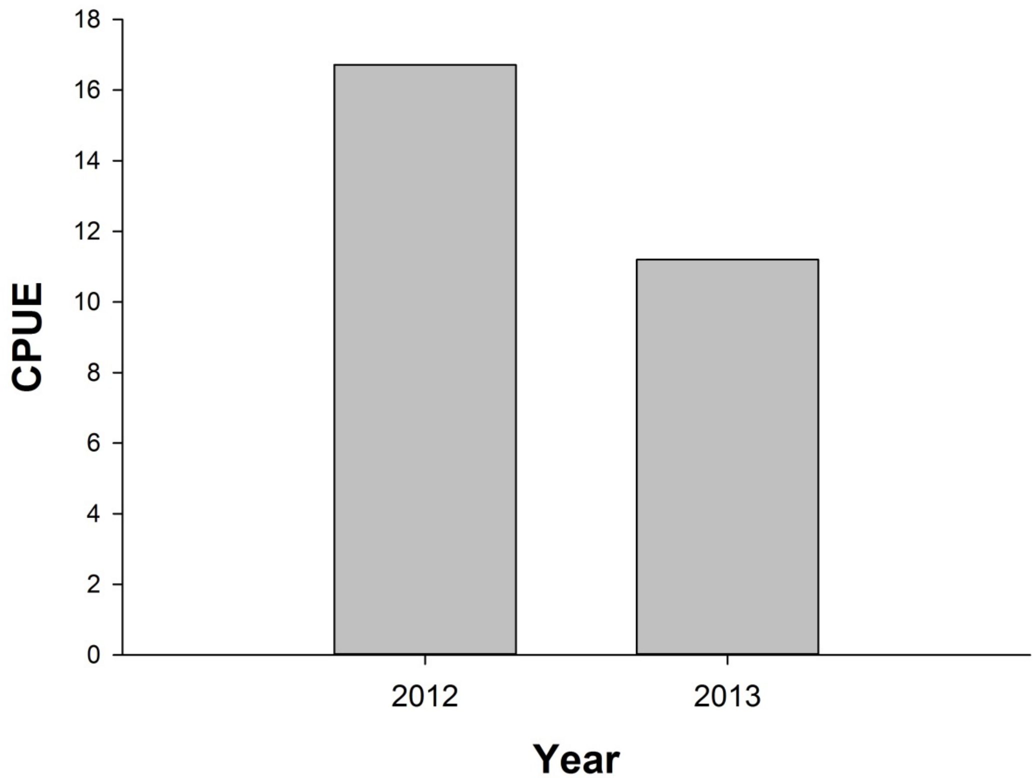


Figure 14. Comparison of mean abundance (CPUE = catch per tow) of fishes across habitats, clusters and adjacent sampling sites, and sampling dates between April – August 2012 and April – October 2013 as collected with otter trawl. There were no collections during October 2012 due to Superstorm Sandy.

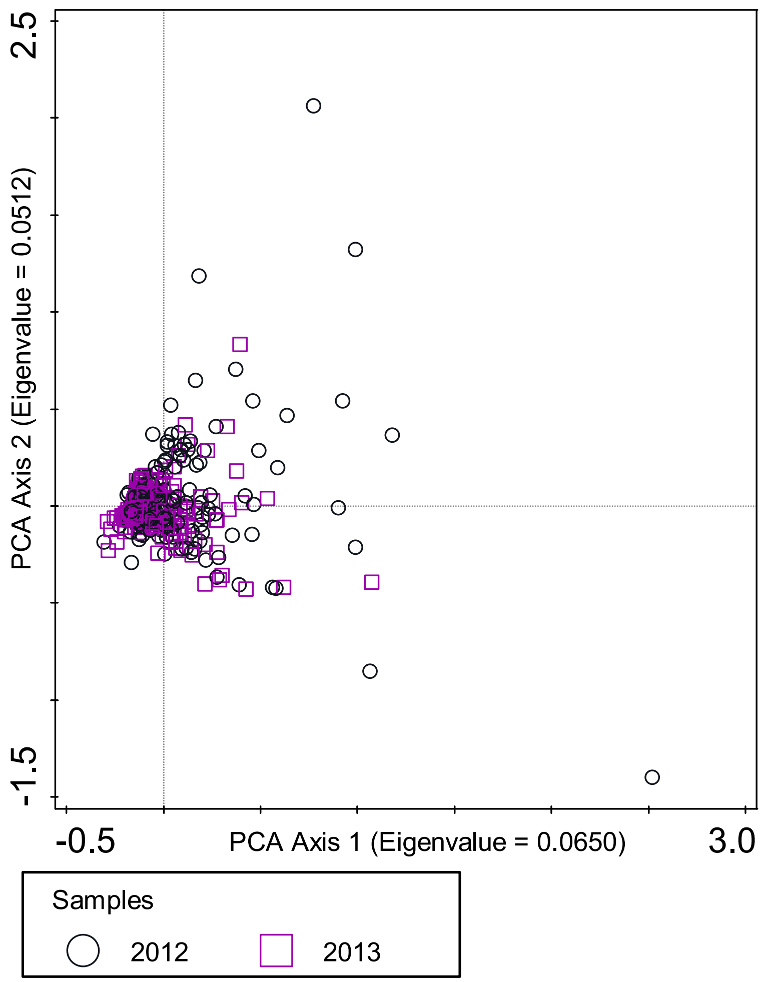


Figure 15. Scatter plot of sample loading scores of the first two axes from a principle components analysis on species composition collected from various locations in Barnegat Bay (Figure 1) in 2012 and 2013. Individual observations represent a sampling event at a given location during a given month and pool all individual trawl sets within that site/month

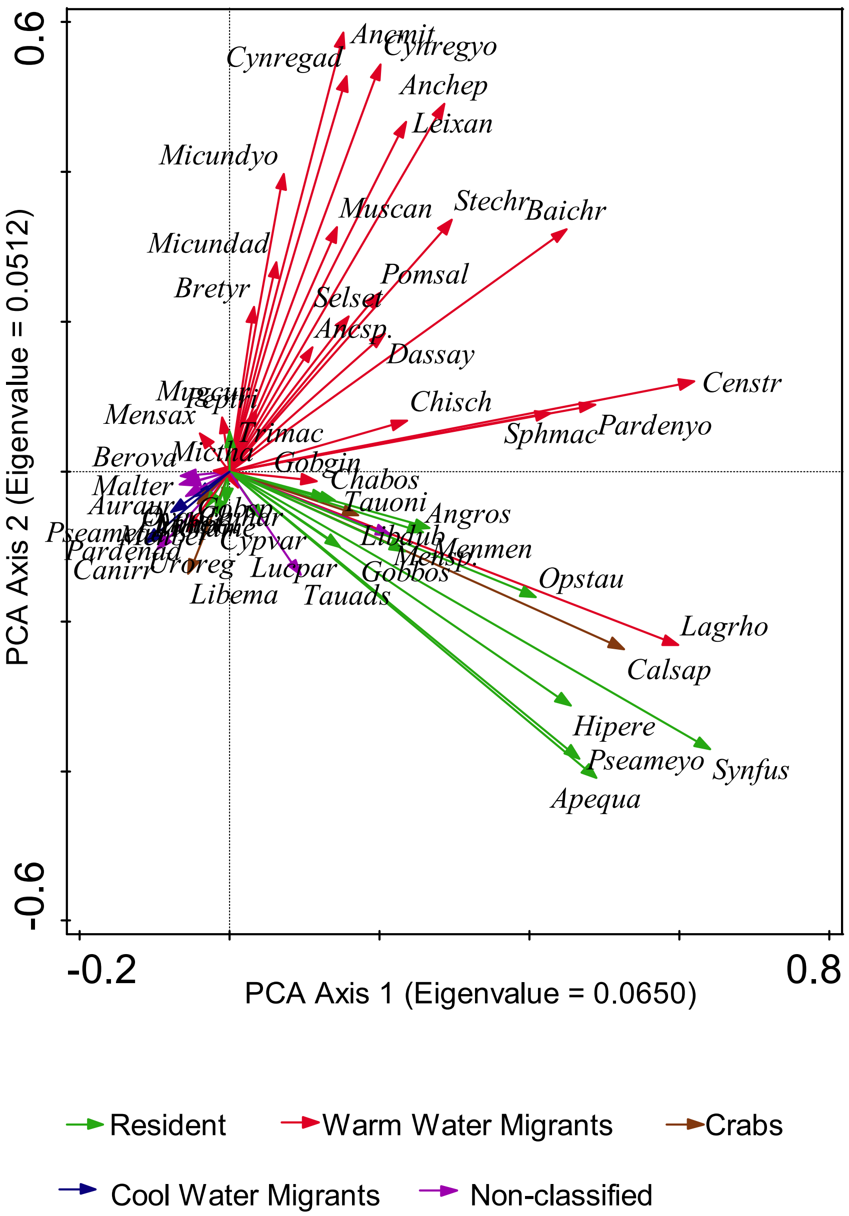


Figure 16. Co-occurrence trend in species collected by otter trawl in 2012 and 2013 in Barnegat Bay as represented by loading scores of the first two principle components analysis. Abundance of each species increases in the direction of arrows relative to occurrence in the samples shown in Figure 14, which is in the same ceonospace. 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 9A for full spelling). In addition, “ad” at the end of a spelling indicates adult and “yo” indicates juvenile for species classified into ontogenetic guilds.

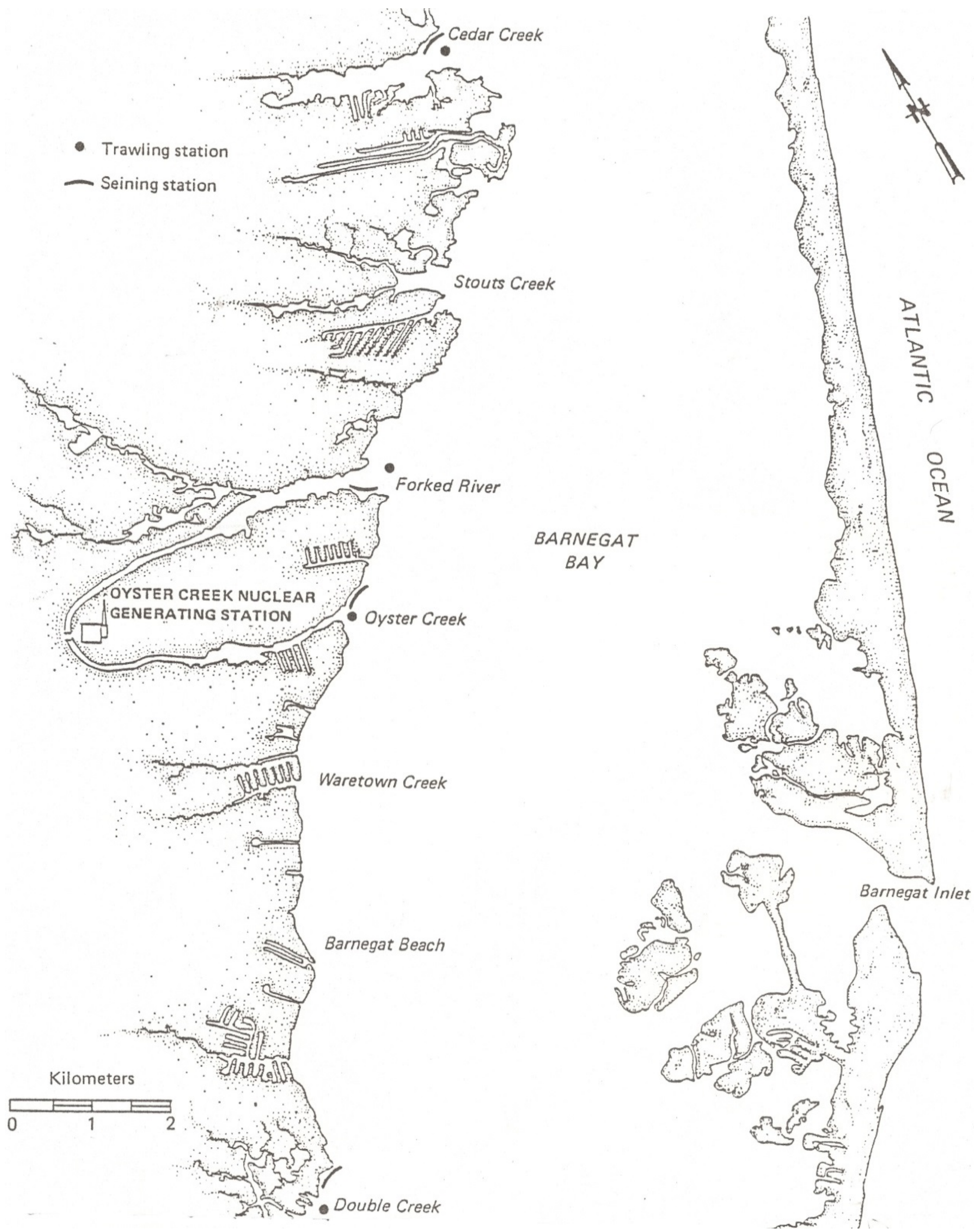


Figure 17. Sites sampled by Icththyological Associates, Inc. during environmental impact assessment for the OCNGS in 1970's and compared with our own recent sampling in 2012 and 2013.

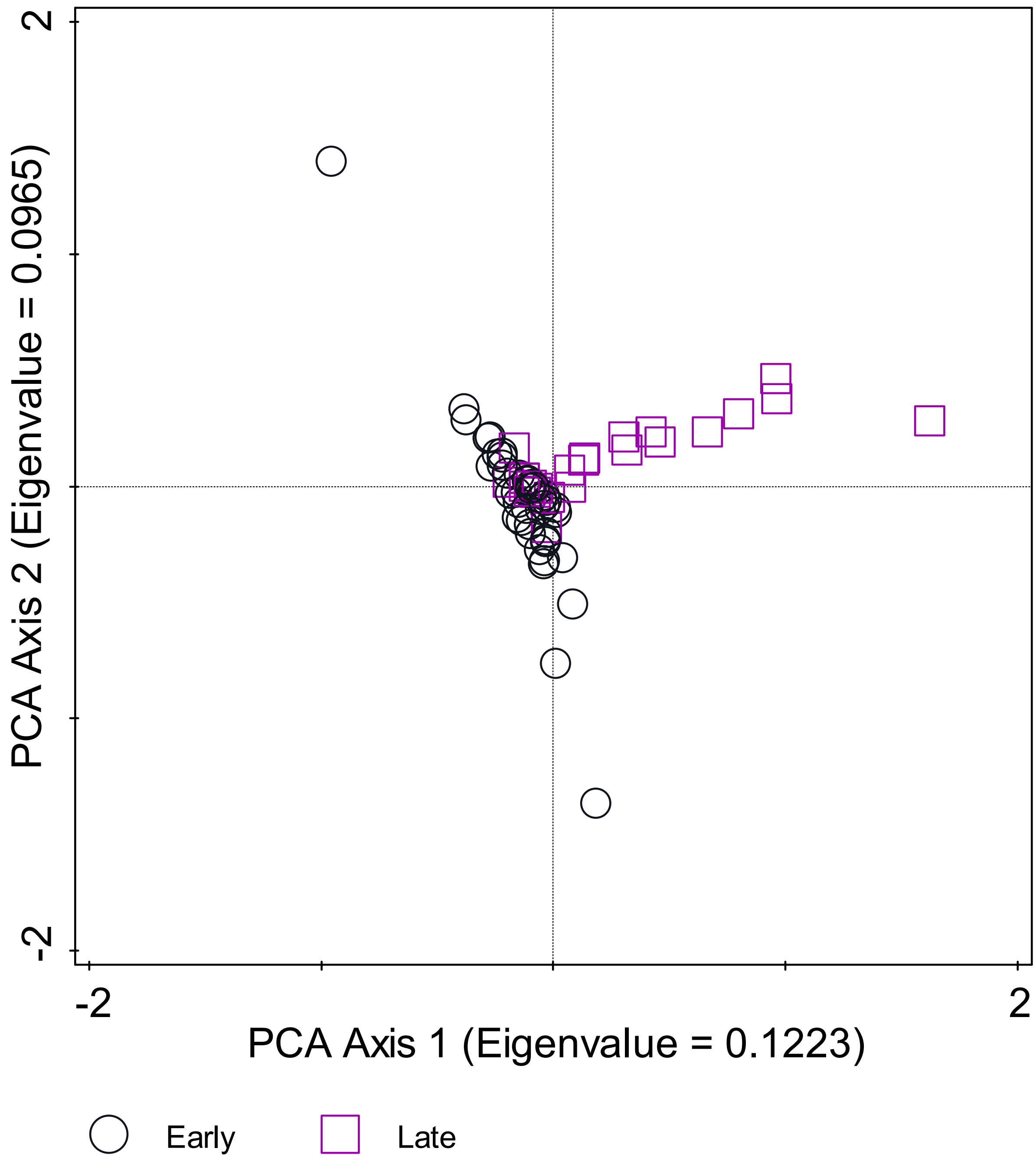


Figure 18. Graphical representation of the first two axes from a principle components analysis on species composition collected at four sites near OCNGS. Early observations include data collected in the late 1970s and early 1980s and Late observations include data collected in 2012 and 2013.

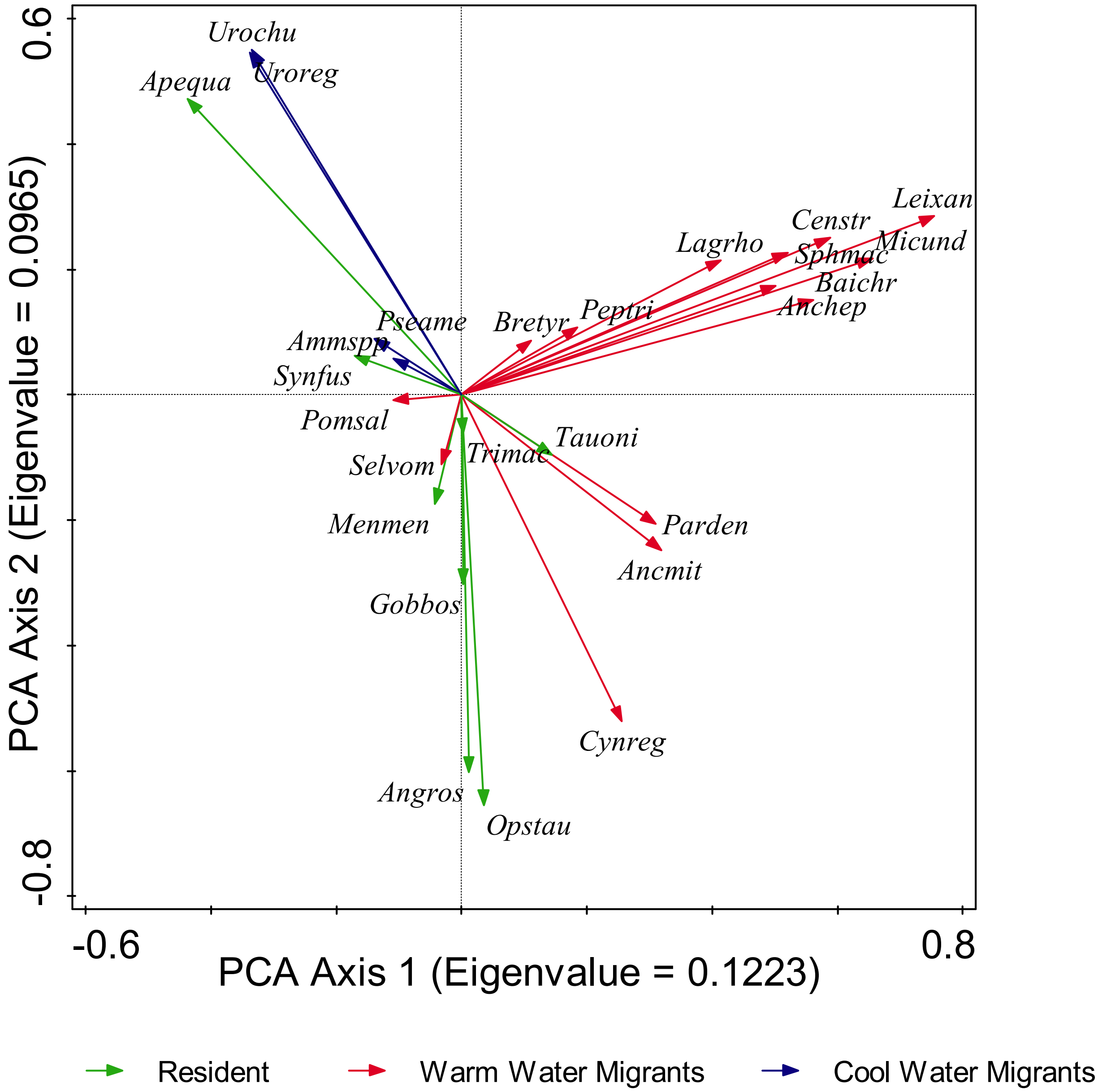


Figure 19. Graphical representation of the first two axes from a principle components analysis on species composition collected at four sites near OCNGS (Fig. 17). Species are categorized as resident, warm-water migrants, and cool-water migrants according to Kennish and Lutz (1984), with the exception 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).

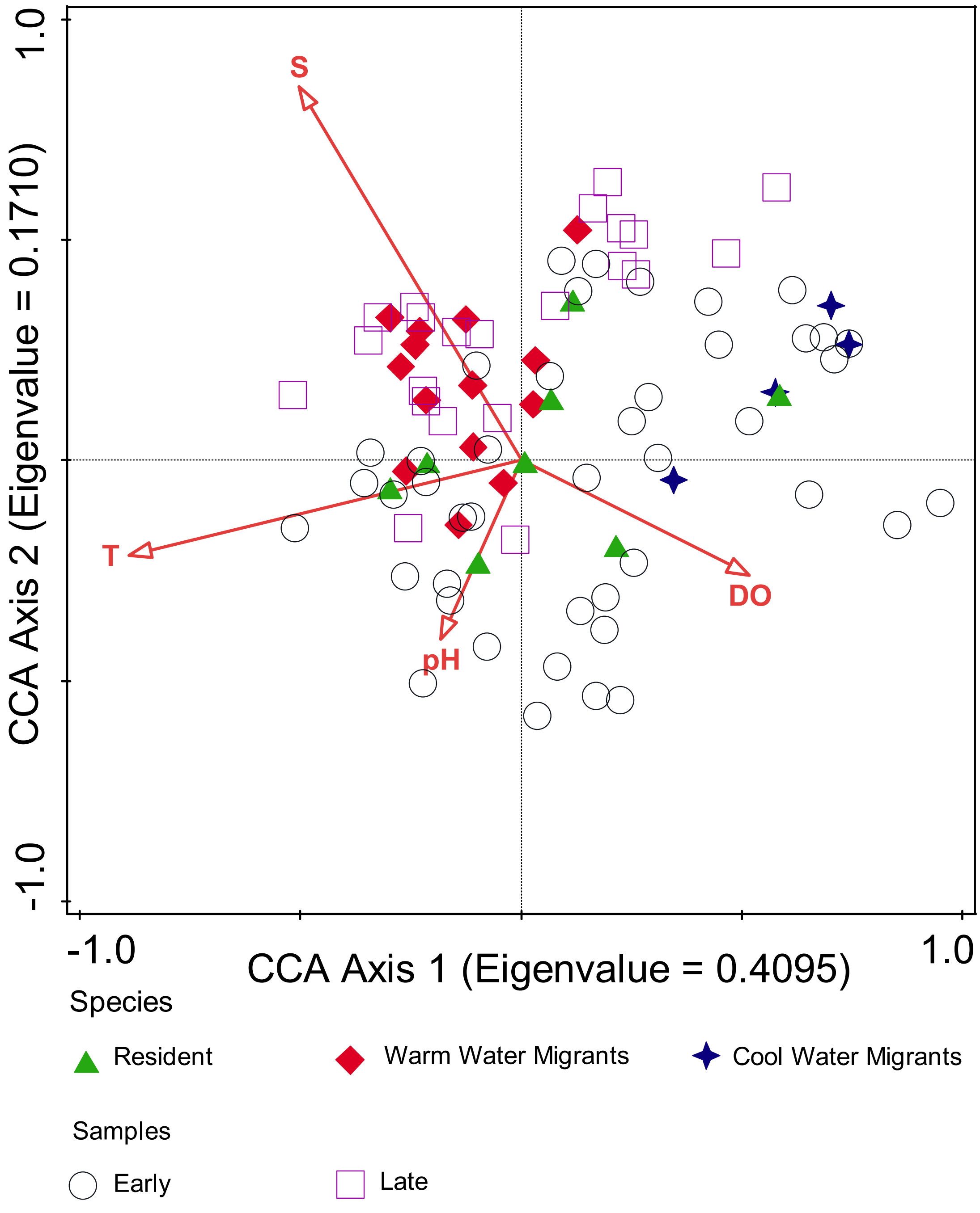


Figure 20. Graphical representation of the first two axes from a canonical correspondence analysis on species composition and environmental data collected at four sites near OCNGS (Fig. 13). Environmental vectors include temperature (T), salinity (S), dissolved oxygen (DO), and pH. Early (late 1970s/early 1980s) and Late (2012/2013) observations are identified by open symbols and individual species loading scores are identified by solid symbols.

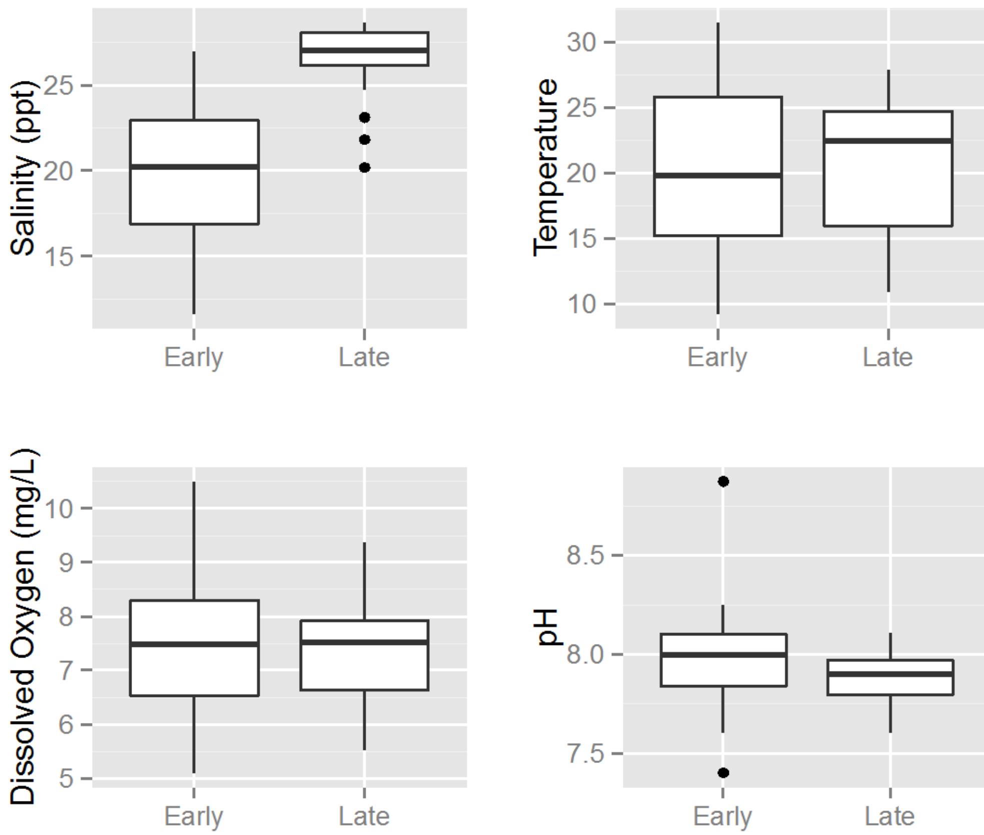


Figure 21. Box-plots of Early (late 1970s/early 1980s) and Late (2012/2013) environmental data collected at four sites near OCNGS (Fig. 13). Median values are represented by thick black lines, interquartile ranges are represented by the upper and lower bounds of the boxes, minimum and maximum values are represented by the upper and lower whiskers, and outliers are represented by dots.

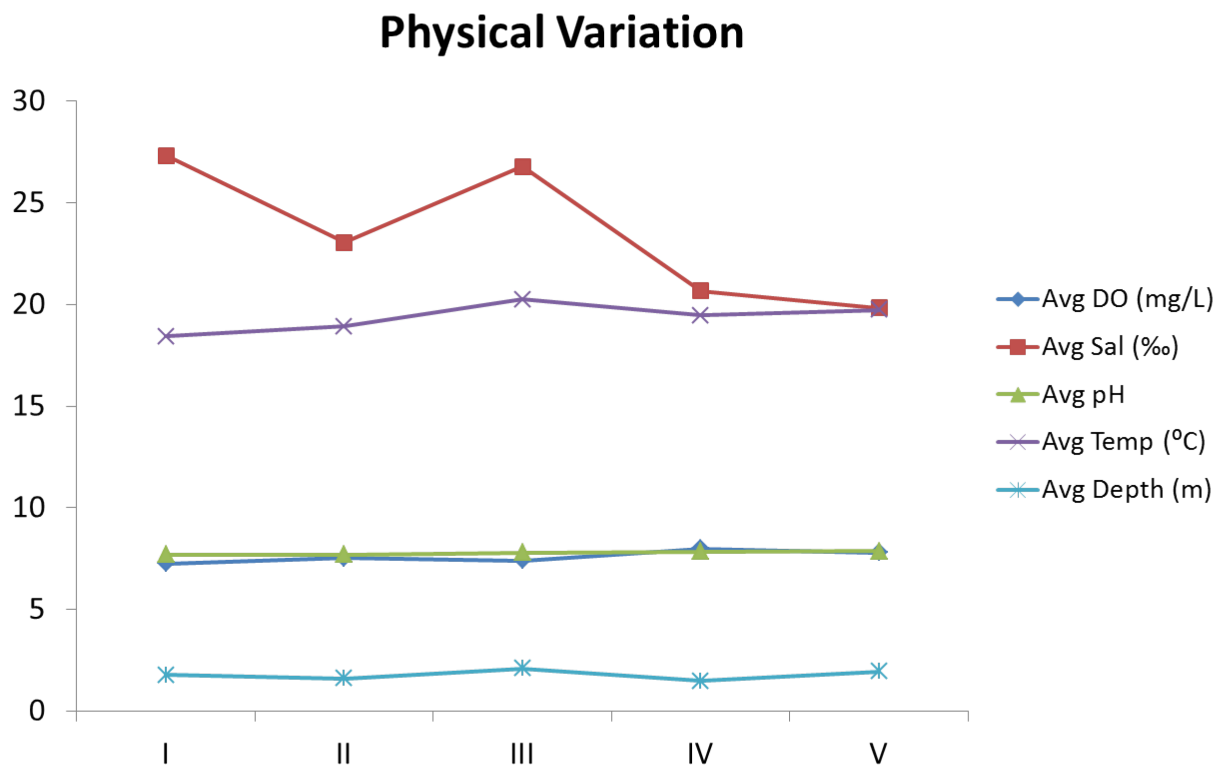


Figure 22. Variation in environmental variable (dissolved oxygen, salinity, pH, temperature, depth) by cluster (see Fig. 1) across all otter trawl sampling in 2013

Figure 23. 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).

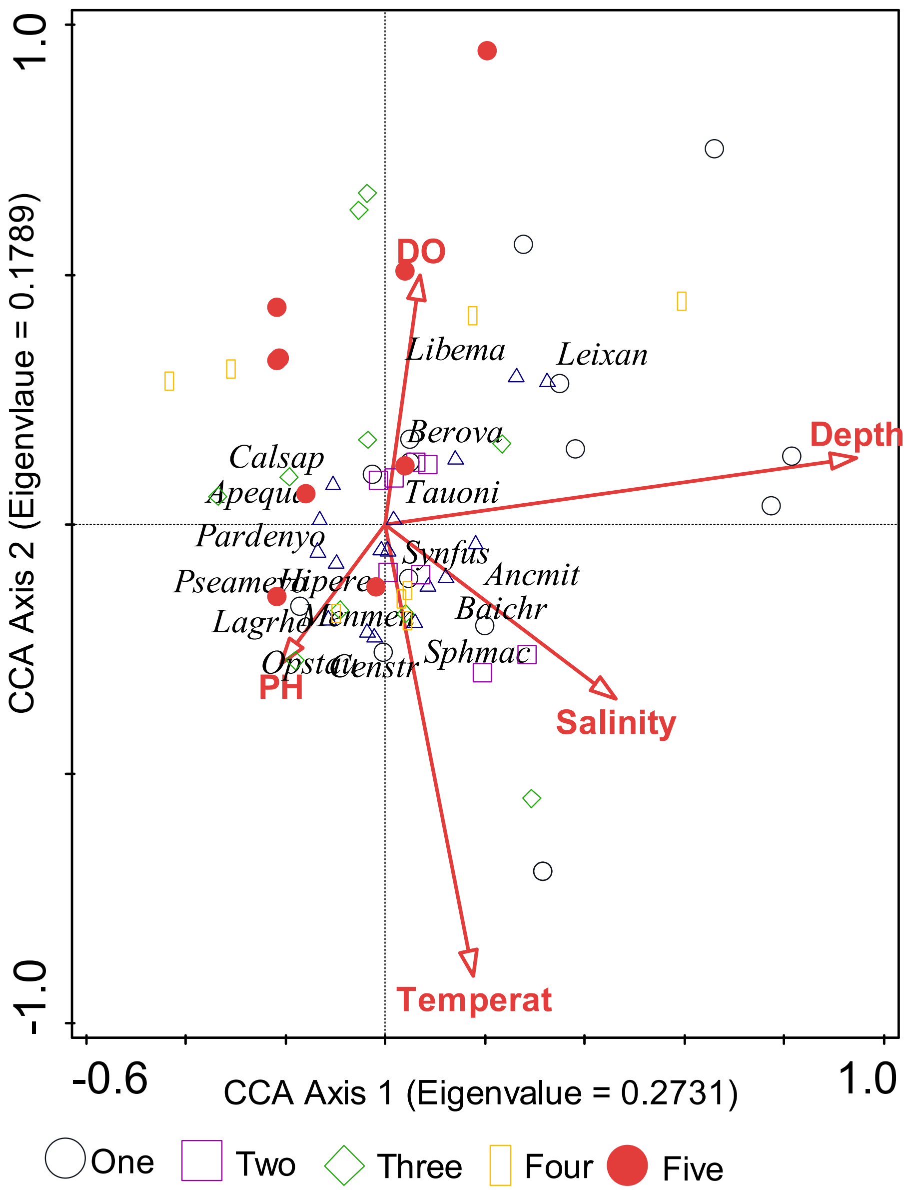


Figure 24. Tri-plot representation of the distribution of samples (geometric symbols) across physical/chemical gradients (arrows pointing in direction of increasing values) and species (text), on the first two axes from a canonical correspondence analysis on species composition and environmental data 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).

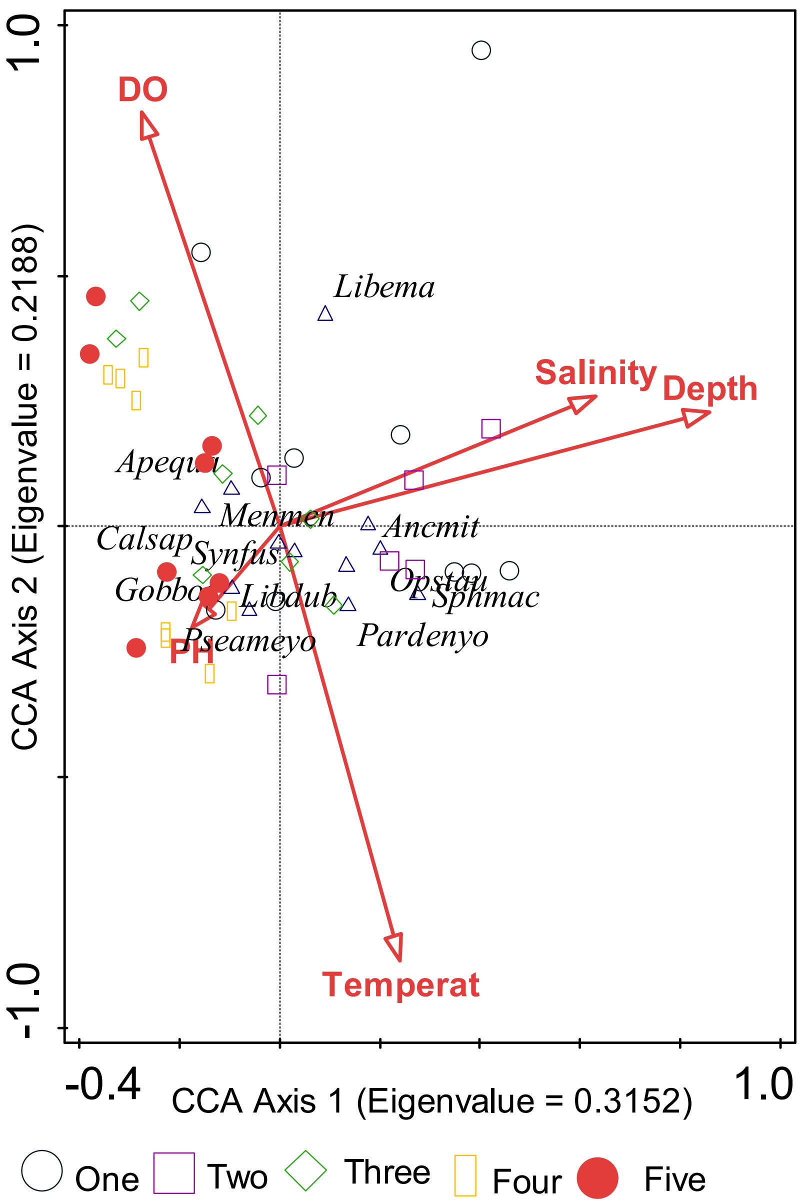
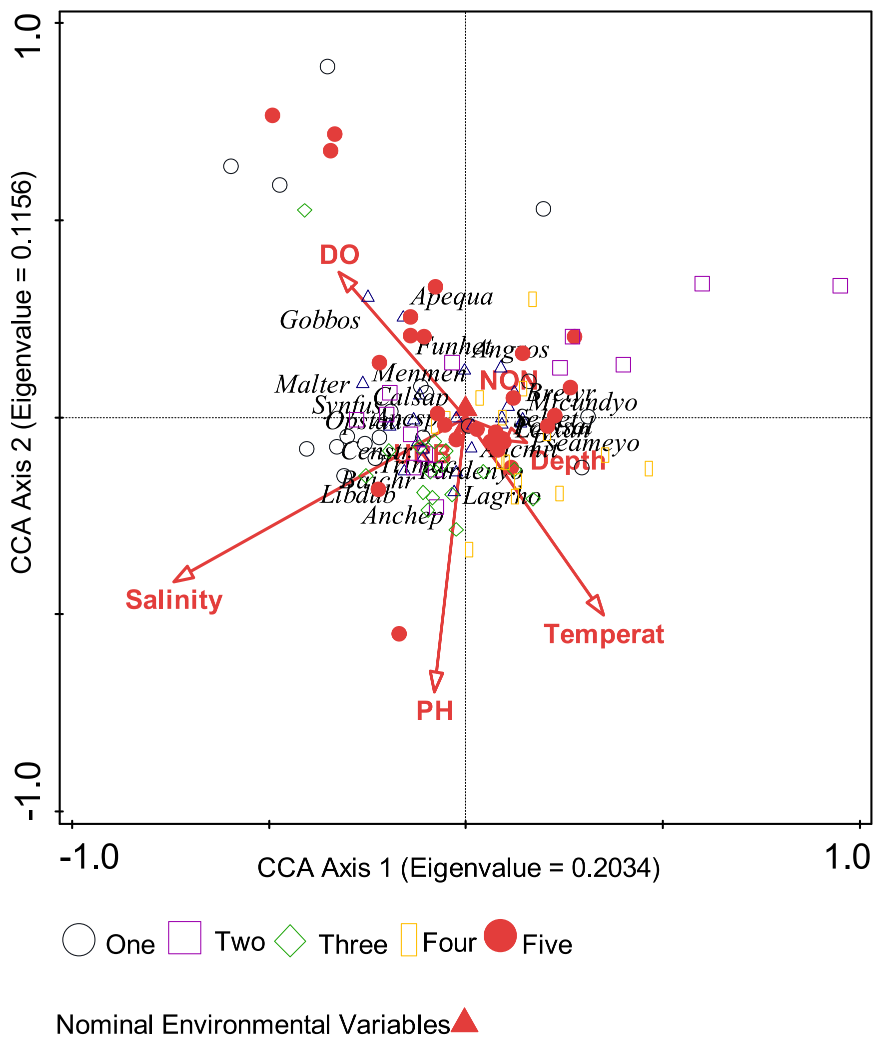


Figure 25. Tri-plot representation of the distribution of samples (geometric symbols) across physical/chemical gradients (arrows pointing in direction of increasing values) and species (text), on the first two axes from a canonical correspondence analysis on species composition and environmental data collected from marsh creek locations in Barnegat Bay in 2012. Environmental vectors include temperature (T), salinity (S), dissolved oxygen (DO), and pH. A categorical variable described as either urbanized (URB) or non-urbanized (NON)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).



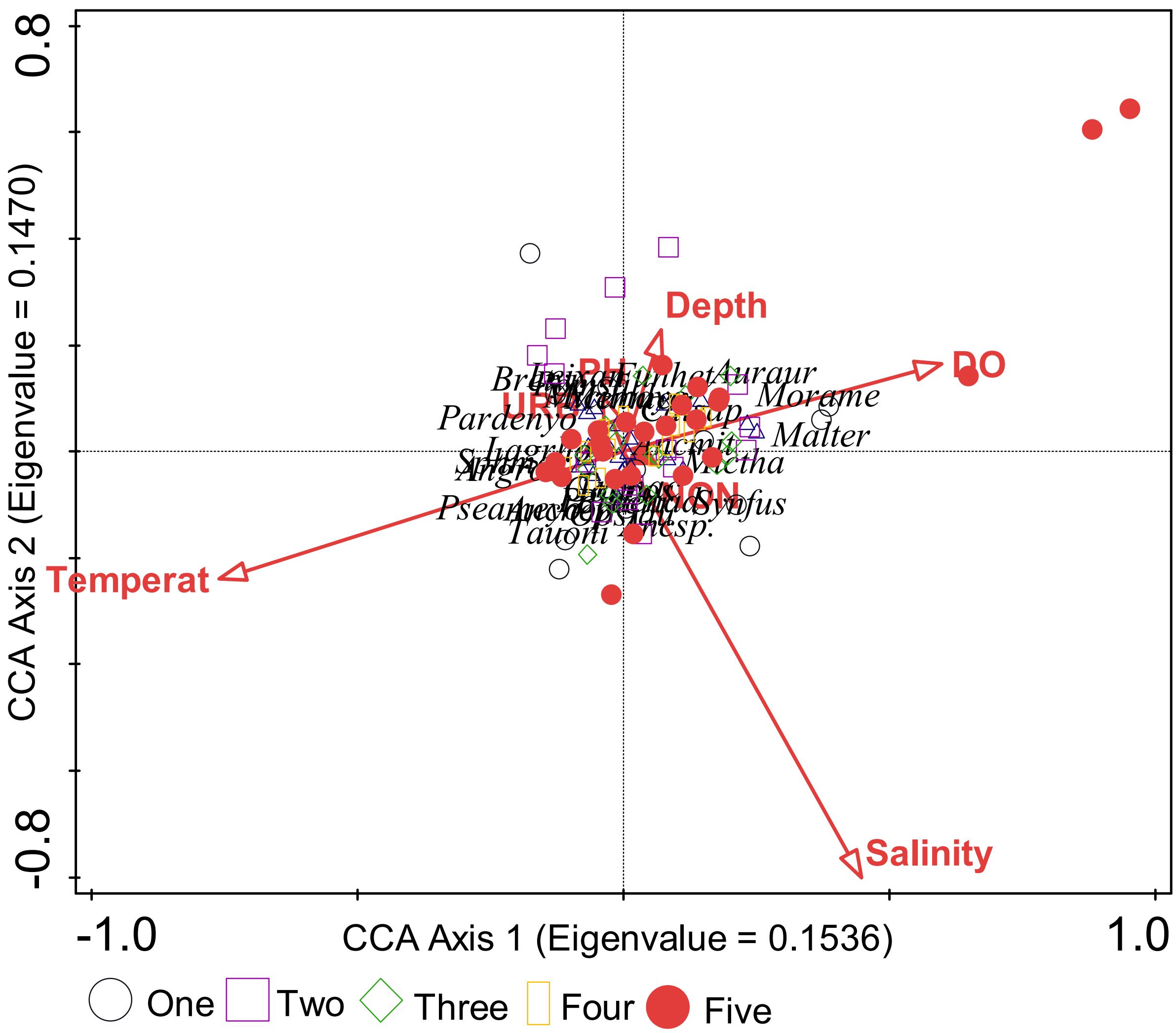


Figure 26. Tri-plot representation of the distribution of samples (geometric symbols) across physical/chemical gradients (arrows pointing in direction of increasing values) and species (text), on the first two axes from a canonical correspondence analysis on species composition and environmental data collected from marsh creek locations in Barnegat Bay in 2013. Environmental vectors include temperature (T), salinity (S), dissolved oxygen (DO), and pH. A categorical variable described as either urbanized (URB) or non-urbanized (NON)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).

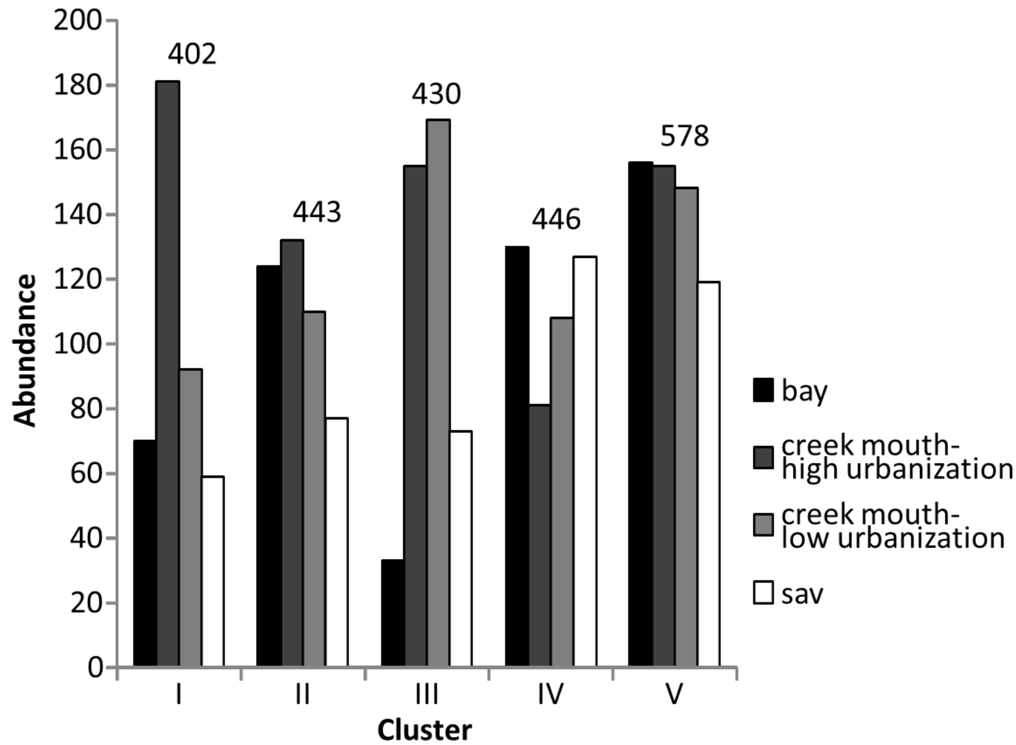


Figure 27. Abundance of blue crabs from traps deployed in four habitats at each cluster May-August, 2013. The numbers above the bars indicate the number of crabs captured per cluster.

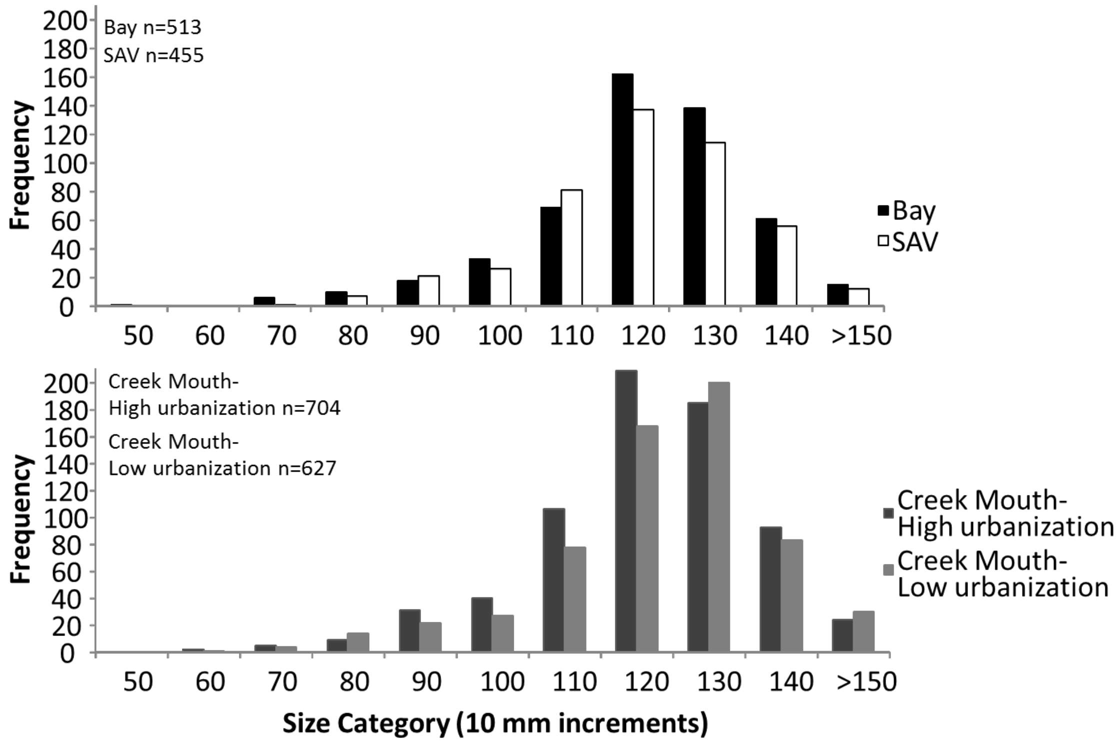


Figure 28. Size frequency distributions of blue crabs from traps deployed in four habitats at each cluster May-August, 2013.

.

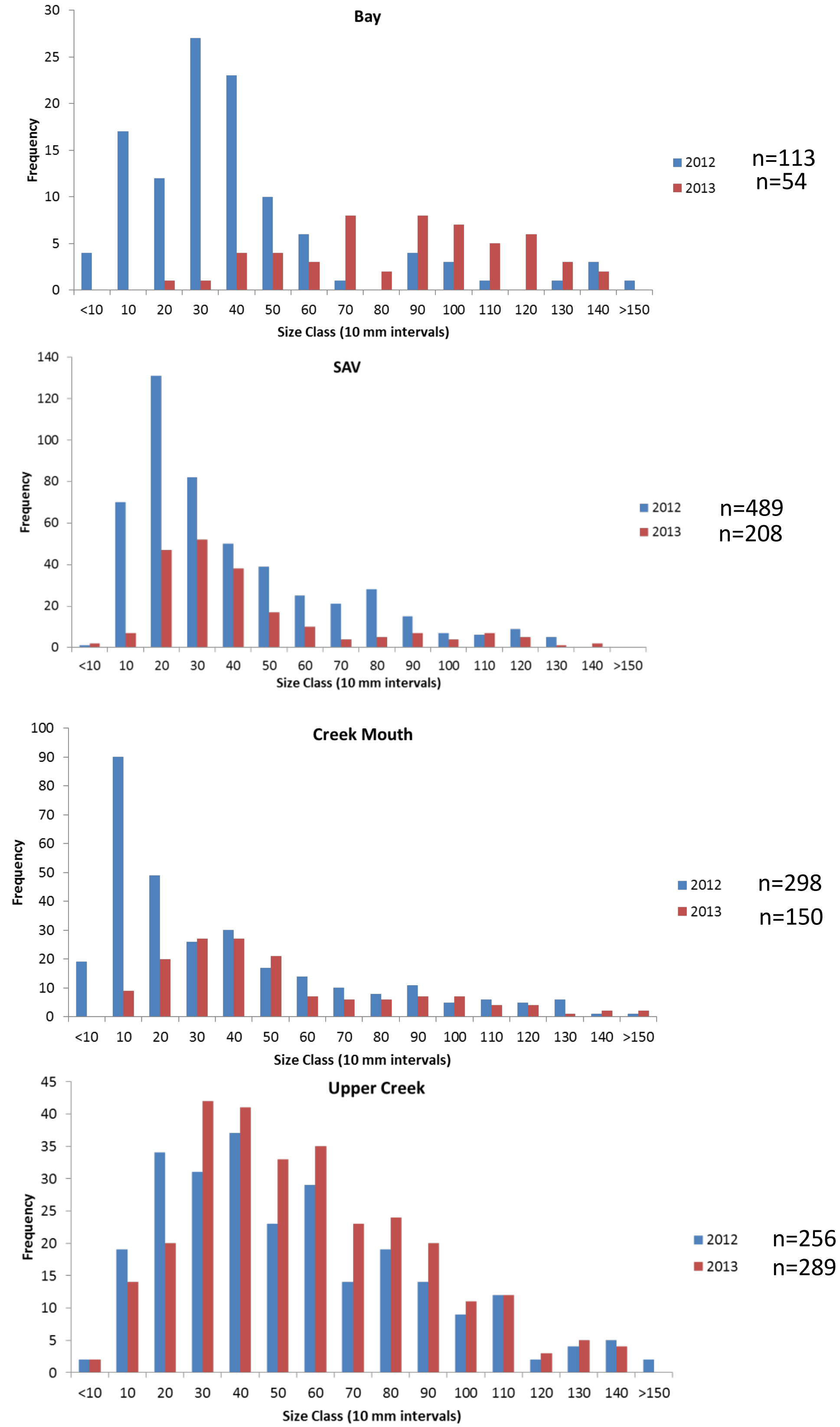


Figure 29. Size frequency distributions of blue crabs from June and August trawl samples in four habitats (clusters combined), 2012 and 2013. The numbers adjacent to the years are sample sizes.

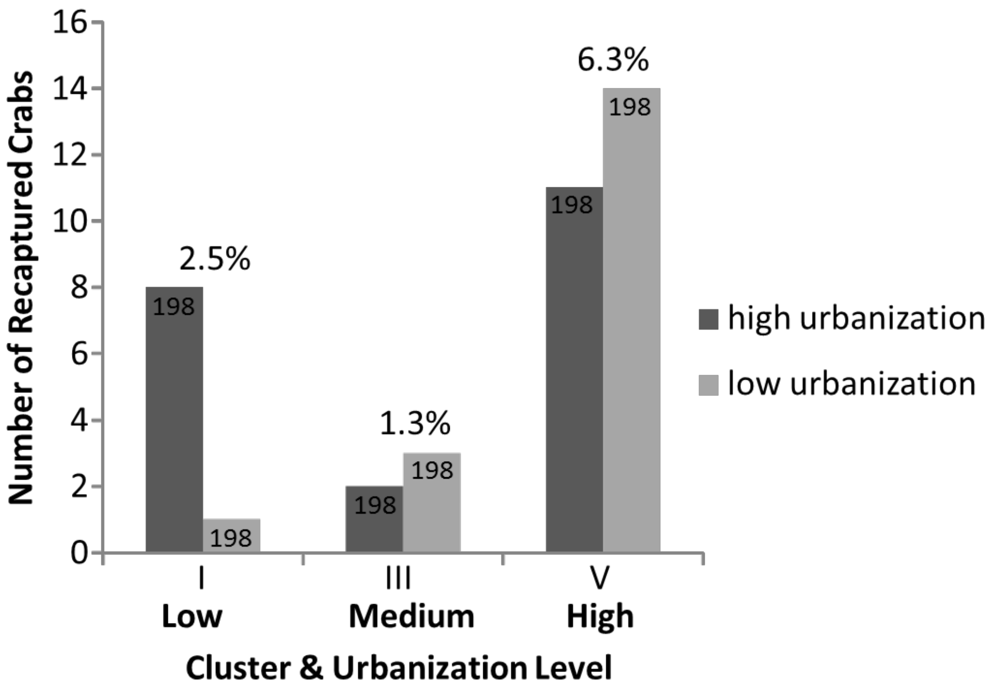


Figure 30. Number of crabs recaptured according to the cluster and creek type from which they were released, June-August 2013. The numbers inside each bar indicate the number of crabs tagged at each creek. The percentages above the bars indicate the recapture percentage for each cluster.

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.

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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. Compiled up to October 2013.

Able, K.W., C.W. Talbot and J.K. Shisler. 1983. The spotfin killifish, Fundulus luciae, is common in New Jersey salt marshes. Bull. N.J. Acad. Sci. 28(1):7-11.

Talbot, C.W. and K.W. Able. 1984. Composition and distribution of larval fishes in New Jersey high marshes. Estuaries 7(4A):434-443.

Coorey, D.N., K.W. Able and J.K. Shisler. 1985. Life history and food habits of the inland silversides, Menidia beryllina, in a New Jersey salt marsh. Bull. N.J. Acad. Sci. 30(1):29-38.

Talbot, C.W., K.W. Able and J.K. Shisler. 1986. Fish species composition in New Jersey salt marshes: Effects of marsh alterations for mosquito control. Trans. Amer. Fish. Soc. 115:269-278.

Vouglitois, J.J, K.W. Able, R.J. Kurtz and K.A. Tighe. 1987. Life history and population dynamics of the bay anchovy in New Jersey. Trans. Amer. Fish. Soc. 116(2):141-153.

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.

Wilson, K.A., K.W. Able, and K.L. Heck Jr. 1990. Habitat use by juvenile blue crabs: a comparison among habitats in southern New Jersey. Bull. Mar. Sci. 46(1):105-114.

Able, K.W. 1990. Life history patterns of New Jersey salt marsh killifishes. Bull. N.J. Acad. Sci. 35(2):23-30.

Able, K.W., R.E. Matheson, W.W. Morse, M.P. Fahay and G.R. Shepherd. 1990. Patterns of summer flounder Paralichthys dentatus early life history in the Mid-Atlantic Bight and New Jersey estuaries. Fish. Bull. U.S. 88(1):1-12.

Wilson, K.A., K.A. Able and K.L. Heck Jr. 1990. Predation rates on juvenile blue crabs in estuarine nursery habitats: Evidence for the importance of macroalgae (Ulva lactuca). Mar. Ecol. Prog. Ser. 58(3):243-251.

Sogard, S.M. and K.W. Able. 1991. A comparison of eelgrass, sea lettuce macroalgae, and marsh creeks as habitats for epibenthic fishes and decapods. Est. Coast. Shelf Sci. 33:501-519.

Rountree, R.A. and K.W. Able. 1992. Fauna of polyhaline subtidal marsh creeks in southern New Jersey: Composition, abundance and biomass. Estuaries 15(2):171-185.

Sogard, S.M. and K.W. Able. 1992. Growth variation of newly settled winter flounder (Pseudopleuronectes americanus) in New Jersey estuaries as determined by otolith microstructure. Neth. J. Sea Res. 29(1-3):163-172.

Sogard, S.M., K.W. Able and M.P. Fahay. 1992. Early life history of the tautog Tautoga onitis in the Mid-Atlantic Bight. Fish. Bull. U.S. 90:529-539.

Rountree, R.A. and K.W. Able. 1992. Foraging habits, growth, and temporal patterns of salt-marsh creek habitat use by young-of-year summer flounder in New Jersey. Trans. Am. Fish. Soc. 121: 765-776.

Rountree, R.A. and K.W. Able. 1993. Diel variation in decapod crustacean and fish assemblages in New Jersey polyhaline marsh creeks. Est. Coast. Shelf Sci. 37: 181-201.

Keefe, M. and K.W. Able. 1994. Contributions of abiotic and biotic factors to settlement in summer flounder, (Paralichthys dentatus). Copeia 1994(2):458-465.

Smith, K. J. and K.W. Able. 1994. Salt-marsh tide pools as winter refuges for the mummichog, Fundulus heteroclitus, in New Jersey. Estuaries 17(1B):226-234.

Sogard, S.M. and K.W. Able. 1994. Diel variation in immigration of fishes and decapod crustaceans to artificial seagrass habitat. Estuaries 17(3): 622-630.

Able, K.W., M.P. Fahay and G.R. Shepherd. 1995. Early life history of black sea bass Centropristis striata in the Mid-Atlantic Bight and a New Jersey estuary. Fish. Bull. 93: 429-445.

Rountree, R.A. and K.W. Able. 1996. Seasonal abundance, growth and foraging habits of juvenile smooth dogfish, Mustelus canis, in a New Jersey estuary. Fish. Bull. 94(3): 522-534.

Szedlmayer, S.T. and K.W. Able. 1996. Patterns of seasonal availability and habitat use by fishes and decapod crustaceans in a southern New Jersey estuary. Estuaries 19(3): 697-707.

Able, K.W., D.A. Witting, R.S. McBride, R.A. Rountree and K.J. Smith. 1996 Fishes of polyhaline estuarine shores in Great Bay - Little Egg Harbor, New Jersey: a case study of seasonal and habitat influences, pp. 335-353 In: Nordstrom, K.F. and C.T. Roman (eds.) Estuarine Shores: Evolution, Environments and Human Alterations. John Wiley & Sons, Chichester, England.

Rountree, R.A. and K.W. Able. 1997. Nocturnal fish use of New Jersey marsh creek and adjacent bay shoal habitats. Est. Coast. Shelf Sci. 44: 703-711

Able, K.W. and M.P. Fahay. 1998. The First Year in the Life of Estuarine Fishes in the Middle Atlantic Bight. Rutgers University Press. 342 p.

Duval, E.J. and K.W. Able. 1998. Aspects of the life history of the seaboard goby, Gobiosoma ginsburgi, in estuarine and continental shelf waters. Bull NJ Acad. Sci. 43(1): 5-10.

Witting, D.A., K.W. Able and M.P. Fahay. 1999. Larval fishes of a Middle Atlantic Bight estuary: assemblage structure and temporal stability. Can. J. Fish. Aquat. Sci. 56: 1-10.

Phelan, B.A., R. Goldberg, A.J. Bejda, J. Pereira, S. Hagan, P. Clark, A.L. Studholme, A. Calabrese and K.W. Able. 2000. Estuarine and habitat-related differences in growth rates of young-of-the-year winter flounder (Pseudopleuronectes americanus) and tautog (Tautoga onitis) in three northeastern US estuaries. J. Exp. Mar. Biol. Ecol. 247: 1-28.

Chant, R.J. M.C. Curran, K.W. Able and S.M. Glenn. 2000. Delivery of winter flounder (Pseudopleuronectes americanus) larvae to settlement habitats in coves near tidal inlets. Est. Coast. Shelf Sci. 51: 529-541.

Sogard, S.M., K.W. Able and S.M. Hagan. 2001. Long-term assessment of settlement and growth of juvenile winter flounder (Pseudopleuronectes americanus) in New Jersey estuaries. J. Sea Res. 45(3-4): 189-204.

Jivoff, P.R. and K.W. Able. 2001. Characterization of the fish and selected decapods in Little Egg Harbor. Journal of Coastal Research SI (32): 178-196.

Bologna, P.A.X., A. Wilbur and K.W. Able. 2001. Reproduction, population structure, and recruitment failure in a bay scallop (Argopecten irradians Lamarck) population from coastal New Jersey, USA. J. Shellfish Research 20(1): 89-96.

McBride, R.S., M.P. Fahay and K.W. Able. 2002. Larval and settlement periods of the northern searobin (Prionotus carolinus) and the striped searobin (P. evolans). Fish. Bull. 100:63-73.

Curran, M.C. and K.W. Able. 2002. Annual stability in the use of coves near inlets as settlement areas for winter flounder (Pseudopleuronectes americanus). Estuaries 25(2): 227-234.

Warlen, S.M., K.W. Able and E. Laban. 2002. Recruitment of larval Atlantic menhaden (Brevoortia tyrannus) to North Carolina and New Jersey estuaries: evidence for larval transport northward along the east coast of the United States. Fish. Bull 100(3): 609-623.

Smith, K.J. and K.W. Able. 2003. Dissolved oxygen dynamics in salt marsh pools and its potential impacts on fish assemblages. Mar. Ecol. Prog. Ser. 258: 223-232.

Correia, A.T., K.W. Able, C. Antunes, and J. Coimbra. 2004. Early life history of the American conger eel (*Conger oceanicus*) as revealed by otolith microstructure and microchemistry of metamophosing leptocephali. Mar. Biol. 145: 477-488.

Able, K.W., M.P. Fahay, D.A. Witting, R.S. McBride and S.M. Hagan. 2006. Fish settlement in the ocean vs. estuary: comparison of pelagic larval and settled juvenile composition and abundance from southern New Jersey, USA. Estuarine, Coastal and Shelf Science 66: 280-290.

Able, K.W., K.J. Smith and S.M. Hagan. 2005. Fish composition and abundance in New Jersey salt marsh pools: sampling technique effects. Northeastern Naturalist 12(4): 485-502.

Hare, J.A. and K.W. Able. 2007. Mechanistic links between climate and fisheries along the east coast of the United States: explaining population outbursts of Atlantic croaker (*Micropogonias undulatus*). Fisheries Oceanography 16:1, 31-45.

Sullivan, M.C., K.W. Able, J.A. Hare and H.J. Walsh. 2006. *Anguilla rostrata* glass eel ingress into two U.S. east coast estuaries: patterns, processes and implications for adult abundance. Journal of Fish Biology 69:1081-1101.

Sullivan, M. C., M. J. Wuenschel and K. W. Able. 2009. Inter- and intra-estuary variability in ingress, condition, and settlement of the American eel *Anguilla rostrata*: implications for estimating and understanding recruitment. Journal of Fish Biology 74:1949-1969.

Able, K. W., M. C. Sullivan, J. A. Hare, G. Bath-Martin, J. C. Taylor, and R. Hagan. 2011. Larval abundance of summer flounder (*Paralichthys dentatus*) as a measure of recruitment and stock status. Fishery Bulletin 109:68-78.

Able, K. W., T. M. Grothues, P. M. Rowe, M. J. Wuenschel, and J. M. Vasslides. 2011. Near-surface larval and juvenile fish in coastal habitats: comparisons between the inner shelf and an estuary in the New York Bight during summer and fall. Estuaries and Coasts 34(4):726-738.

Able, K. W., D. M. Allen, J. A. Hare, D. E. Hoss, K. E. Marancik, G. Bath-Martin, P. M. Powles, D. E. Richardson, J. C. Taylor, H. J. Walsh, S. M. Warlen, and C. Wenner. 2011. Life history and habitat use of the speckled worm eel, *Myrophis punctatus,* along the east coast of the United States. Environmental Biology of Fishes 92:237-259. DOI: 10.1007/s10641-011-9837-8.

Grothues, T. M., K. W. Able, and J. H. Pravatiner. 2012. Winter flounder (*Pseudopleuronectes americanus* Walbaum) burial in estuaries: acoustic telemetry triumph and tribulation. Journal of Experimental Marine Biology and Ecology 438:125-136.

Appendix Table 4.

American Eel Supply to an Estuary and Its Tributaries: Spatial Variation in Barnegat Bay, New Jersey

Kenneth W. Able*, Jennifer M. Smith, Jamie F. Caridad

Abstract

We evaluated the spatial variation in the supply of *Anguilla rostrata* (Lesueur) (American eel) glass eels and elvers to a Mid-Atlantic Bight estuary (Barnegat Bay, New Jersey) by sampling over two years at multiple inlets, thoroughfares to adjacent estuaries, and tributaries. Both inlets and all three thoroughfares provided sources of glass eels to Barnegat Bay. However, the level of supply to individual tributaries was markedly different, although size and pigmentation stage was consistent. The difference between tributaries might reflect distance from inlet supply and local human disturbance (a large lagoon-front housing development in one tributary). These pronounced differences imply that glass eel and elver supply to tributaries should be taken into consideration before mitigation or restoration is attempted in response to the decline of this species in North America.

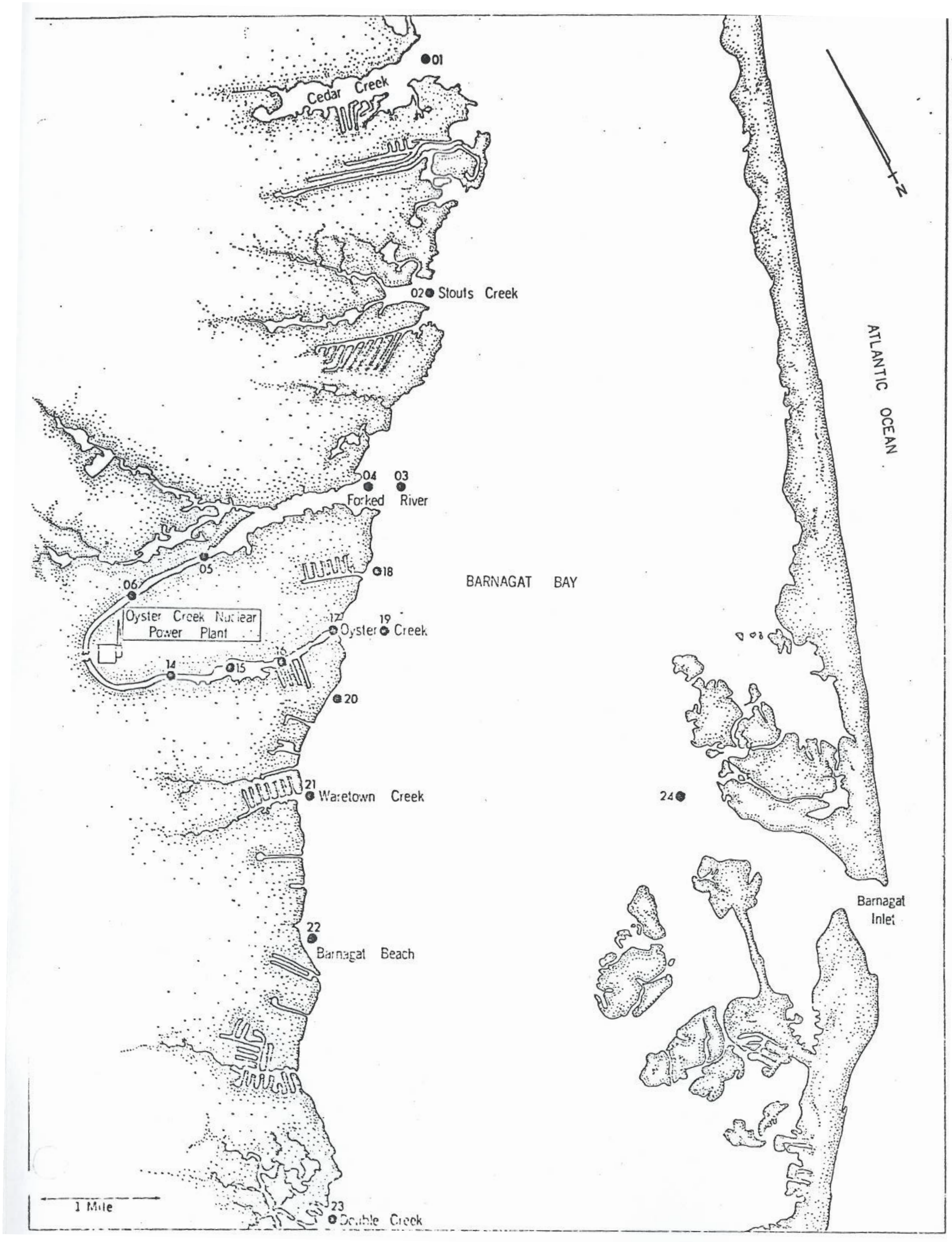
Appendix Table 5.

Temporal variation in winter flounder recruitment at the southern margin of their range: Is the decline due to increasing temperatures?

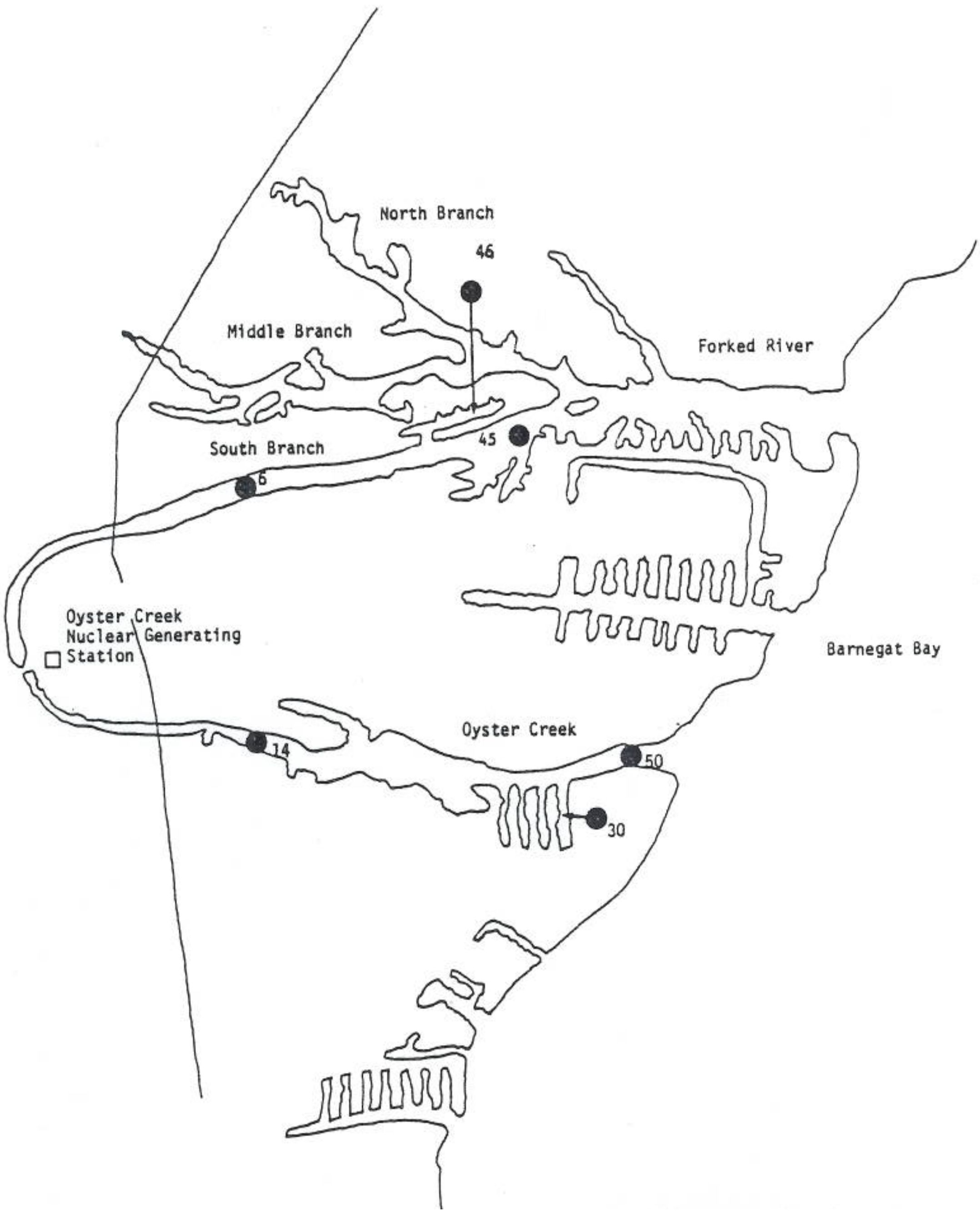
K. W. Able*, T. M. Grothues, J. M. Morson, K. E. Coleman

Abstract

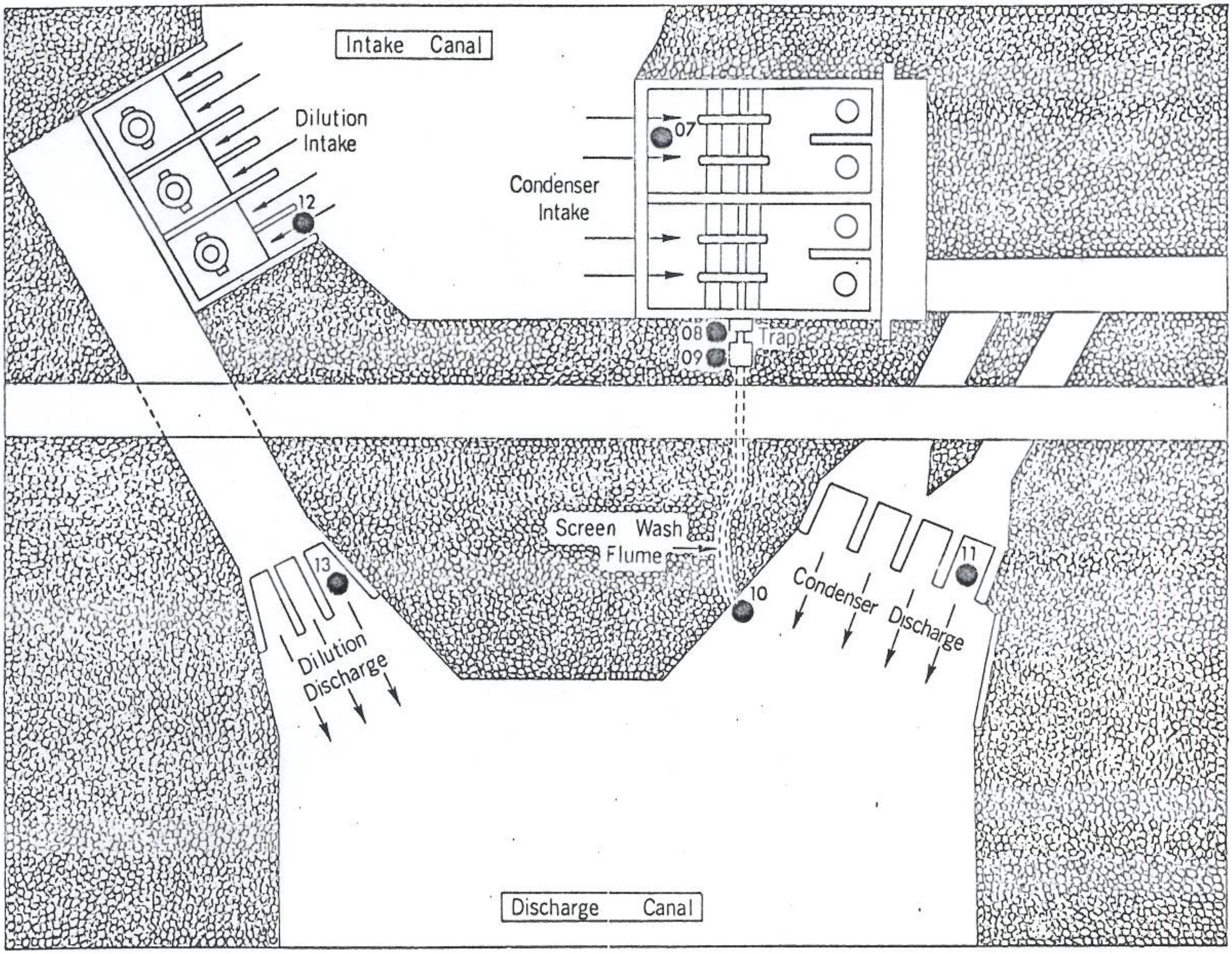
The southernmost stock of winter flounder (*Pseudopleuronectes americanus*), a cold temperate species of the Northwest Atlantic, has not recovered from overfishing despite continued restrictive measures, and appears to be contracting northward. We regressed larval and settled juvenile abundance (after accounting for adult and larval contribution to variation, respectively) on temperature over several decades from collections in New Jersey, USA, at the southern edge of their range to determine if increasing temperatures during the first year of life were responsible for this contraction. A significant stock/recruitment relationship at both stages was moderate, explaining 27.5 % of the variance for larvae on adults and 20.6 % for juveniles on larvae. There was no significant effect of average monthly temperature in explaining variance of the residuals for larvae, or of degree day on explaining the abundance of residuals for juveniles over a months-long settlement period. However, in both cases residuals were widely distributed at cold temperatures while they were always low at warm temperatures. Thus, years in which spring temperatures were warm (5-7 ^{o}C for February, 7-9 for March, and 11-20 for May) always experienced poor recruitment. Therefore, while temperature cannot account for past recruitment failure, it may be climbing to a tipping point where stock response changes. It is likely that a secondary effect, such as phenological intersection with predators that is itself dependent on temperature, plays a more important role than heat stress in determining recruitment success.



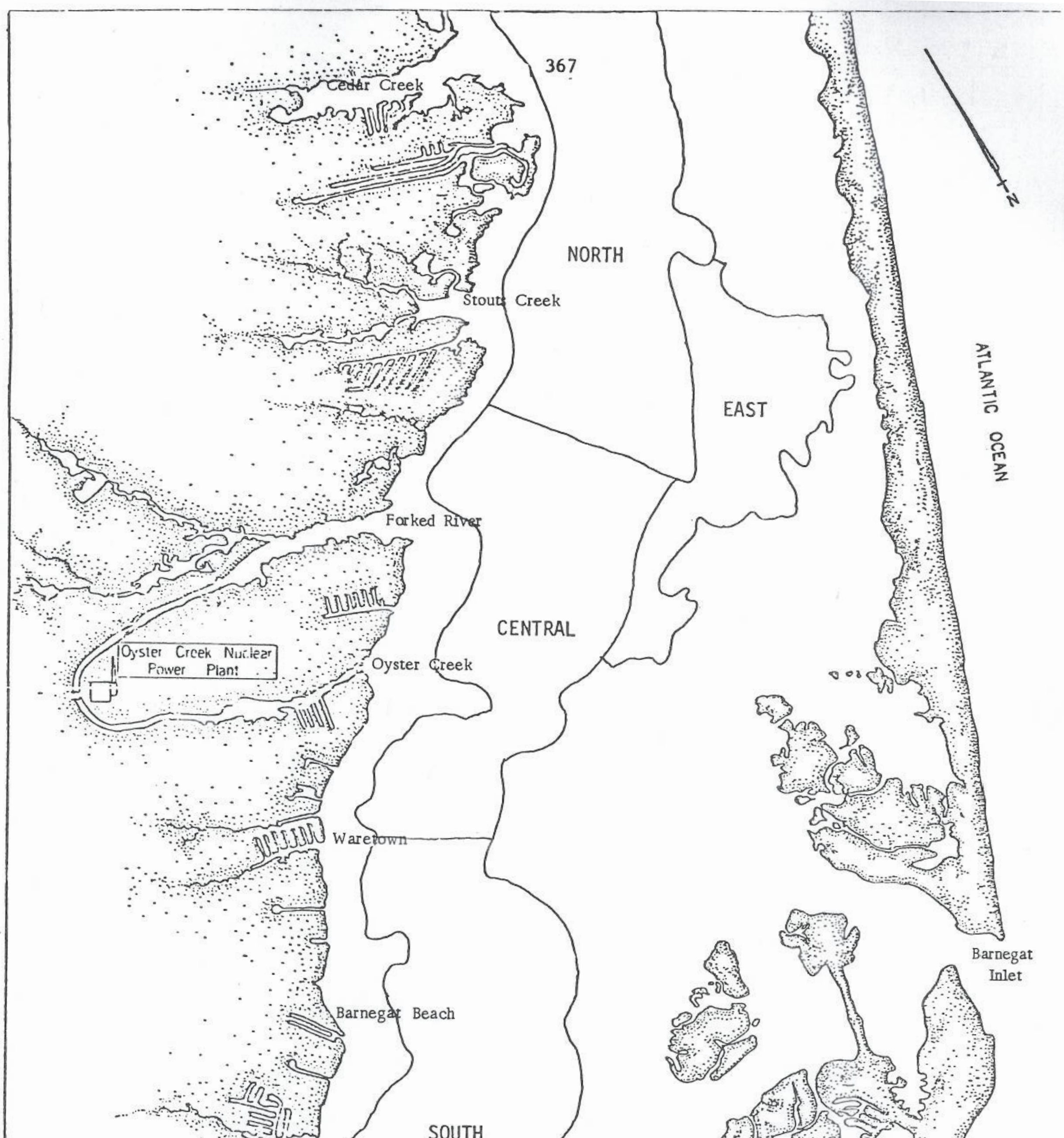
Appendix Figure 1. Sampling locations for biological collections taken for the Oyster Creek Nuclear Generating Station



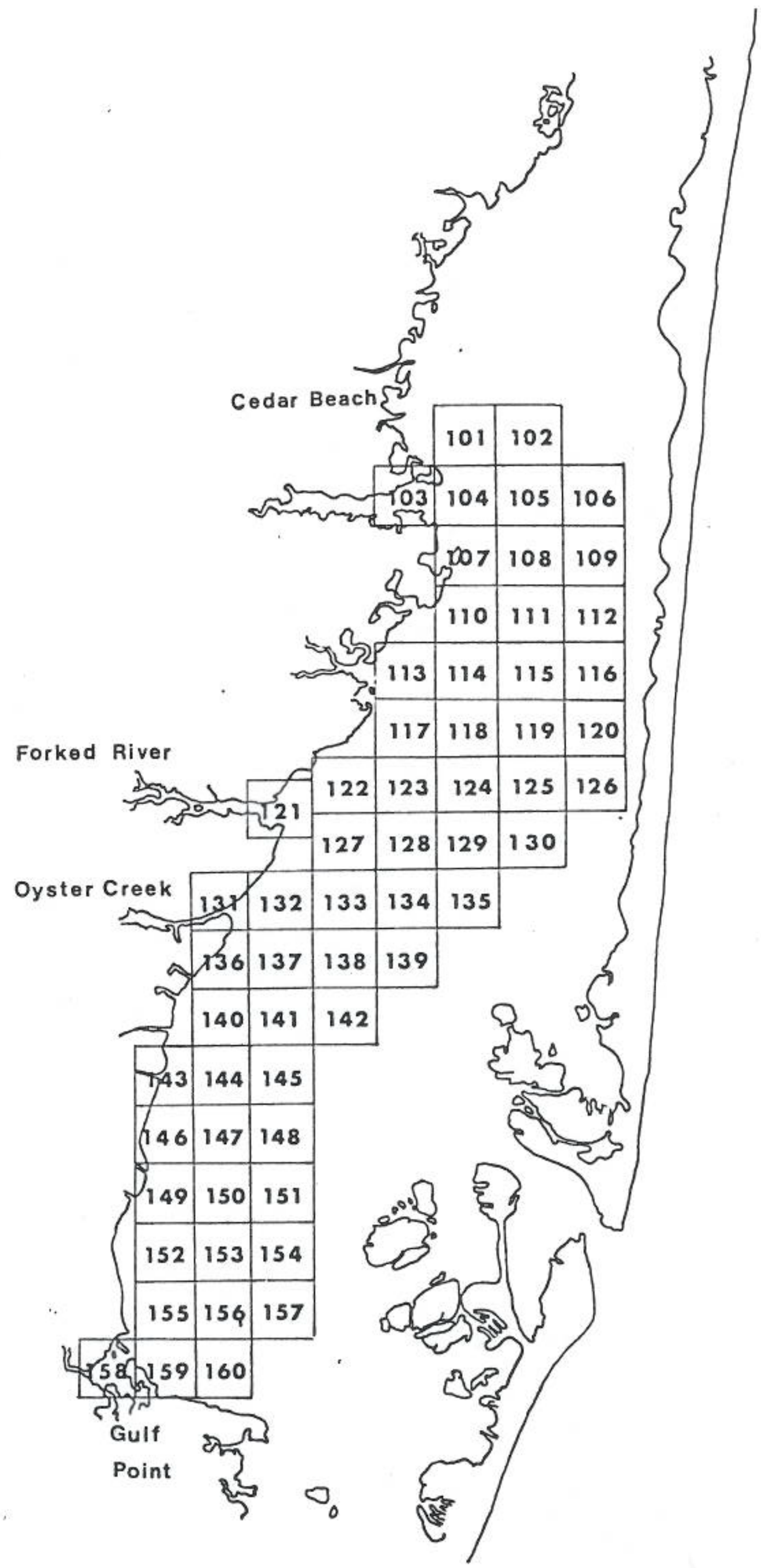
Appendix Figure 2. Sampling locations for ichthyoplankton collections for Oyster Creek Nuclear Generating Station thermal effects studies.



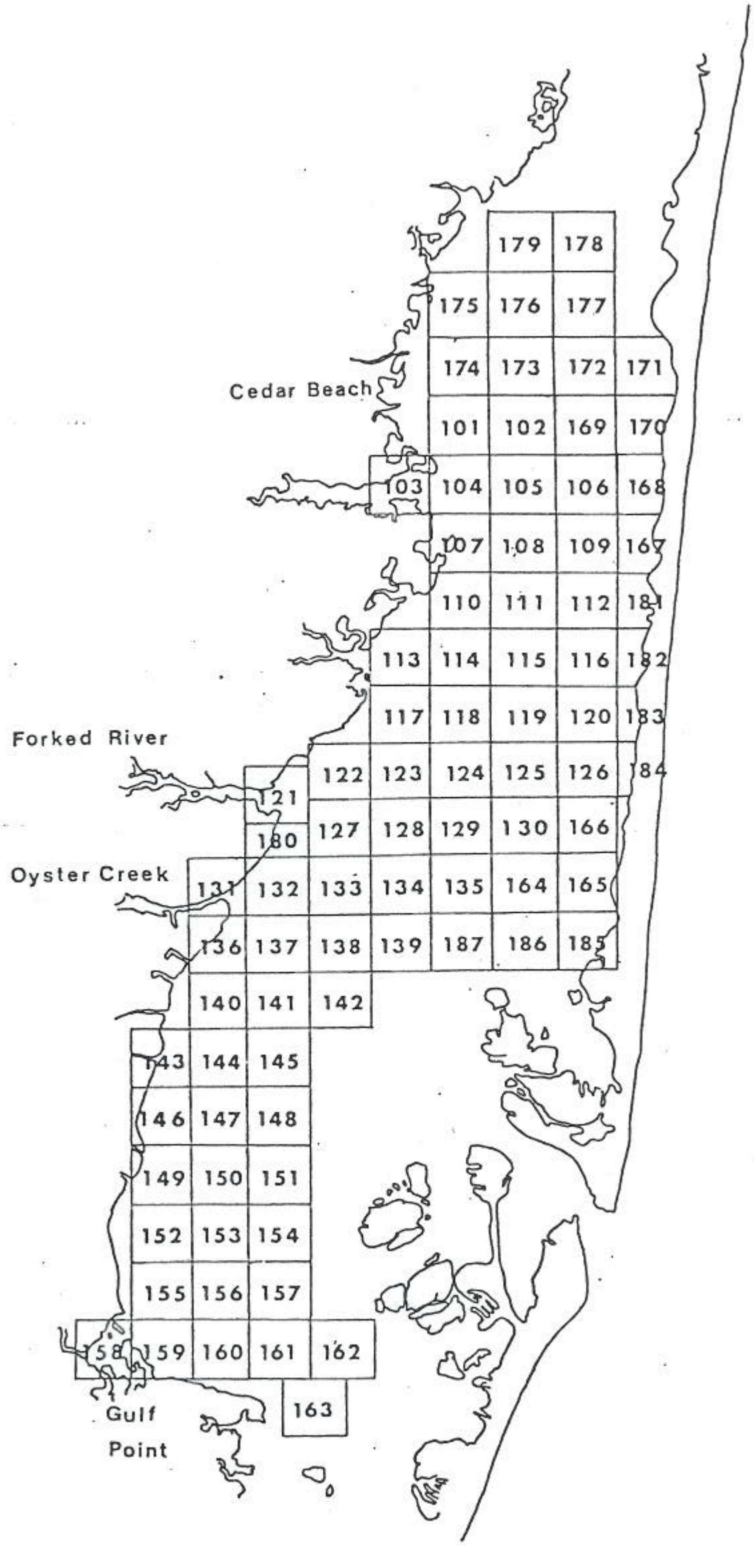
Appendix Figure 3. Sampling locations (●) for biological collections at Oyster Creek Nuclear Generating Station.



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



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



Appendix Figure 6. Quadrates used for ichthyoplankton population studies in Barnegat Bay.