Barnegat Bay—Year 1

Assessment of Fishes and Crabs Responses to Human Alteration of Barnegat Bay

Dr. Ken Able, Rutgers University, Principal Investigator
Dr. Paul Jivoff, Rider University, co-Investigator
Dr. Thomas M Grothues, Rutgers University, co-Investigator
Roland Hagan, Rutgers University, Quality Assurance Officer

Project Manager:
Bruce Ruppel, Division of Science, Research & Environmental Health

Thomas Belton, Barnegat Bay Research Coordinator

Dr. Gary Buchanan, Director—Division of Science, Research & Environmental Health

Bob Martin, Commissioner, NJDEP

Chris Christie, Governor

Barnegat Bay Year One Final Report

Project Title: Assessment of Fish and Crab Responses to Human Alteration in Barnegat Bay*

Dr. Ken Able, Rutgers University, Project Manager
able@marine.rutgers.edu

Dr. Paul Jivoff, Rider University, co-Manager
pjivoff@rider.edu

Dr. Thomas M Grothues, Rutgers University, co-Manager
grothues@marine.rutgers.edu

Roland Hagan, Rutgers University, Quality Assurance Officer
rhagan@marine.rutgers.edu

Tom Belton, NJDEP Research Coordinator
thomas.belton@dep.state.nj.us

Marc Ferko, NJDEP Quality Assurance Officer
marc.ferko@dep.state.nj.us

Bruce Ruppel, NJDEP Co-Manager
bruce.ruppel@dep.state.nj.us

Gary Buchanan, NJDEP Co-Manager
gary.buchanan@dep.state.nj.us

Brandon Muffley NJDEP Bureau of Marine Fisheries
brandon.muffley@dep.state.nj.us

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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 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 (along the north-south gradient in urbanization) variation in the Bay. During Year One we have 1) 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. Most fishes are represented by young-of-the-year individuals < 160 mm. Macrofauna is highly seasonal with abundance greatest in the summer. There was also a seasonal overturn of species. Abundance and diversity also changed across the spatial scale. For fishes associated with submerged aquatic vegetation (SAV, eelgrass, widgeon grass and macroalgae) habitat, more individuals of fewer species occurred in the more urbanized northern portion of the bay. However, a greater spatial effect was evident as indicated by the relationship between sample sites and distance to inlets. Enhanced water quality near inlets may also be substantial enough to explain greater fish abundance near inlets. The pattern was somewhat different for fishes in marsh creeks, which have a more direct connection to urbanization through shoreline alteration than SAV habitats, and which contain more resident species. In these, temperature and dissolved oxygen level was an important corollary of assemblage difference. Temperature reflected a seasonal common to all sites, but dissolved oxygen has local drivers and has the potential as a mechanism by which urbanization influences fish habitat. Further analysis, and continued collections in Year Two will focus on the seasonal and annual variation across the urbanization gradient.

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 highly impacted northern upper bay to the less impacted southern (Little Egg Harbor) lower bay, although the degree of human alteration varies between watersheds as well. The uncertainty regarding the effects of human alteration have prompted numerous efforts to positively influence Barnegat Bay, but there is no 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 all life history stages of fishes (larvae, juveniles, adults) and most stages of blue crabs. During Year One, we: 1) determined seasonal variation in species composition and abundance for larval fishes at Barnegat Inlet, Point Pleasant Canal and at Little Egg Inlet, 2) determined 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, determined the distribution and abundance of adult fish and adult blue crabs. Throughout this sampling effort we sought representative fish species of economical (e.g. striped bass, white perch, black sea bass, tautog) and ecological (e.g. Atlantic silverside, bay anchovy, menhaden and other herrings, sand lance) importance. This sampling, and subsequent analysis, also highlighted species known to be in decline (e.g. winter flounder, river herring, and weakfish). In addition, systematic sampling with a variety of gears provides increased opportunities to collect data on invasive species (e.g. mitten crabs). While this goal is largely descriptive of necessity, in that so little has been previously been quantified regarding fish use of this bay along any gradient, analysis focuses on the description of temporal and spatial gradients of which we can ask questions in further study. In recognition of the overarching goals, gradient analysis is driven by posing several specific null hypothesis. These are:

> $H_0$1: There is no difference in fish and crab abundance relative to gradients of urbanization in the Barnegat Bay on the bay-wide scale
>
> $H_0$2: There is no difference in the constituency of fish and crab assemblages relative to gradients of urbanization in the Barnegat Bay on the bay-wide scale
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> $H_0$3: There is no difference in fish and crab abundance relative to gradients of urbanization on the within-site scale
>
> $H_0$4: There is no difference in the constituency of fish and crab assemblages relative to gradients of urbanization on the within-site scale
>
> $H_0$5: There is no difference in the size of fish and crabs along the urbanization gradient as an indicator of growth and environmental health.

We determine the response of the fishes and crabs to urbanization using a variety of sampling techniques across multiple life history stages. First, we extended an ongoing (since 1988) otter trawl survey in the lower bay (Little Egg Harbor) for juvenile and adult fish and crabs 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 evaluate the responses to the pattern of human alteration by using species composition, abundance and size data of these major faunal groups. Second, we evaluate 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. Urbanization itself was measured through several broad scale factors reflective of the general first descriptive view of this estuary; population density and surface area cover by type (Agricultural, Barren lands, Forests, Water) on the bay-wide scale and shoreline modification on the within-site scale as described below in greater detail.

We also investigated the movement of crabs among sites in response to urbanization as reflected by fishing pressure (including recreational). We used a mark-recapture tagging protocol that was designed to assess movement of crabs within and between areas. We predict that recapture rates will positively correlate with the human urbanization gradient. We tested the specific null hypothesis

$H_0$6: There is no difference in movement of crabs among creeks as a function of urbanization.

Project Design and Methods

Study Sites

The Barnegat Bay watershed (≈ 1,730 km^2) is dominated by shallow (< 2m 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. 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 parts per thousand (ppt) 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 ppt) 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. 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 isolated sample clusters (Table 1) along the north-south axis of the bay. The exact location of each cluster (Fig. 1) was influenced by our knowledge of habitat distributions within each cluster and in some instances prior studies (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 likely to be urbanized and those likely to be fairly natural. The latter (natural sites) were chosen to correspond with the location of samples from previous studies in the central bay (Kennish and Lutz 1984). There was a focused effort to evaluate the response of fishes in terms of assemblage constituency and abundance in marsh creeks, because they might more immediately reflect urbanization effects than open bay sites through several mechanisms. For example, nutrients reach the bay through these shorelines after drainage from the creek water sheds, demersal or structure-oriented fishes may respond to shoreline alteration such as bulkheading, and hypoxia could be highly localized. 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).

Sampling Techniques

To determine the species composition and seasonal and annual variation in abundance and size, larval fish were sampled seasonally (spring and early and late summer) on night flood tides using plankton nets (1 m diameter mouth, 1.0 mm mesh, 3 tows on each date) (Table 3). 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. 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 response of juvenile and adult fishes and blue crabs, each habitat/location was sampled seasonally (spring and early summer) during the daytime using otter trawl sampling techniques (Table 4). All of the priority fauna (fishes, crabs) were collected with three replicate tows at each station using an otter trawl .9 m headrope, 19 mm mesh wings and 6.3 mm mesh liner. For each otter trawl sample the water depth, surface water temperature, salinity, and dissolved oxygen was recorded with a hand-held YSI meter. The amount of vegetation in the trawl was also quantified as an indication of cover and detrital base available. Vegetation was separated into agal and seagrass components and the volume of each component was measured separately, unless volumes were massive (many 10s of litters) in which case the contribution of each was estimated as a percent of the total. Volume was measured uncompressed in bucket on which graduations of 2 L were marked. Quantities smaller than 1 L were measured in a 300 mL graduated cylinder. Very small amounts, such as a few grass blades, were marked as “Trace”.

In order to determine distribution of larger juvenile and adult fishes in distance and time, 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). Gill nets were set (2 nets per site) for 60 minutes during each sampling day. If no fish were caught in the initial 60 minute period, the nets were reset for another hour to increase catch probability.

Trap sampling for blue crabs 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., menhaden). As part of a mark-recapture study during trap sampling, a day was designated for tagging crabs from each location. Once per month (twice in July and

August), a sample of adult crabs (1650 total and varying monthly depending on how many crabs were available in the traps) 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). Tags were evenly divided (275 each) among 6 creeks, one highly urban urban and one lowly urban creek each in Clusters I, III, and V. 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.

Quality Assurance

Our program has a NJDEP approved QAPP. We did not deviate from the QAPP. Data were reviewed at multiple levels as described in the QAPP, (i.e. fish ids were checked, every data entry from sheet to computer was checked and also verified in a process consistent with treatment of metadata and data at RUMFS (Vasslides et al. 2011). All errors were corrected at checking.

Results and Discussion

Characteristics of Study Sites

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 for land use in each cluster. These are Agricultural, Barren Land, Forest, Urban, Water, and Wetlands (Table 1). 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 land cover types (Percent Agricultural, Barren lands, Forests) were either poorly represented as a fraction of the total or were similar (percent water) among clusters.

Within each cluster, we selected representative habitat types including submerged aquatic vegetation, tidal creeks (upper and lower), and open bay for sampling fishes and crabs (Fig. 1, Table 2). Preliminary analysis of these habitats varies by cluster as well. The more urbanized clusters have fewer and shorter marsh creeks with borders of emergent vegetation (Fig. 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. The dominant submerged vegetation was either eelgrass (*Zostera marina*) and widgeongrass (*Ruppia maritima*) combined, or macroalgae of various types (Table 2). The volume of submerged vegetation varied among and within habitats and clusters (Table 2). Average creek length is greater in Clusters I, II and III while the degree of urbanization is highest in Clusters III, IV and V (Table 1, Fig. 2). This inverse relationship may be a consequence of urbanization arising from the manipulation and grading of historical marsh lands for development.

The environmental characteristics at each habitat varied more by habitats within clusters then between clusters during the February, April and June sampling period (Table 2, Fig. 3). Salinities were generally high (>20 ppt) in Clusters I, II and III. The lowest values typically occurred in Clusters IV and V. Temperature was similar across all clusters. Dissolved oxygen levels were typically high (> 5 mg/L) during most of these sampling periods.

Fishes

Data collection of larval (Table 3), juvenile and adult fishes, and blue crabs (Table 4 and 5) proceeded as planned except that larval fish sampling in October did not occur due to Hurricane Sandy. Collections (including otter trawl, gill net, and plankton net samplings) from 54 total sites have been gathered during February reconnaissance and April, June, August, and October 2012 sampling of fishes. The data for plankton net, otter trawl and gill net sampling has been entered and verified. This resulted in 615 otter trawl tows during the year that collected 8993 fishes and 2432 crabs (Table 4). Over the same period there were 73 gill net collections, which found 185 fishes and 79 crabs (Table 5). The low CPUE of gill nets appears to be a function of daytime net avoidance, possibly influenced by copious amounts of drift algae being entangled in the nets. Early results from comparative nocturnal/diurnals gill net sampling in Year 2 support this, with much higher nighttime CPUE.

The fish length composition varied with gear and month, but not by habitat or along the urbanization gradient. The smallest fishes were represented by collections of larvae with plankton net collections and the largest were of juveniles and adults from gill net collections, while those from otter trawl collections were largely of intermediate length (Fig. 4). The occurrence of large individuals (> 160 mm) were represented by American eels, smooth dogfish, weakfish, summer flounder, and winter flounder. The fish lengths by sampling month clearly indicated two dominant size classes in otter trawl samples with one class indicated by modes of 50 mm in April, 60 – 70 mm in June, and 140 mm in August (Fig. 5). These are primarily young-of-the-year of many different species. Another group occurred at sizes of about 40 mm in June, with similar modes in August and a mode of 50 mm in October. These interpretations of size classes could be influenced by gear avoidance and the departure of larger individuals from Barnegat Bay in late summer and early fall. The composite length frequencies across the entire year appeared similar between habitat types with bay, upper creek, lower creek and submerged aquatic vegetation habitats with two length modes, one at approximately 40 – 70 mm and another at 130 – 160 mm (Fig. 6). The submerged aquatic vegetation habitat appeared to have slightly larger fishes at > 160 mm. Each cluster along the urbanization gradient (Clusters I – V), which was composed of all habitat types, had two similar modes as those indicated by habitat type (Fig. 7).

The monthly occurrence of individual species (Table 6) was as expected for most species based on past experience (Able and Fahay 2010). Typical spring species included Atlantic herring and winter flounder. Other species were commonly collected in most months including American eel, fourspine stickleback, Atlantic menhaden, Atlantic silversides, blue crabs and spider crabs. Late summer and fall collections were characterized by weakfish, white mullet and Atlantic moonfish. The common occurrence of spot in most months was somewhat surprising because this southern species does not occur in New Jersey estuaries in every year (Able and Fahay 2010).

Larval fishes were collected and enumerated in every month and every site sampled in 60 collections overall (Table 3). The greatest sources of larvae to Barnegat Bay from external sources during February, April and June occurred at Little Egg Inlet with lesser densities at Barnegat Inlet in each month and lowest values at Pt. Pleasant Canal. The greatest densities of larvae within Barnegat Bay often occurred at the Oyster Creek Nuclear Generating Station (OCNGS) in Forked River (February and June) where high current speeds are maintained by the power plant intake pumps. The third highest density occurred in February at Oyster Creek (power plant discharge canal).

The fish species composition from otter trawl tows was limited in February and more diverse in April and June, and somewhat lower in October (Table 6). This general pattern is as expected because of the seasonal nature of estuarine use by fishes in Little Egg Harbor (Jivoff and Able 2001) and in nearby estuaries (Able et al. 1996, Able and Fahay 2010).

STATISTICAL EVALUATION OF THE DATA

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 smothering of SAV as compared to shoreline engineering in creeks, we compared richness, abundance, and species turnover for these habitats in separate, focused analyses. We used principal components analysis (PCA) to reduce the total fish assemblage variation into its most important latent trends. We did this separately for bay sites, SAV sites only, and creek sites only. Bay sites included Creek Mouth sites, which were open water sites near the creek sites so that the described gradient in bay sites was influenced by the same spatial gradient as that for creek sites. Analysis of creek sites used the average of upper and lower creek reaches within a creek within a month, because sampling of these reaches was meant to ensure adequate representation of fishes using creeks relative to the urban gradient rather than to explore differences in microhabitat use. Creek Mouth sites were not included in the Creek PCA. For examination of the bay-wide scale, results from all tows within a month within a site were averaged. PCA loading factors (amplitudes of site scores along the first two principle components) were used as proxy for the overall assemblage overturn and compared to environmental gradients or categorical treatments. Categorical treatment (cluster, urbanization/natural category among creeks, habitat type among bay samples) applied the Kruskall Wallis non-parametric ANOVA ranked sums test for global differences and were followed by pairwise t-tests using the Tukey-Kramer honest significant difference criteria. Relation of fish assemblage to gradients in continuous independent variables (temperature, salinity, dissolved oxygen) were examined by non-parametric regression using the Spearman rank correlation with p values from Monte-Carlo permutation tests.

Assemblage variation in the bay sites was dominated by a seasonal trend expressed along both major eigenaxes (PCA 1, eigenvalue = 0.36, PCA 2 eigenvalue =0.18, Fig. 8 A, B, C). Variation along the first was driven primarily by *Anchoa mitchilli*, *Anchoa hepsetus*, *Leistomus xanthurus*, and *Bairdiella chrysoura* with increasing abundance in August and October, and by an increase in *Callinectes sapidus*, *Apeltes quadracus*, and *Syngnathus fuscus* in June (Fig. 8 A). *Urophycis regia*, *Limulus polyphemus*, and *Cancer irroratus* were collected primarily in February or April samples, which were otherwise depauperate (Fig 8 A). Many other species were either abundant and persistent starting June, or were uncommon but uniformly so and so did not contribute strongly to these trends. This was further reflected by a significant correlation between sample loading factors on both eigenaxes and temperature (rho = 0.38 and 0.35 respectively, $p < 0.01$ for both, Table 7). The divergent seasonal trends exhibited as PCA 1 and PCA 2 broke weakly along spatial lines corresponding to the predesignated Sample Clusters of the urbanization gradient (Fig 8 B). Envelopes of all Cluster categories overlapped considerably and the Kruskall Wallis test failed to reject the null hypothesis that there was no difference among clusters along either PCA 1 or PCA 2 (Table 7). However, there was a significant difference in distribution among bay habitat types along both PCA 1 ($p = 0.04$) driven by a preference for open bay sites and similar creek mouth by the two anchovy species and 3 scieanids in summer, and along PCA 2 ($p < 0.01$) by *C. sapidus*, *A . quadracus*, *S. fuscus* and others, and this habitat divergence was evident primarily in June (Table 7, Fig 8 C). Pairwise Tukey-Kraner tests showed that bay sites and creek mouth sites, which are similar soft bottom habitats differing to our knowledge only as a function of distance from the creek mouth or inlet, were not significantly different from each other as measured by either eigenaxes scores while SAV site differed from both. Significant correlation of PCA 2 (rho = 0.4.2, $p < 0.01$, Table 1) on depth, and a negative correlation of of PCA 1 on DO (rho = -0.32, $p < 0.01$, Table 7) may be tied to this habitat effect. There was no significant relationship between salinity and sample constituency on either eigenaxis.

A focused analysis of just the SAV habitat samples from April through October by Heather Afford for her George H. Cook honors thesis, found that seasonality dominated the patterns for both abundance and diversity metrics in that habitat. However, when this is accounted for, abundance and diversity also changed across the spatial scale. For fishes associated with submerged aquatic vegetation (SAV) habitat, more individuals of fewer species occurred in cluster I than cluster V (Fig 9). However, a greater spatial effect was evident as the relationship with sample site distance to inlets, through which recruits and more saline water arrive. The effects of inlets on water quality, especially salinity, and larval delivery may also be substantial enough to mitigate urbanization effects for fishes in open bay SAV habitat, especially because these sites are along the eastern side of Barnegat Bay in each cluster and are thus not as closely tied to land use patterns that define urbanization mostly through development of the western site of the bay.

A seasonal trend was also evident in creek sites even though more species found in those are residents than is the case for open bay habitats. The first eigenaxis (PCA 1) explained by far the most variance (eigenvalue = 0.46) and owed primarily to increasing abundance of *A. mitchilli*, *L. xanthurus*, and *Brevoortia tyrannus* (all non-resident species) (Fig 10 A). The second eigenaxis was relatively weak (eigenvalue = 0.15) but it was along this axis that separation by Cluster designation was periodically apparent even though samples were much more similar at other times throughout the year (Fig 10 B). Thus, differences owed to episodic fish occurrences, rather than persistent trends, and 2 of the 3 species that were most important in driving this variation (*B. tyrannus, and L. xanthurus*) occur in highly patchy schooling distribution while the third (*Selene setapinnis*) is a rare or uncommon recruit from southerly spawning stock. Fish abundance, species richness, and temperature increased from February through June and August in the creek mouth and upper creek habitats, but temperature declined in October (Fig. 11, 12). There was no significant difference in samples as an effect of distance (Cluster designation) along the urbanization gradient for either of the two principle eigenaxes (Table 8). Further, there was no apparent separation of creek samples within cluster as a factor of local urbanization measures on either eigenaxis (Fig 10 C) and Kruskal Wallis ANOVA tests failed to reject a null hypothesis of no difference (Table 8) . Spearman rank correlation tests failed to find significant relationships between sample score and salinity or depth, but PCA 1 scores were positively and significantly related to temperature (rho =0.37, $p = 0.01$) and negatively related to DO (rho = -0.47, $p < 0.01$) (Table 8). Fish abundance and richness in creek habitats were both lowest in Cluster V and second lowest in Cluster II (Fig. 13). This is likely related to diminishing supply as a function of distance from the inlets, or of diminishing resources provided by the same.

Crabs

During twelve days of trap sampling (3 days each in month May-August), 2,295 blue crabs were captured exhibiting variation among clusters and among habitats within clusters (Fig. 14). Length frequency distributions show the benefit of using two types of gear (trawl and traps) to examine crab abundance. Trawls clearly target juveniles while traps target adults (Fig. 15). These data also indicate potential abundance differences among habitats, particularly for juvenile crabs, with SAV containing the most juveniles of any habitat (Fig. 15). Certainly, SAV is well known as a critical habitat for juvenile blue crabs and recruits, but our data also indicate adults use SAV as well. Adults use SAV as a habitat for molting. Thirty-two percent (32%) of adults captured in SAV were recovering from molting as compared to only

14% of adults in open bay habitats. In addition, these data suggest distinct differences in the size distribution of crabs among habitats. For example, in SAV there is a distinct mode at 20mm and the majority of crabs in this habitat are 30mm or smaller whereas the upper creeks lack a clearly defined mode with a relatively uniform distribution of crabs from 10 to ~90mm (Fig. 15). This suggests SAV is particularly important for recruits while alternative habitats become important as crabs grow. Finally, these data suggest an effect of local urbanization level on juvenile abundance with 4 times as many juveniles captured in the low urbanized upper creeks as compared to the high urbanized upper creeks (Fig. 15). This suggests juveniles may be more sensitive to the impacts of urbanization on habitat characteristics and/or quality whereas adults are more prone to the direct effects of increased human population associated with urbanization. During six days of tagging crabs (1 day each in May and June; 2 days each in July and August), a total of 1,650 crabs were tagged and released (Fig. 16). To date, we have information on 60 recaptured crabs; the distribution of these crabs agrees with our prediction that the number of recaptures positively correlates with the degree of urbanization. At this point, this correlation appears to apply only to the regional urbanization gradient (i.e., among clusters) but not to the local degree of urbanization (i.e., between creeks within clusters).

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*). Abundance of sea nettles (*Chrysaora quinquecirrha*) and ctenophores (*Mnemiopsis leidyi*) was measured at all of the sampling locations in June, August and October of year 1. Otter trawl collection sites included 15 sites in the bay, 5 developed creeks, 6 underdeveloped creeks and 11 sites dominated by submerged aquatic vegetation, across the five clusters. Passive plankton data were also collected at 4 sites. Sea nettles were more prevalent north of Lavallette (cluster V) and ctenophores more abundant to the south. Sea nettle size ranged from 15-100 mm in diameter, and when sex ratios were collected (only at some collection sites), 90% or more were found to be female. Ctenophores ranged from 15-80 mm in diameter. Salinity was a determining factor for sea nettle distribution, as research on the species in the Chesapeake suggests; sea nettles were found in only one site with salinity greater than 20.3 ppt, and salinity was a significant covariate in a logistic regression model for presence/absence of nettles. The results also suggest that development may be a significant factor in determining sea nettle abundance; nettles were found in developed creeks, but not undeveloped ones. Ctenophores were found temporally and geographically in inverse abundance to sea nettles, suggesting (again, as supported by work in the Chesapeake) that sea nettles may be key predators on ctenophores.

A methodological comparison was also conducted to compare otter trawling, plankton net towing and beach seining in order to bring together data on gelatinous zooplankton from the RUMFS trawl sampling, the Monmouth University plankton netting and the Barnegat Bay Partnership beach seining. Unfortunately, gelatinous zooplankton densities were low overall and an effective comparison could not be made.

We are examining the entrance of American eels into Barnegat Bay as a part of a Barnegat Bay Partnership grant to enhance glass eel and elver passage into the Bay. We are expanding this effort with our current inlet sampling for larval fishes and are preparing a manuscript to present our findings. To date, it is clear that glass eels enter all inlets to the Bay (including from Point Pleasant Canal) but their use of tributaries is variable and the focus of continued analysis.

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 have agreed to provide a tutorial on larval fish identification for Monmouth University personnel. 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 are also providing logistical support for several other bay projects. These include supplying fish from our otter trawl samples for USGS (Kelly Smalling) for toxicology studies. We are also arranging for vessel support to the Barnegat Bay Partnership (Martha Maxwell-Doyle) for a project related to wetlands monitoring and assessment.

Remote Data Entry – testing of a remote data entry system for fishes and crabs occurred on July 10, 2012 at inshore bay sites and on July 13, 2012 at offshore locations to determine efficiency of data recording while performing research in the field. Inability to reliably connect to the data entry program from all locations has caused us to discontinue this effort.

Conclusions and Recommendations for Future Research

Preliminary findings from 2012 indicate that there are large numbers of larval fishes at the OCNGS in both the intake (Forked River) and discharge (Oyster Creek) sampling. This may have important implications on fish populations for current and future fish population dynamics in the bay when the plant is shut down and the flow through and temperature regime is drastically altered.

Our preliminary analysis of juvenile fish distribution (abundance and species diversity) is that it is not strongly correlated with the overall north-south gradient in urbanization of the watershed. However, this large scale population gradient may not adequately capture the gradient of more localized changes with more direct influences on fish habitat, for example the way in which land is altered rather than just how much of it is altered. Further, it appears that the proximity to the Barnegat Bay inlet is important in regulating habitat water quality for fishes in the open bay. Likewise, spatial water quality variation demonstrates the importance of circulation and it is possible that circulation obfuscates urbanization effects, for example by concentrating eutrophication in places other than the closest proximity to large human populations. In any case, in this first year of sampling, it is not apparent that intense urbanization of the upper Barnegat Bay relative to the lower, less urbanized bay has substantially impacted juvenile fish use on the local scale.

Several questions will need to be addressed in future work: 1) is the pattern of distribution stable enough among years to draw such general conclusions?, 2) do artifacts of local urbanization practices (land use change, eutrophication) telegraph themselves as non-point (bay-wide) impacts such as overall fish productivity increase or decrease? This will be partially addressed in continued analysis of the current data set by comparing “urbanized” and “natural” creeks within, rather than among, clusters, 3) do impacts occur following threshold dynamics rather than linear dynamics (for example no change in habitat use at current dissolved oxygen levels, but abrupt and profound changes at slightly lower levels)? Studies of the fine scale movement and behavior of fishes using telemetry will be important in answering these further questions, for example to demonstrate whether fish roam among sites or remain local and how individuals respond to temporal or spatial events rather than gradients.

During Year Two we plan to continue most aspects of the sampling in Year One in order to evaluate annual variation in fish and crab response to the urbanization gradient. Emphasis will be on the otter trawl sampling. In addition, we anticipate that we will add some day/night comparisons in otter trawl sampling during the summer to enhance our gill net collections. We expect to eliminate winter otter trawl sampling (February) in order to compensate for this additional effort. Winter sampling yielded few fish of any species because most of the region's species migrate south or offshore in winter. We will continue larval fish (plankton net) sampling at inlets as well as for adult fish (gill nets) in Clusters I, III, IV.

Recommendations and Application and Use by NJDEP

In the longer term, we recommend continued sampling by plankton net (for larval fishes) and otter trawl (for juvenile and adult fishes and crabs) in Barnegat Bay to resolve influences on the macrofauna. These influences may include retirement of the power plant, continued urbanization, reduced freshwater flow, and climate change. The timing of this sampling should correspond with long-term sampling currently being conducted at Little Egg Inlet (for larval fishes) and the Mullica River – Great Bay estuary (for juvenile and adult fishes). Continued sampling is also necessary to evaluate effects from Hurricane Sandy by examining more than one year of post-Sandy data on fishes and crabs.

References

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.

Able, K. W. and M. P. Fahay. 2010. Ecology of Estuarine Fishes: Temperate Waters of the Western North Atlantic. Johns Hopkins University Press, Baltimore, MD.

Able, K.W., K.M.M. Jones and D.A. Fox. 2009. Large nektonic fishes in marsh creek habitats in the Delaware Bay estuary. Northeastern Naturalist 16(1):27-44.

Able, K.W. and S.C. Kaiser. 1995. New Jersey estuaries finfish resource assessment, phase I: Literature Summary. IMCS Technical Report 95-01.

Chant, R.J. 2001. Tidal and Subtidal motion in a shallow bar-built multiple inlet/ bay system. Journal of Coastal Research. 32: 102-114.

Clementi, G. K.W. Able, and T.M. Grotheus. 2012. Salt marsh fish assemblages along an urbanization gradient in Barnegat Bay. Poster Presentation at Research Internship in Ocean Sciences (RIOS). Institute of Marine and Coastal Sciences, August 2012.

Cunico, A.M., Allan, D.J., and Agostinho, A.A. 2011. Functional convergence of fish assemblages in urban streams of Brazil and the United States. Ecological Indicators (11): 1354-1359.

Grothues, T.M. and K.W. Able. 2003. Response of juvenile fish assemblages in tidal salt marsh creeks treated for Phragmites removal. Estuaries 26(2B): 563-573.

Grothues, T.M. and K.W. Able. 2003. Discerning vegetation and environmental correlates with subtidal marsh fish assemblage dynamics during Phragmites eradication efforts: interannual trend measures. Estuaries 26(2B): 574-586.

Hagan, S.M., Able, K.W., Witting, A.M., Muzeni, and McLellan, J. 2002. Long-term Fish and Associated Environmental Data Management at the Rutgers University Marine Field Station. Rutgers University Institute of Marine and Coastal Sciences Technical Report:100-20.

Jivoff, P. in prep. Adult population structure in Barnegat Bay, New Jersey.

Jivoff, P. Assessing population structure, reproductive potential and movement of adult blue crabs in Barnegat Bay. Final Report to the Barnegat Bay Partnership. 2011.

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.

Joo, W., Gage, S.H., and Kasten, E.P. 2011. Analysis and interpretation of variability in soundscapes along an urban-rural gradient. Landscape and Urban Planning (103): 259-276.

Kennish, M.J. 1992. Ecology of Estuaries: Anthropogenic Effects. CRC Press, Boca Raton, FL.

Kennish, M.J. 2001. Characterization of the Barnegat Bay- Little Egg Harbor estuary and watershed. Journal of Coastal Research. 32: 3-12.

Kennish, M. J. 2010. Seagrass decline in New Jersey coastal lagoons: A reponse to increasing eutrophication. Pp 167 - 201 *In* Kennish, M. J., and H. W. Paerl (eds.) Coastal Lagoons: Critical Habitats of Environmental Change. CRC Press, Boca Raton, FL.

Kennish, M. J., S. B. Bricker, W. C. Dennison, P. M. Gilbert, R. J. Livingston, K. A. Moore, R. T. Noble, H. W. Paerl, J. M. Ramstack, S. Seitzinger, D. A. Tomasko, and I. Valiela.. 2007. Barnegat Bay-Little Egg Harbor Estuary: Case study of a highly eutrophic coastal bay system. Ecological Applications 17(5) Supplement 2007: S3 – S16.

Kennish, M. J., and R. A. Lutz, eds. 1984. Ecology of Barnegat Bay, New Jersey. Springer, New York. NY.

Lathrop, R. J., and J. A. Bognar. 2001. Habitat loss and alteration in the Barnegat Bay region. Journal of Coastal Research Special Issue 32:212-229.

Lathrop, R. G., R. M. Styles, S. P. Seitzinger, and J. A. Bognar. 2001. Use of GIS mapping and modeling approaches to examine the spatial distribution of seagrasses in Barnegat Bay, New Jersey. Estuaries 24(6A): 904-916.

Rountree, R.A. and Able, K.W. 1997. Nocturnal fish use of New Jersey marsh creek and adjacent bay shoal habitats. Estuarine, Coastal, and Shoal Science 44:703-711.

Sogard, S. M. 1989. Colonization of artificial seagrass by fishes and decapods crustaceans: importance of proximity to natural eelgrass. Journal of Experimental Marine Biology and Ecology 133:15-37.

Sogard, S. M. 1992. Variability in growth rates of juvenile fishes in different estuarine habitats. Marine Ecology Progress Series 85:35-53.

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. Estuarine, Coastal and Shelf Science 33:501-519.

Sugihara, T., C. Yearsley, J.B. Durand and N.P. Psuty. 1979. Comparison of natural and altered estuarine systems: Analysis. Rutgers University Center for Coastal and Environmental Studies Pub. No. NJ/RU-DEP-11-9-79.

Sullivan, M.C., R.K. Cowen, K.W. Able, and M.P. Fahay. 2006. Applying the basin model: Assessing habitat suitability of young-of-the-year demersal fishes on the New York Bight continental shelf. Continental Shelf Research 26:1551-1570.

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.

Vasslides, J.M., J.L. Rackovan, J.L. Toth, R. Hagan, and K.W. Able. 2011. Metadata Manual for Fish and Environmental Records at the Rutgers University Marine Field Station. Rutgers University Marine Field Station Technical Report: 2011-1.

Wilson, K. A., K. W. Able, and K. L. Heck, Jr. 1990a. Predation rates on juvenile blue crabs in estuarine nursery habitats: evidence for the importance of macroalgae (*Ulva lactuca*). Marine Ecology Progress Series 58:243-251.

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

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.

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: 222-230.

Appendices

Meetings attended – Rutgers and Rider University investigators and technicians attended relevant meetings on *1/4/12, 2/15/12, 2/24/12, 3/29/12, and 12/7/12.*

Outreach- Outreach was begun through interviews of investigators by print press and the ensuing publication of a news article in The SandPaper (February 1, 2012). P.I. Ken Able was interviewed regarding the bay study and how Rutgers will be assessing fish and crab responses to urbanization of the bay. Co-PI Paul Jivoff presented a seminar titled "Blue crabs in Barnegat Bay: Potential interactions between reproductive biology and fishing pressure" at the Institute for Marine and Coastal Sciences at Rutgers University, New Brunswick on March 7, 2013

Table 1. General characteristics (based on NJDEP 2009 data) of each sample cluster 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 during 2012 for Feb, Apr, June, August, and October. 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	Station	Dominant Emergent Vegetation Along Shoreline	Dominant Submerged Vegetation	Maximum Volume of SAV in Trawl Tows (liters)	Salinity Range (ppt)	Temperature Range (°C)	Dissolved Oxygen Range (mg/L)
I	Bay	STA 5	Spartina, Phragmites	Macroalgae, Seagrass	10 0.1	29.2-30.3	6.4-23.0	5.1-10.4
		B110	Spartina, Phragmites	Macroalgae, Seagrass	11 0.1	27.3-31.5	5.0-22.8	6.2-11.6
	SAV	STA 3	Spartina, Phragmites	Macroalgae, Seagrass	8 14	25.8-31.0	4.8-23.7	5.9-10.1
		STA 52	Spartina, Phragmites	Macroalgae, Seagrass	51 10	27.4-31.4	5.1-23.0	5.7-21.3
	Creek Mouth	STA 15	Spartina, Phragmites	Macroalgae	221	26.7-29.0	7.3-24.2	6.2-11.2
		STA 50	Spartina	Macroalgae	110	26.7-29.0	6.9-25.4	4.8-10.2
	Upper Creek	STA 14	Upland	Macroalgae	13	10.9-22.2	8.5-25.0	2.7-11.2
		STA 51	Spartina	Macroalgae	7	28.6-29.0	7.4-24.3	4.8-10.9
II	Bay	STA 60	-	Macroalgae, Seagrass	3 5	26.6-28.3	16.6-26.0	5.4-7.3
		STA 61	-	Macroalgae, Seagrass	0.2 1	27.4-29.1	16.6-27.0	6.6-7.2
	SAV	STA 66	Spartina, Phragmites	Macroalgae, Seagrass	3 6	28.8-29.4	15.9-26.4	5.7-7.4
		STA 67	Spartina, Phragmites	Macroalgae, Seagrass	2 6	29.2-30.0	15.8-25.5	5.0-8.5
	Creek Mouth	STA 62	Spartina	Macroalgae, Seagrass	36 0.1	26.5-28.8	16.1-25.3	5.3-7.4
		STA 63	Spartina, Phragmites	Macroalgae, Seagrass	0.2 3	27.0-27.7	16.5-26.6	6.2-7.9
								continued

Cluster II	Habitat Type	Station	Dominant Emergent Vegetation Along Shoreline	Dominant Submerged Vegetation	Maximum Volume of SAV in Trawl Tows (liters)	Salinity Range (ppt)	Temperature Range (°C)	Dissolved Oxygen Range (mg/L)
	Creek Upper	STA 64	Spartina	Macroalgae, Seagrass	50 2	21.0-24.0	15.5-24.8	2.7-6.7
		STA 65	Upland	Macroalgae, Seagrass	0.1 0.1	5.5-15.7	17.3-28.0	4.1-9.9
III	Bay	STA 70	-	Macroalgae, Seagrass	13 0.1	27.0-28.7	6.4-24.8	6.7-10.2
		STA 71	-	Macroalgae, Seagrass	29 0.10	26.8-28.3	5.8-23.7	7.1-10.1
	SAV	STA 76	Spartina, Phragmites	Macroalgae, Seagrass	63 142	27.8-29.4	4.7-24.9	6.5-10.6
		STA 77	Spartina, Phragmites	Macroalgae, Seagrass	207 46	28.4-29.1	4.9-26.0	6.6-11.3
	Creek Mouth	STA 72	Spartina, Phragmites	Macroalgae	10	26.4-28.1	6.5-28.2	5.7-11.2
		STA 73	Spartina, Phragmites	Macroalgae, Seagrass	35 0.1	26.5-27.7	9.0-25.7	6.7-10.2
	Creek Upper	STA 74	Upland	Macroalgae	0.5	25.6-26.5	11.3-30.0	5.2-10.7
		STA 75	Upland	Macroalgae	2	26.0-26.4	6.9-25.2	5.4-10.6
IV	Bay	STA 80	-	Macroalgae	0.5	20.1-22.2	13.3-25.8	6.8-7.7
		STA 81	-	Macroalgae, Seagrass	2 0.4	17.5-19.0	13.0-25.8	6.5-8.1
	SAV	STA 86	Upland	Macroalgae, Seagrass	0.5-95 17	22.5-24.9	12.4-26.8	6.7-9.1
		STA 87	-	Macroalgae, Seagrass	1-5 7	19.6-20.1	13-27.6	6.0-9.2
	Creek Mouth	STA 82	Spartina, Phragmites	Macroalgae, Seagrass	1 0.01	22.9	14-27.1	5.4-8.8
		STA 83	Spartina, Phragmites	Macroalgae, Seagrass	4 2	20.0-20.4	14-26.0	5.1-8.5
								continued

Cluster IV	Habitat Type	Station	Dominant Emergent Vegetation Along Shoreline	Dominant Submerged Vegetation	Maximum Volume of SAV in Trawl Tows (liters)	Salinity Range (ppt)	Temperature Range (°C)	Dissolved Oxygen Range (mg/L)
	Creek Upper	STA 84	Spartina, Phragmites	Macroalgae, Seagrass	5 0.1	20.7-21.2	14.8-27.4	5.3-8.6
		STA 85	Upland	Macroalgae	0.5	17.2-19.5	17.3-27.7	4.4-9.2
V	Bay	STA 90	-	Macroalgae, Seagrass	8 0.1	7.6-20.1	5.3-24.4	6.5-11.9
		STA 91	-	Macroalgae, Seagrass	11 0.5-4	18.0-20.7	5.1-27.7	7.2-12.2
	SAV	STA 96	-	Macroalgae, Seagrass	1 7	17.1-20.1	5.5-26.3	6.8-11.5
		STA 97	Spartina, Phragmites	Macroalgae, Seagrass	91 58	17.3-20.2	5.0-26.0	6.4-11.5
	Creek Mouth	STA 92	upland, Spartina, Phragmites	Macroalgae	240	20.0-21.7	6.4-27.3	6.7-11.6
		STA 93	Spartina, Phragmites	Macroalgae	105	20.2-21.8	6.4-27.1	6.0-11.6
	Creek Upper	STA 94	-	Macroalgae	1	22.4-22.9	6.9-25.7	6.0-11.1
		STA 95	Spartina, Phragmites, upland	Macroalgae, Seagrass	40 1	20.5-21.8	6.3-28.3	5.0-11.1

Table 3. Sampling effort for larval fishes in Barnegat Bay during 2012. See Fig. 1 for locations of clusters. Planned sampling in October cancelled because of Hurricane Sandy. NS = no sample.

Cluster	Location	Number of Tows by Month	Number of Fishes by Month	Number of Crabs by Month	Total Fish Density (ind/1000 m)
I	Little Egg Inlet	Feb: 3	48	0	55.8
		April: 3	106	3	71.8
		June: 3	1481	3	1014.7
		August: 3	89	1	1467.6
		October:	NS		
III	Barnegat Inlet	Feb: 3	17	0	34.6
		April: 3	9	1	50.2
		June: 3	409	40	1469.7
		August: 3	80	1	2106.9
		October:	NS		
	Forked River	Feb: 3	2473	67	2378.9
		April: 3	171	1	138.8
		June: 3	1497	63	748.9
		August: 3	170	4	2768.2
		October:	NS		
	Oyster Creek	Feb: 3	1271	10	1199.8
		April: 3	54	2	52.4
		June: 3	870	6	1230.7
		August: 3	249	6	1364.6
		October:	NS		
V	Pt. Pleasant Canal	Feb: 3	21	0	35.3
		April: 3	5	0	4.7
		June: 3	69	16	146.4
		August: 3	14	5	105.6
		October:	NS		
TOTAL		60	9103	229	

Table 4. Sampling effort with otter trawl in Barnegat Bay during 2012. 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 by Month	Number of Fishes by Month	Number of Crabs by Month
I	Bay	Feb: 6	0	3
		April: 6	5	6
		June: 6	4	46
		Aug: 6	173	1
		Oct: 6	1034	6
	SAV	Feb: 9	4	3
		April: 9	7	16
		June: 9	45	82
		Aug: 9	340	0
		Oct: 9	97	18
	Creek Mouth	Feb: 6	1	0
		April: 6	81	8
		June: 6	44	16
		Aug: 6	122	40
		Oct: 6	76	6
	Upper Creek	Feb: 6	3	6
		April: 6	166	43
		June: 6	591	85
		Aug: 6	15	8
		Oct: 6	74	33
II	Bay	April: 6	2	22
		June: 6	2	0
		Aug: 6	34	0
		Oct: 6	185	1
	SAV	April: 6	1	2
		June: 6	13	16
		Aug: 6	166	17
		Oct: 6	17	1
	Creek Mouth	April: 6	8	2
		June: 6	253	3
		Aug: 6	6	0
		Oct: 6	14	2
	Creek Upper	April: 6	4	20
		June: 6	111	5
		Aug: 6	40	8
		Oct: 6	15	18
III	Bay	Feb: 6	1	1
		April: 6	2	9
		June: 6	1	7
		Aug: 6	848	1
		Oct: 6	20	0
	SAV	Feb: 6	9	1
		April: 6	14	12
		June: 6	635	412
		Aug: 6	82	7
		Oct: 6	67	87
	Creek Mouth	Feb: 6	0	0
		April: 6	126	12
		June: 6	12	22
		Aug: 6	76	57
		Oct: 6	21	0
	Creek Upper	Feb: 6	1	1
		April: 6	1	2
		June: 6	8	45
		Aug: 6	23	70

Cluster	Habitat Type	Number of Tows by Month	Number of Fishes by Month	Number of Crabs by Month
III	Upper Creek	Oct: 6	15	15
IV	Bay	April: 6	8	0
		June: 6	14	5
		Aug: 6	468	19
		Oct: 6	226	5
	SAV	April: 6	28	365
		June: 6	22	21
		Aug: 6	148	5
		Oct: 6	3	26
	Creek Mouth	April: 6	18	11
		June: 6	37	7
		Aug: 6	220	26
		Oct: 6	352	9
	Creek Upper	April: 6	46	10
		June: 6	156	36
		Aug: 6	782	27
		Oct: 6	159	15
V	Bay	Feb: 6	6	1
		April: 6	0	1
		June: 6	18	6
		Aug: 6	248	43
		Oct: 6	32	11
	SAV	Feb: 6	0	1
		April: 6	49	29
		June: 6	4	24
		Aug: 6	40	84
		Oct: 6	24	99
	Creek Mouth	Feb: 6	6	1
		April: 6	2	14
		June: 6	9	117
		Aug: 6	6	27
		Oct: 9	11	33
	Creek Upper	Feb: 6	23	3
		April: 6	12	17
		June: 6	32	19
		Aug: 6	43	5
		Oct: 9	26	6
Total		615	8993	2432

Table 5. Sampling effort with gill nets in Barnegat Bay during 2012. 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 Sets by Month	Number of Fishes by Month	Number of Crabs by Month
I	Bay	April: 2	0	5
		June: 2	3	1
		Aug: 3	9	3
		Oct: 3	3	3
	Creek Mouth	April: 2	3	5
		June: 2	5	1
		Aug: 4	15	4
		Oct: 4	2	0
	Upper Creek	April: 2	0	1
		June: 2	6	0
		Aug: 4	5	1
		Oct: 4	11	4
	SAV	April: 2	0	0
		June: 2	0	0
		Aug: 4	0	0
		Oct: 4	4	31
III	Bay	April: 2	0	0
		June: 2	0	0
		Aug: 4	1	0
		Oct: 4	0	0
	Creek Mouth	April: 2	0	4
		June: 2	1	0
		Aug: 4	17	2
		Oct: 4	6	0
	Creek Upper	April: 2	0	0
		June: 2	0	0
		Aug: 2	1	1
		Oct: 2	1	0
	SAV	April: 2	0	0
		June: 2	0	0
		Aug: 4	27	0
		Oct: 4	0	0
V	Bay	April: 2	0	0
		June: 2	0	0
		Aug: 6	19	4
		Oct: 6	5	0
	Creek Mouth	April: 2	1	0
		June: 2	1	1
		Aug: 4	17	5
		Oct: 4	9	0

Cluster V	Habitat Type	Number of Sets by Month	Number of Fishes by Month	Number of Crabs by Month
	Creek Upper	April: 2	0	0
		June: 2	1	0
		Aug: 4	9	3
		Oct: 4	2	0
	SAV	April: 2	0	0
		June: 2	0	0
		Aug: 4	0	0
		Oct: 4	1	0
Total		73	185	79

Table 6. Fish and crab species composition by otter trawl sample and month across all clusters during 2012. X= species caught in February (n=83 individuals), April (n=1301 individuals), June (n=3103 individuals), August (5175 individuals), and October (3293 individuals) in Barnegat Bay.

Common Name	Scientific Name	Feb	Apr	Jun	Aug	Oct
Herring	*Alosa sp.*			X	X	
Striped Anchovy	*Anchoa hepsetus*		X		X	
Bay Anchovy	*Anchoa mitchilli*		X	X	X	X
American Eel	*Anguilla rostrata*	X	X	X	X	
Four spine Stickleback	*Apeltes quadracus*	X	X	X	X	X
Sheepshead	*Archosargus probatocephalus*					X
Silver perch	*Bairdiella chrysoura*		X		X	X
Atlantic menhaden	*Brevoortia tyrannus*		X	X	X	X
Black sea bass	*Centropristis striata*		X	X	X	X
Striped blenny	*Chasmodes bosquianus*		X	X		X
Striped burrfish	*Chilomycterus schoepfii*				X	
Atlantic herring	*Clupea harengus*	X	X			
Conger eel	*Conger oceanicus*		X			
Weakfish	*Cynoscion regalis*				X	X
Sheepshead minnow	*Cyprinodon variegatus*	X				
Bluntnose stingray	*Dasyatus sayi*				X	
Smallmouth flounder	*Etropus microstomus*					X
Silver mojarra	*Eucinostomus argenteus*					X
Mummichog	*Fundulus heteroclitus*	X	X	X		X
Naked goby	*Gobiosoma bosc*	X		X	X	X
Seaboard goby	*Gobiosoma ginsburgi*	X				
Lined seahorse	*Hippocampus erectus*		X	X	X	X
Feather blenny	*Hypsoblennius hentz*		X			
Pinfish	*Lagodon rhomboides*			X	X	
Spot	*Leiostomus xanthurus*		X	X	X	X
Rainwater killifish	*Lucania parva*					X
Inland silverside	*Menidia beryllina*		X			
Atlantic silverside	*Menidia menidia*	X	X	X	X	X
Northern kingfish	*Menticirrhus saxatilis*				X	X
Atlantic croaker	*Micropogonias undulatus*		X	X	X	X
Green goby	*Microgobius thalassinus*					X
Silver perch	*Morone americana*				X	
White mullet	*Mugil curema*				X	X
Smooth dogfish	*Mustelus canis*			X	X	
Oyster toadfish	*Opsanus tau*	X		X	X	X
Summer flounder	*Paralichthys dentatus*		X	X	X	X
Atlantic butterfish	*Peprilus triacanthus*			X		
Yellow perch	*Perca flavescens*			X		
Black drum	*Pogonias cromis*		X			
Bluefish	*Pomatomus saltatrix*			X	X	
Winter Flounder	*Pseudopluronectes americanus*	X	X	X		
Atlantic moonfish	*Selene setapinnis*				X	X

Northern puffer	*Sphoeroides maculatus*			X	X	
Scup	*Stenotomus chrysops*				X	
Northern pipefish	*Sygnathus fuscus*		X	X	X	X
Inshore lizardfish	*Synodus foetens*				X	
Tautog	*Tautoga onitis*	X	X	X	X	
Hogchoker	*Trinectes maculatus*			X	X	X
Spotted hake	*Urophycis regia*		X			
Blue crab	*Callinectes sapidus*	X	X	X	X	X
Rock crab	*Cancer irroratus*	X	X	X		X
Green crab	*Carcinus maenus*		X	X		X
Longnose spider crab	*Libinia dubia*				X	
Spider crab	*Libinia emarginatum*	X	X	X	X	
Lady crab	*Ovalipes ocellatus*		X			X
Iridescent swimming crab	*Portunus gibbesii*					X
Horseshoe crab	*Limulus polyphemus*		X			
Diamondback terrapin	*Malachemys terrapin*		X	X	X	X

Table 7. Results of statistical analysis on the relationship of bay site fish assemblages as sampled with an otter trawl and environmental gradients. Fish assemblage variation as a response variable is reduced to its two most important orthogonal components by principle components analysis (PCA 1, PCA 2).

PCA 1, cluster factor, Kruskal Wallis test

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	5516.4	9	612.932	9.5	0.3929
Error	42123.6	73	577.036		
Total	47640	82			

PCA 2, cluster factor, Kruskal Wallis test

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	7518.5	9	835.394	12.94	0.1652
Error	40118	73	549.561		
Total	47636.5	82			

PCA 1, habitat factor, Kruskal Wallis test

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	3669.5	2	1834.77	6.32	0.0425
Error	43970.5	80	549.63		
Total	47640	82			

SAV differed from creek mouth, but not bay, bay and creek mouth were same

PCA 2, habitat factor, Kruskal Wallis test

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	10614.3	2	5307.14	18.27	0.0001
Error	37022.2	80	462.78		
Total	47636.5	82			

SAV differed from creek mouth, but not bay, bay and creek mouth were same

Spearmans Rank Correlation

Effect	Response Variable	Correlation	Prob > 0.05 (Permutation test)
Salinity	Axis 1	rho = 0.0170	p = 0.8787
Salinity	Axis 2	rho = -0.1194	p = 0.2821
Temperature	Axis 1	rho = 0.3776	p = 0.0004
Temperature	Axis 2	rho = 0.3514	p = 0.0011
Depth	Axis 1	rho = 0.2040	p = 0.0660
Depth	Axis 2	rho = -0.4192	p = 0.00008
Dissolved oxygen	Axis 1	rho = -0.3219	p = 0.0030
Dissolved oxygen	Axis 2	rho = -0.1644	p = 0.1374

Table 8. Results of statistical analysis on the relationship of marsh creek site fish assemblages as sampled with an otter trawl and environmental gradients. Fish assemblage variation as a response variable is reduced to its two most important orthogonal components by principle components analysis (PCA 1, PCA 2).

PCA 1, cluster factor, Kruskal Wallis test

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	1261.88	5	252.375	7	0.2203
Error	6845.63	40	171.141		
Total	8107.5	45			

PCA 2, cluster factor, Kruskal Wallis test

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	288	5	57.599	1.6	0.9014
Error	7819.5	40	195.488		
Total	8107.5	45			

PCA 1, urban factor, Kruskal Wallis test

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	56.97	1	56.974	0.32	0.5739
Error	8050.53	44	182.966		
Total	8107.5	45			

PCA 2, urban factor, Kruskal Wallis test

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Groups	123.21	1	123.214	0.68	0.4083
Error	7984.29	44	181.461		
Total	8107.5	45			

Spearmans Rank Correlation

Effect	Response Variable	Correlation	Prob > 0.05 (Permutation test)
Salinity	Axis 1	rho = -0.1402	p = 0.3627
Salinity	Axis 2	rho = -0.0488	p = 0.7526
Temperature	Axis 1	rho = 0.3754	p = 0.0120
Temperature	Axis 2	rho = 0.0642	p = 0.6788
Depth	Axis 1	rho = -0.1690	p = 0.2787
Depth	Axis 2	rho = 0.0789	p = 0.6150
Dissolved oxygen	Axis 1	rho = -0.4747	p = 0.0013
Dissolved oxygen	Axis 2	rho = 0.0227	p = 0.8836

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. Stations outside the clusters increase resolution along the spatial gradient and are given their own designation (e.g. Cluster 4-5 in analysis with categorical treatments.

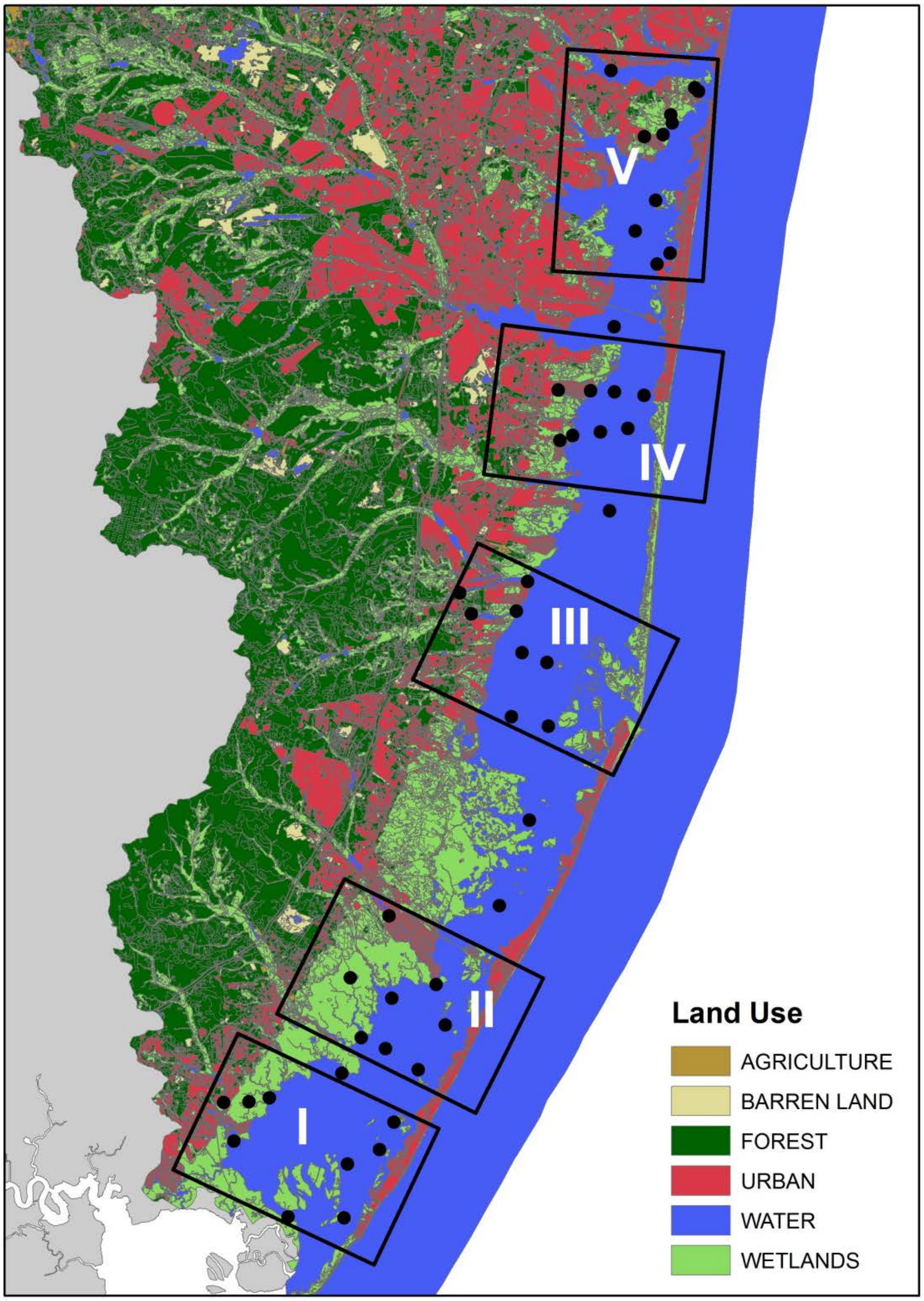


Figure 2. There is a gradient of increasing urbanization in creek watersheds up Barnegat Bay. Average creek length is indirectly proportional to urbanization values based on creek locations while average mouth width is not. See Fig. 1 for locations of clusters.

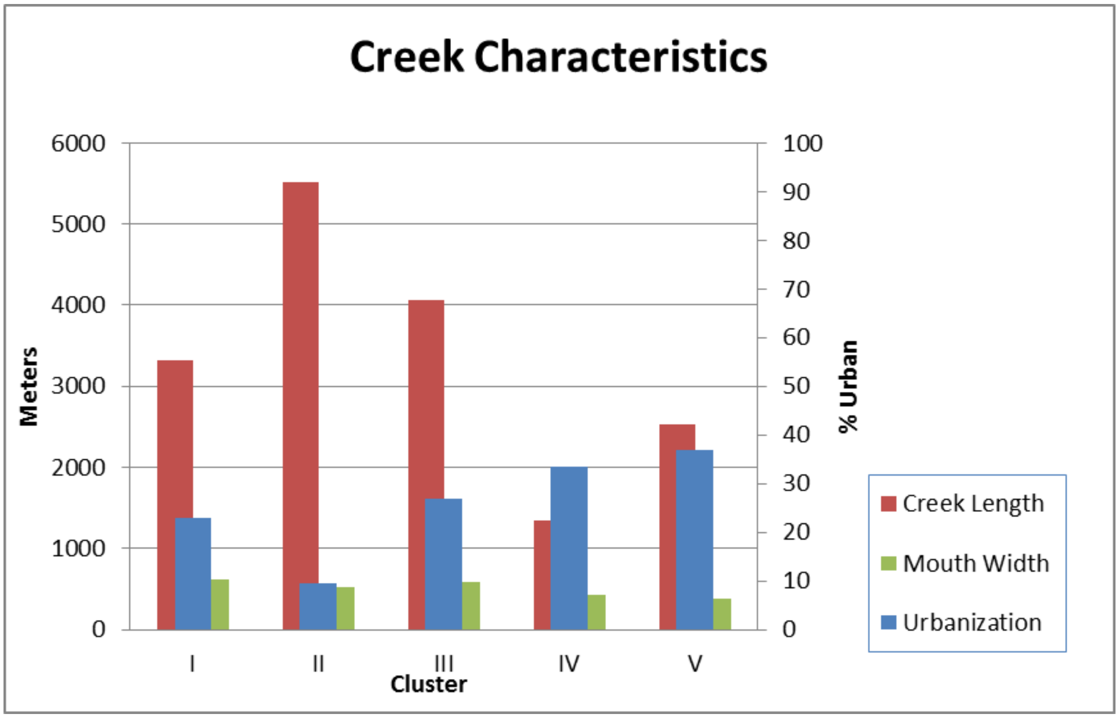


Figure 3. Average physical factors per cluster did not exhibit environmental gradients from April through October 2012. February data were excluded due to lack of sampling at Clusters II and IV. See Fig. 1 for locations of clusters.

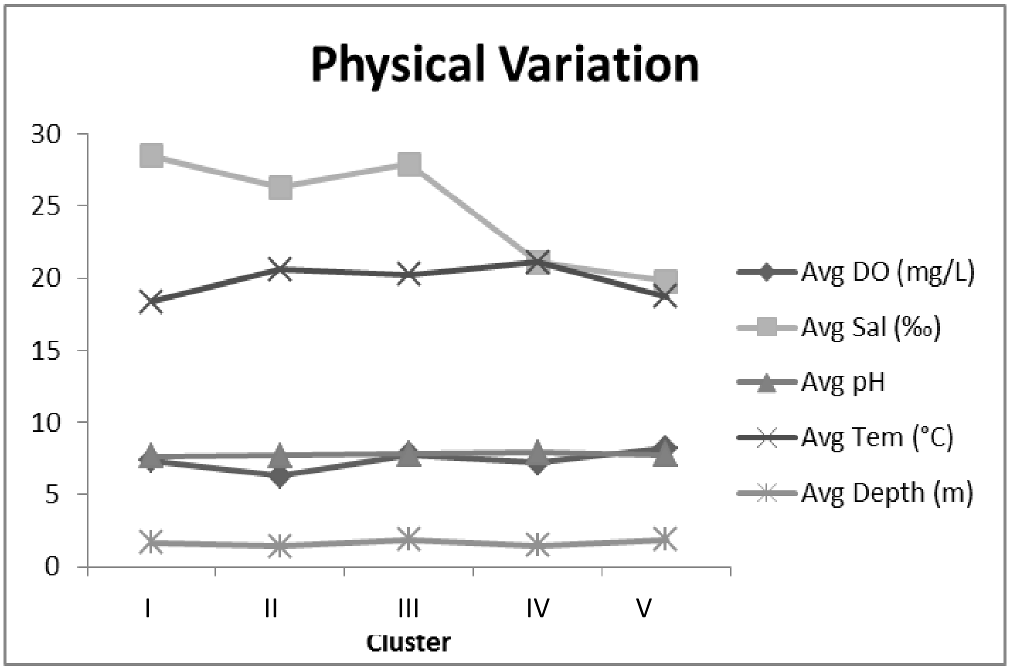


Figure 4. Length-frequency distribution of fish caught in each gear type in combined samples from February, April, June, August, and October 2012. Note the different length axes for each year.

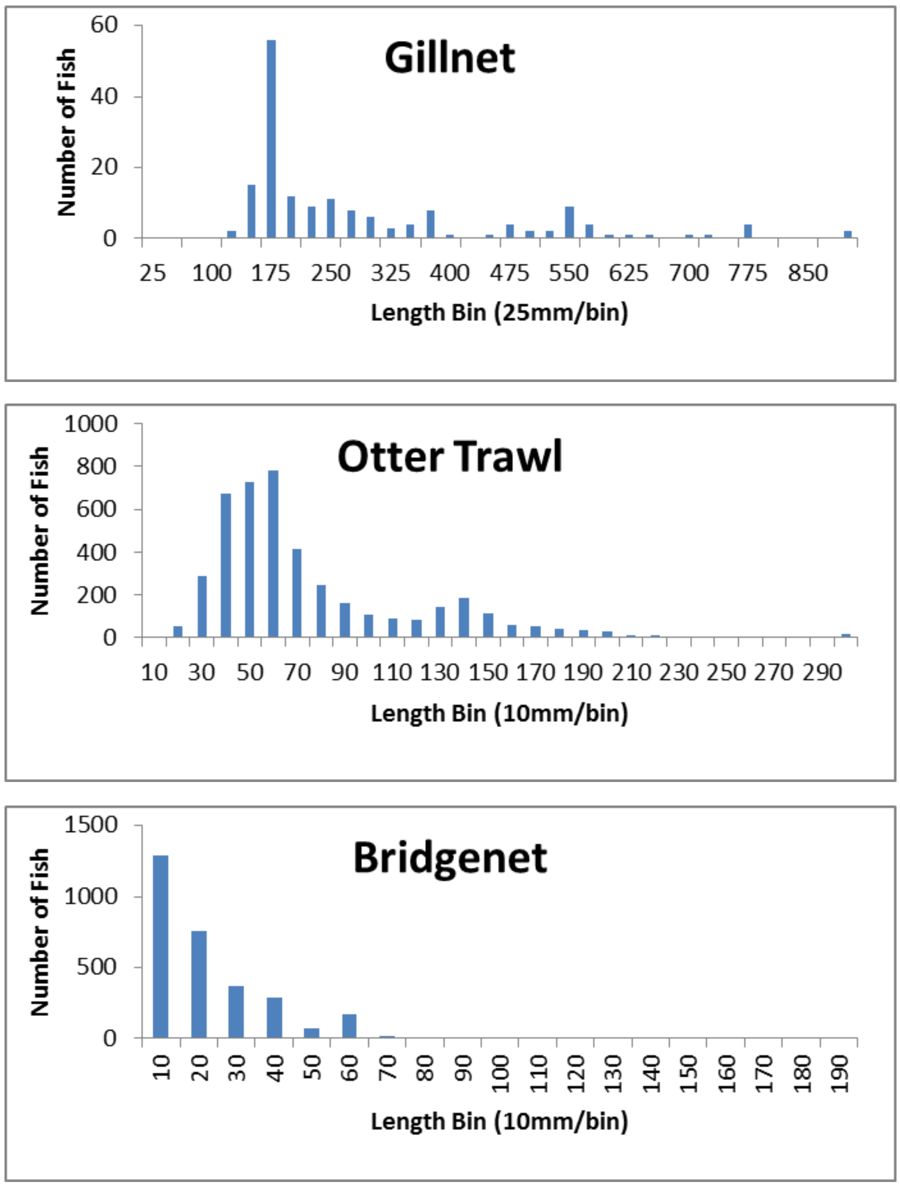


Figure 5. Length-frequency distribution (by month) of fish caught using otter trawl gear in February, April, June, August, and October 2012.

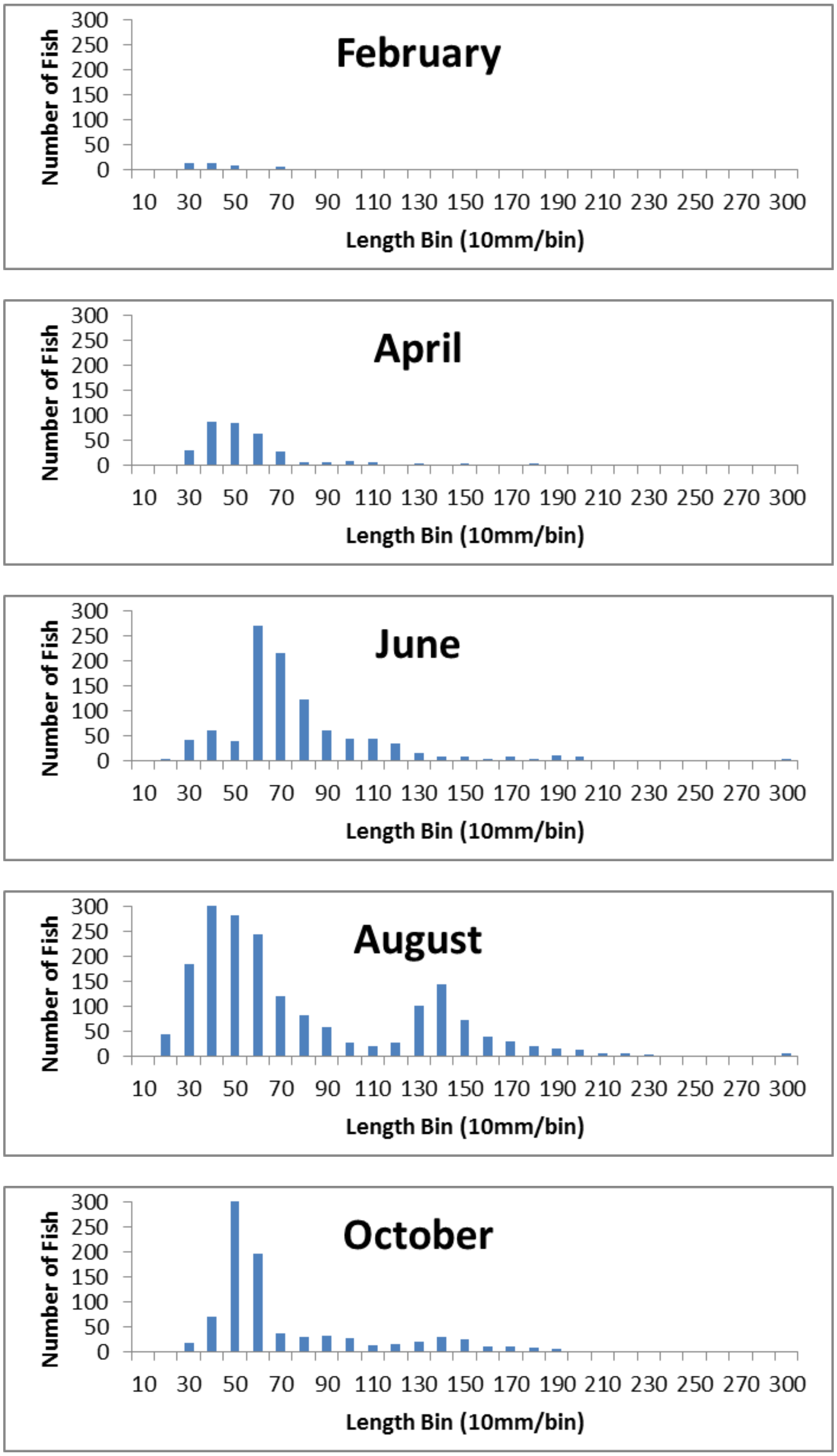


Figure 6. Length-frequency distribution (by habitat type) of fish caught using otter trawl gear in February, April, June, August, and October 2012.

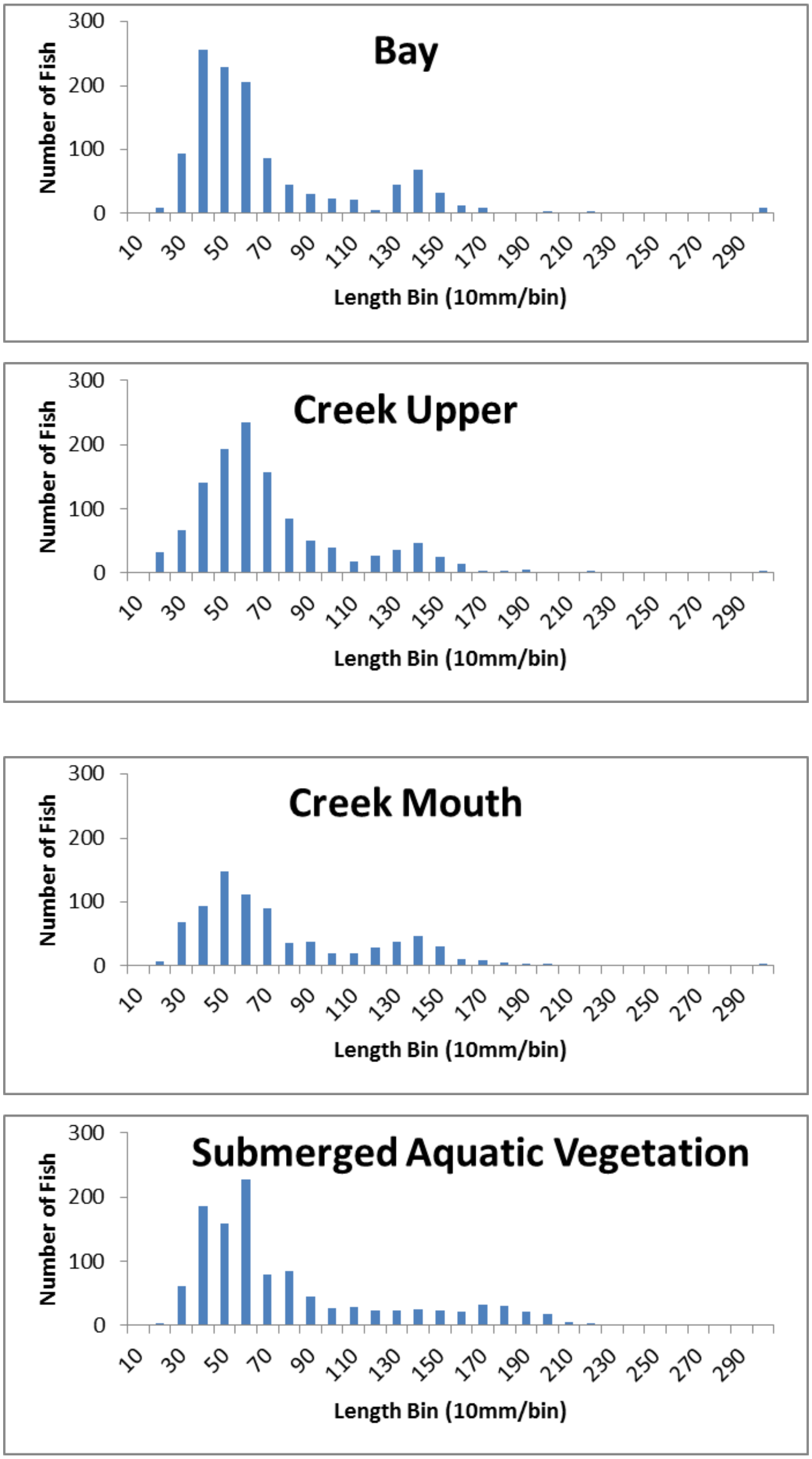
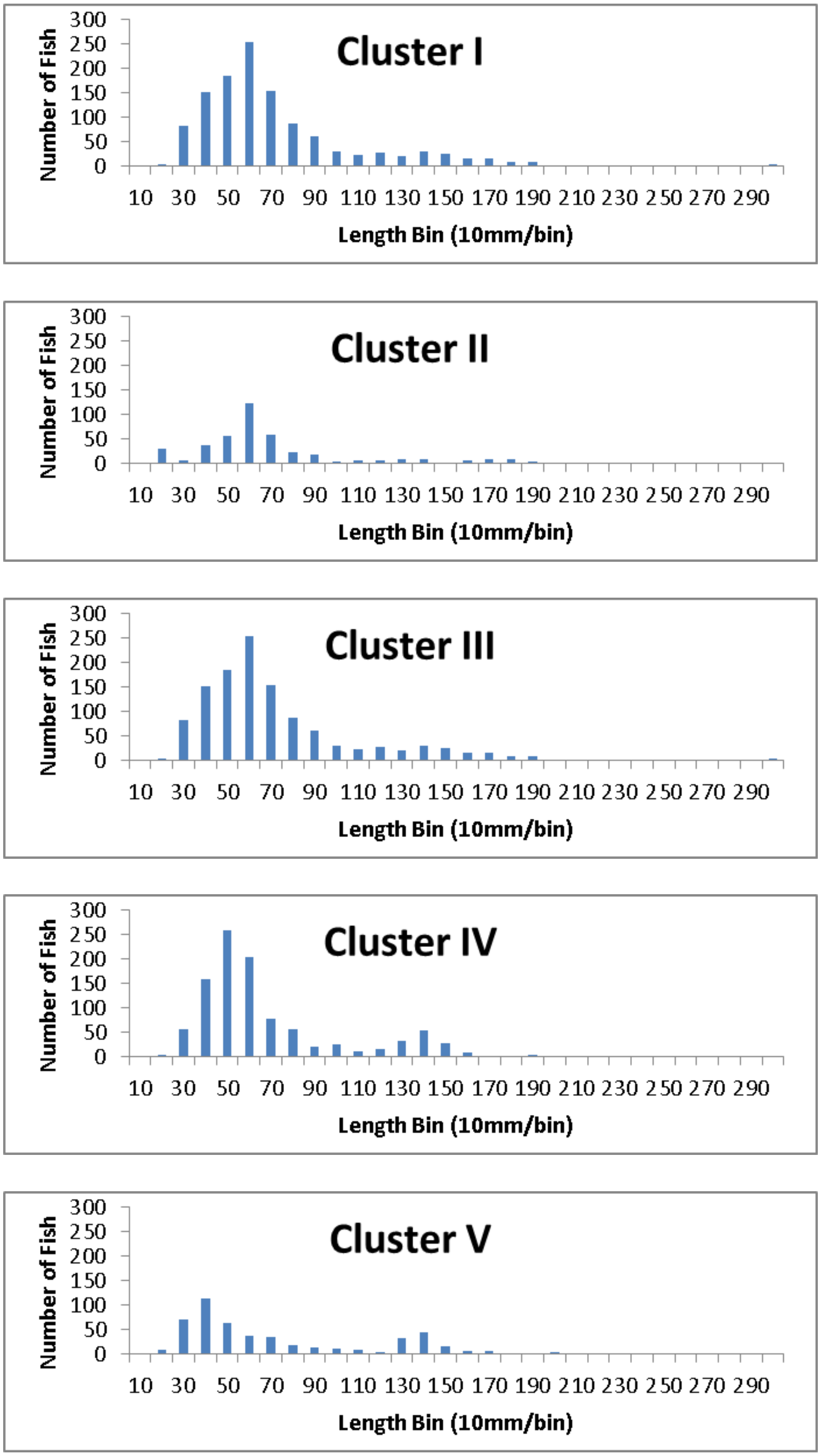


Figure 7. Length-frequency distribution (by cluster) of fish caught using otter trawl gear in February, April, June, August, and October 2012.



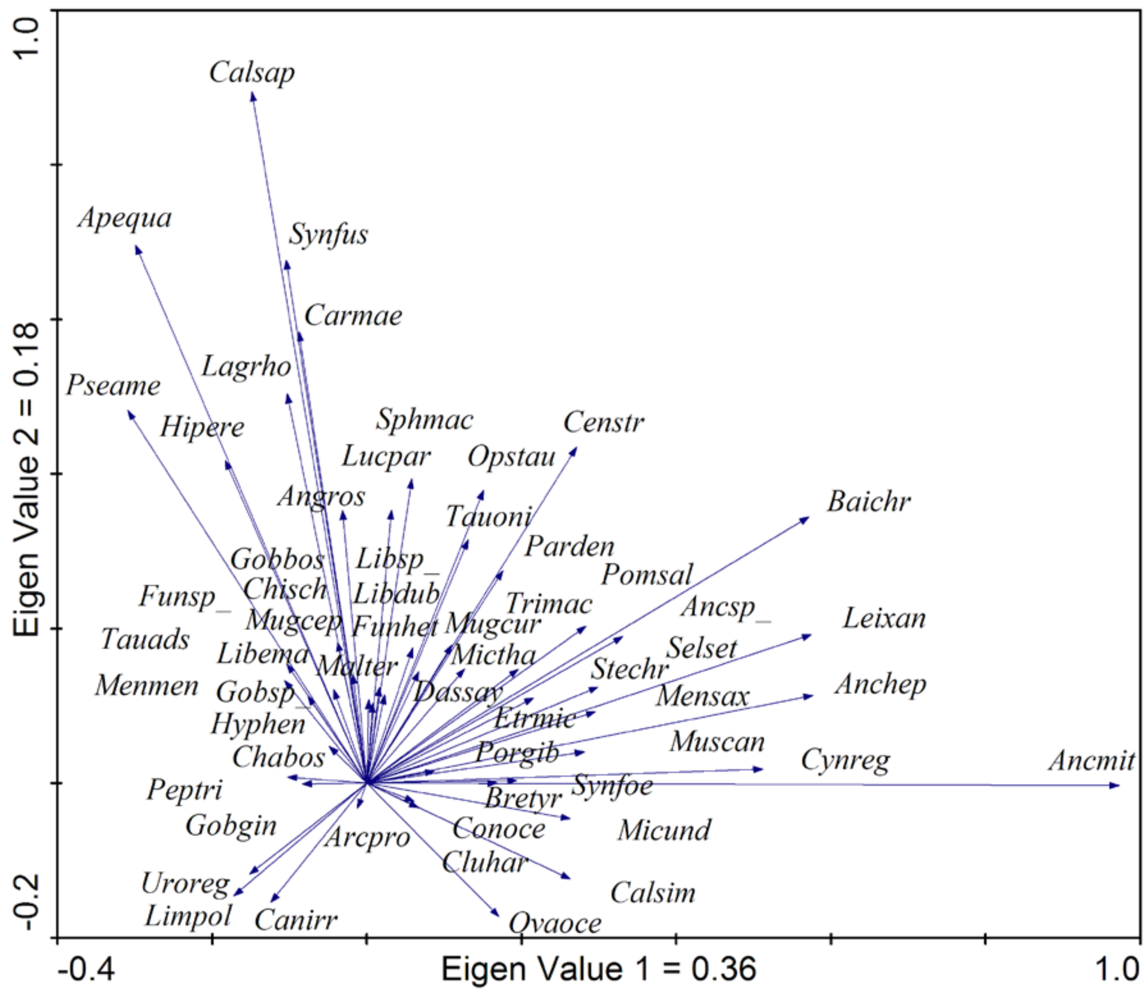


Figure 8 A. Principle components analysis (PCA) plot of species distribution gradients among bay sites by month in the Barnegat Bay in 2012. Species are abbreviated for visibility as the first 3 letters of the genus and first 3 letters of the species. See Table 6 for a complete list of names. The plot is in the same coordinate space as following figures of sample distribution, thus, species gradients relate show the expected distribution of fish among samples. Vector length is an indication of the gradient strength, not overall abundance.

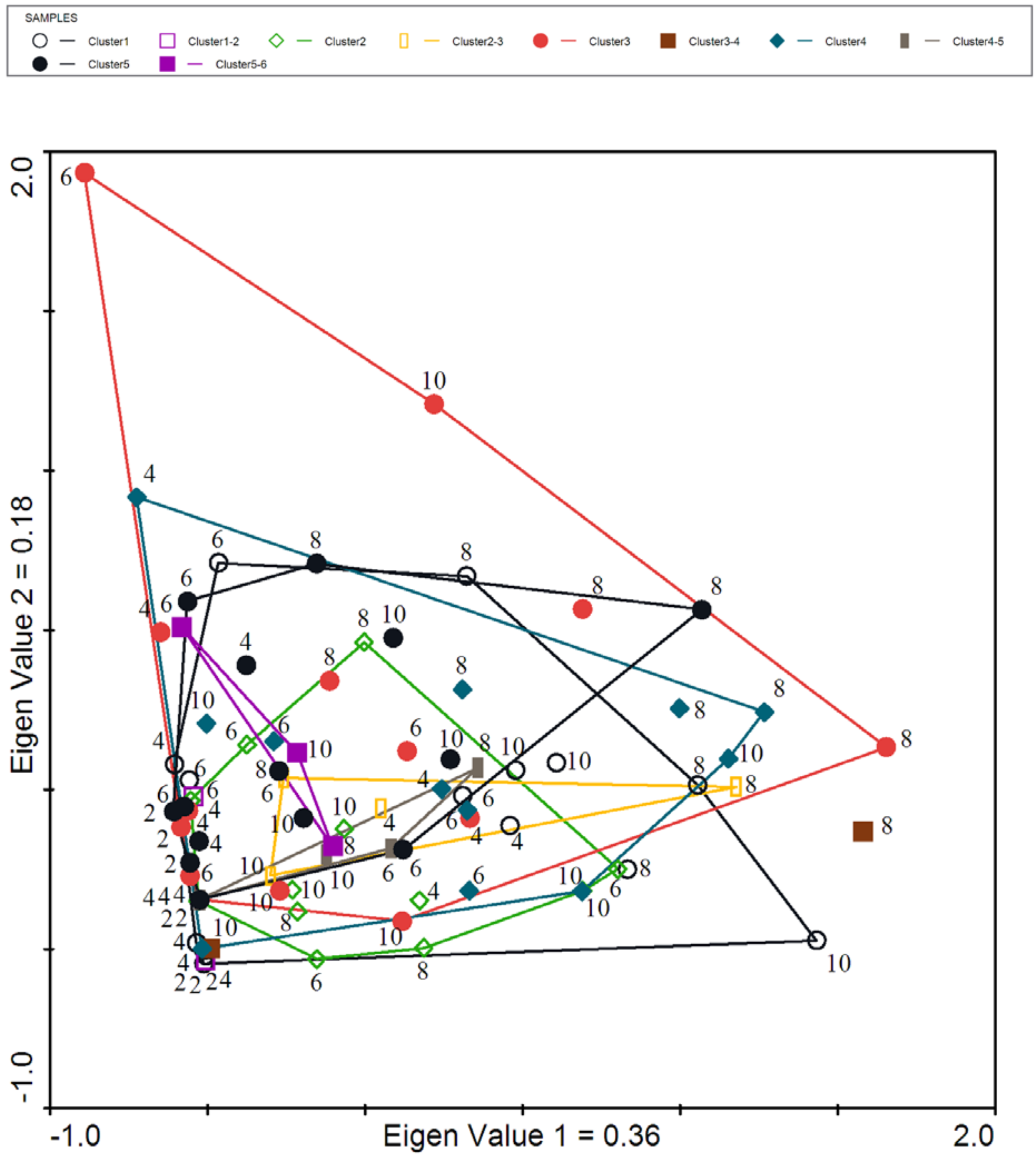


Figure 8 B. Principle components analysis (PCA) plot of bay otter trawl sample distribution sites by month in the Barnegat Bay in 2012. Samples with similar species composition plot near to each other. Samples are coded by the Urbanization Cluster in which they were collected. Envelopes are plotted around all members of a Cluster. Numbers next to the symbols refer to the month of collection. The plot is in the same coordinate space as previous plot of species gradients.

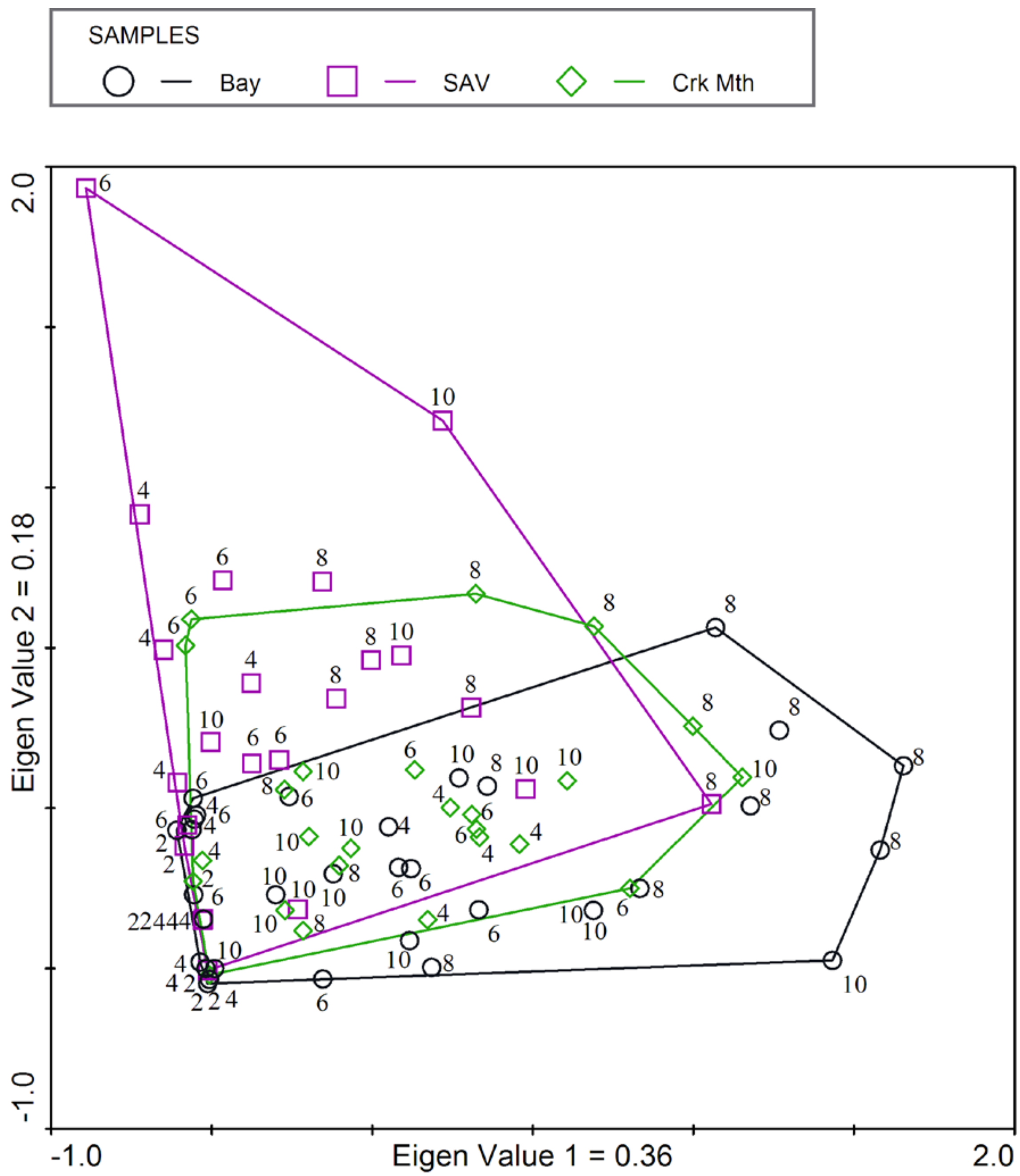
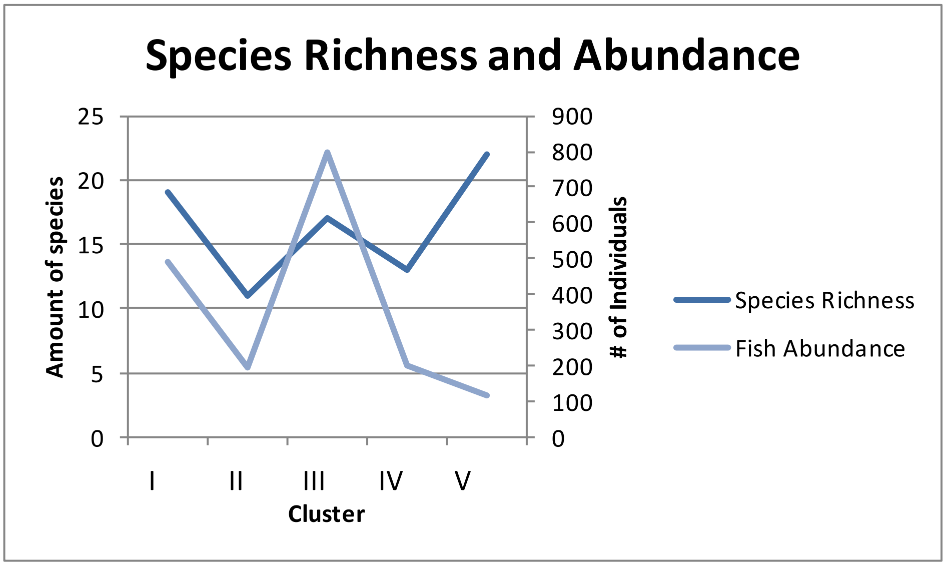


Figure 8 C. Principle components analysis (PCA) plot of bay otter trawl sample distribution sites by month in the Barnegat Bay in 2012 in the same coordinates space as previously. Samples are coded by the habitat type in which they were collected. Envelopes are plotted around all members of a habitat type. Numbers next to the symbols refer to the month of collection.

Figure 9. Species richness and fish abundance in SAV habitat by cluster as measured by trawls in 2012. See Fig. 1 for location of clusters.



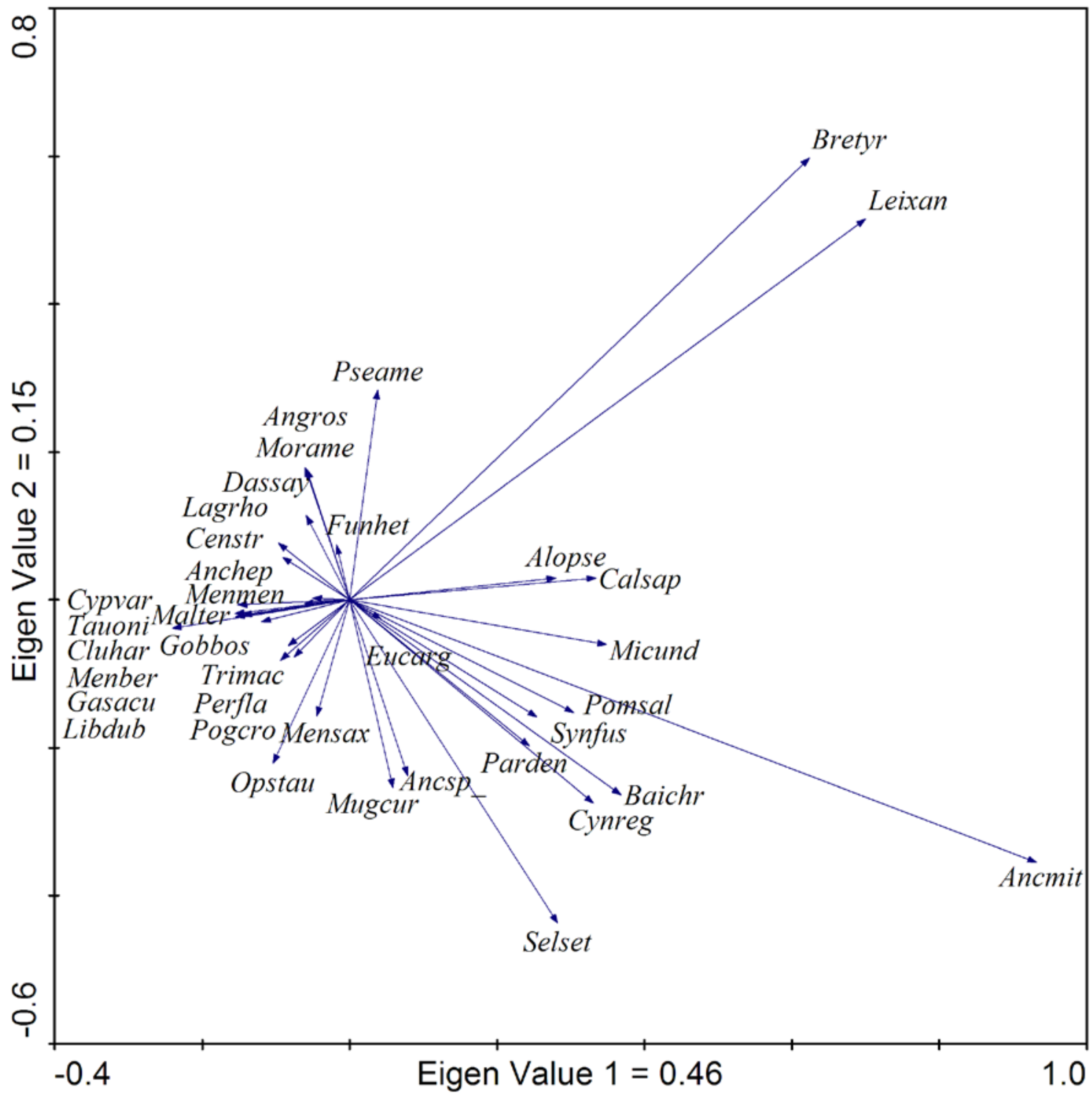


Figure 10 A. Principle components analysis (PCA) plot of species distribution gradients among otter trawl samples of creek sites only the Barnegat Bay in 2012. The plot is in the same coordinate space as the following figures of sample distribution, thus, species gradients show the expected distribution of fish among samples. Vector length is an indication of the gradient strength, not overall abundance. Angle between vectors is the interspecies correlation coefficient.

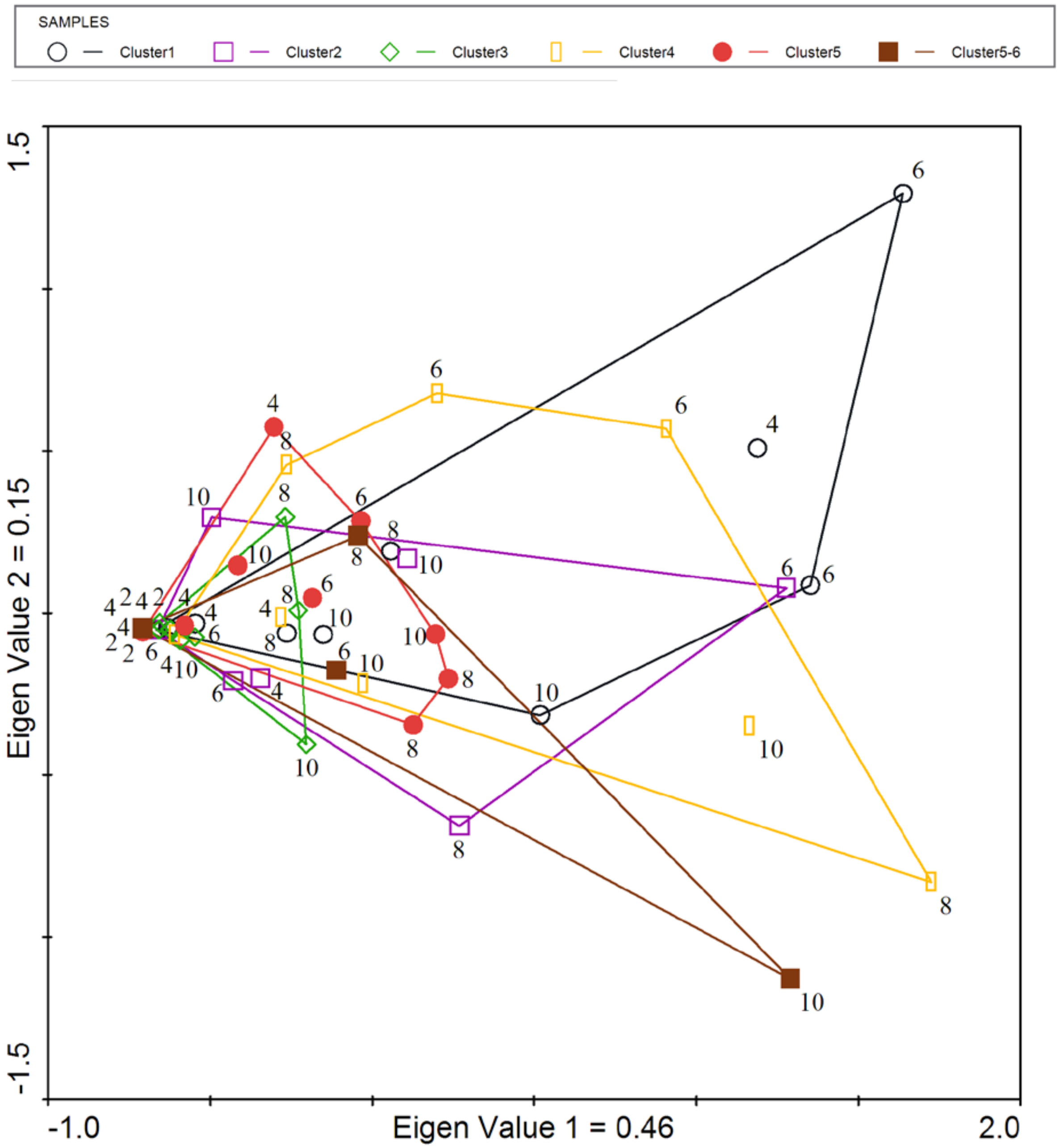


Figure 10 B. Principle components analysis (PCA) plot of otter trawl creek only sample distribution by month in the Barnegat Bay in 2012 in the same coordinates space as 10 A. Samples are coded by the creek designation (see text) in which they were collected. Envelopes are plotted around all members of a designation. Numbers next to the symbols refer to the month of collection.

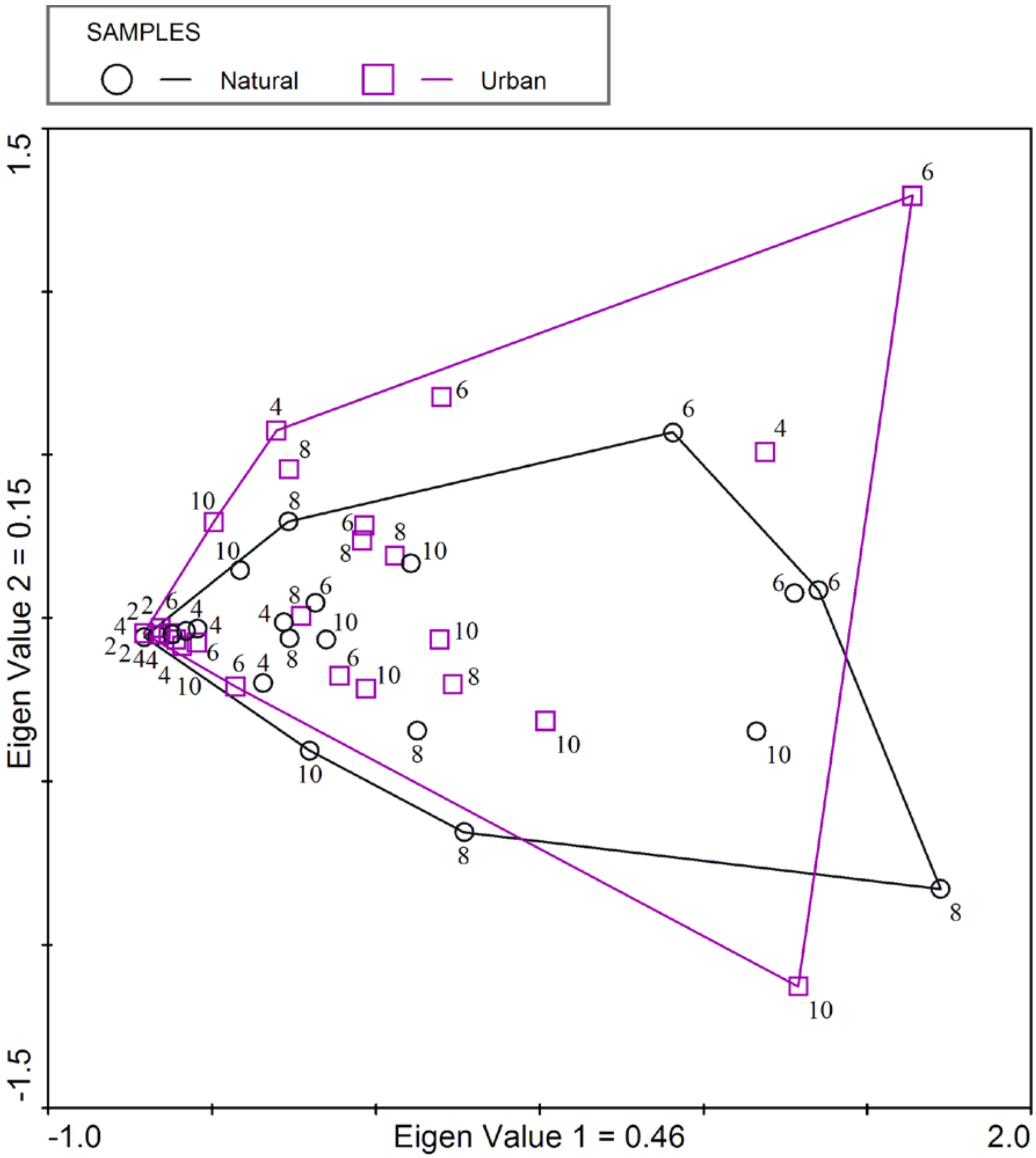


Figure 10 C. Principle components analysis (PCA) plot of otter trawl creek only sample distribution by month in the Barnegat Bay in 2012 in the same coordinates space as 10 A. Samples are coded by the creek designation (see text) in which they were collected. Envelopes are plotted around all members of a designation. Numbers next to the symbols refer to the month of collection.

Figure 11. Abundance and species richness of fishes and temperature in marsh creeks from February through October 2012.

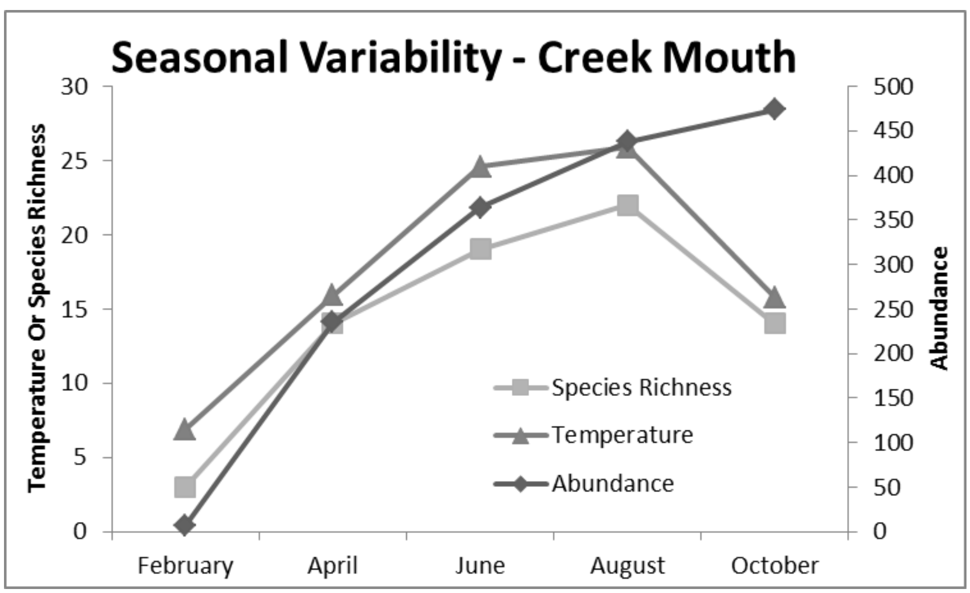


Figure 12. Abundance and species richness of fishes and temperature in marsh creeks from February through October 2012.

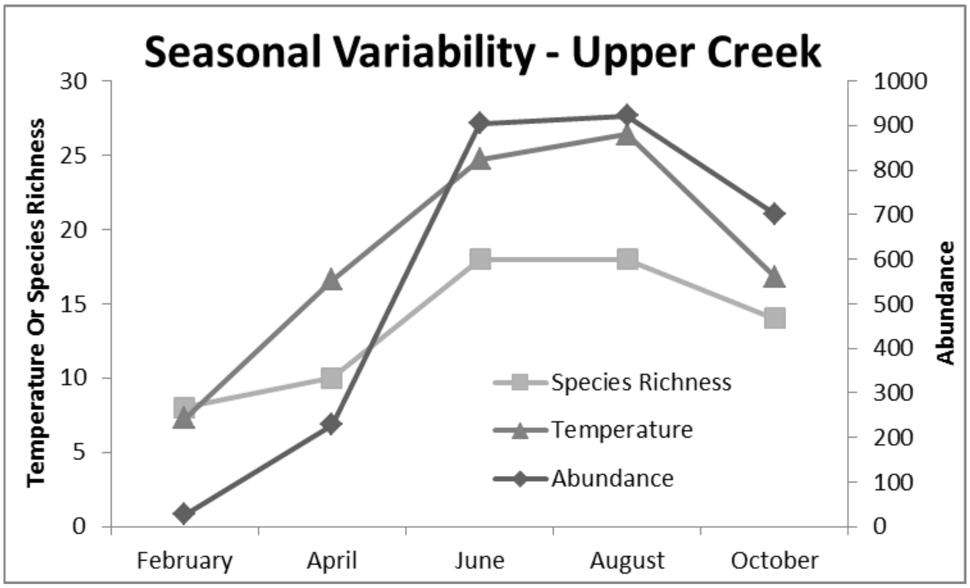


Figure 13. Species richness and abundance at each cluster by sampling month and average abundance and species richness at each cluster for all months sampled. February data were not included because total catch was low.

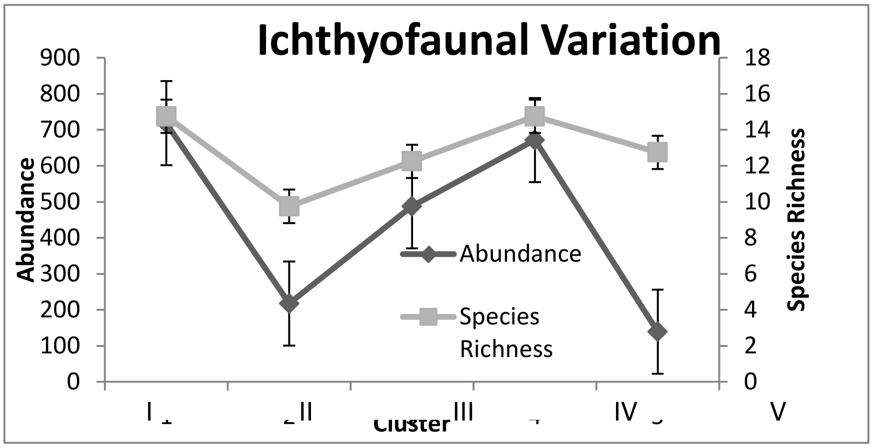


Figure 14. Abundance of blue crabs from traps deployed in four habitats at each cluster June-August, 2012. The numbers above the bars indicate the number of crabs captured per cluster.

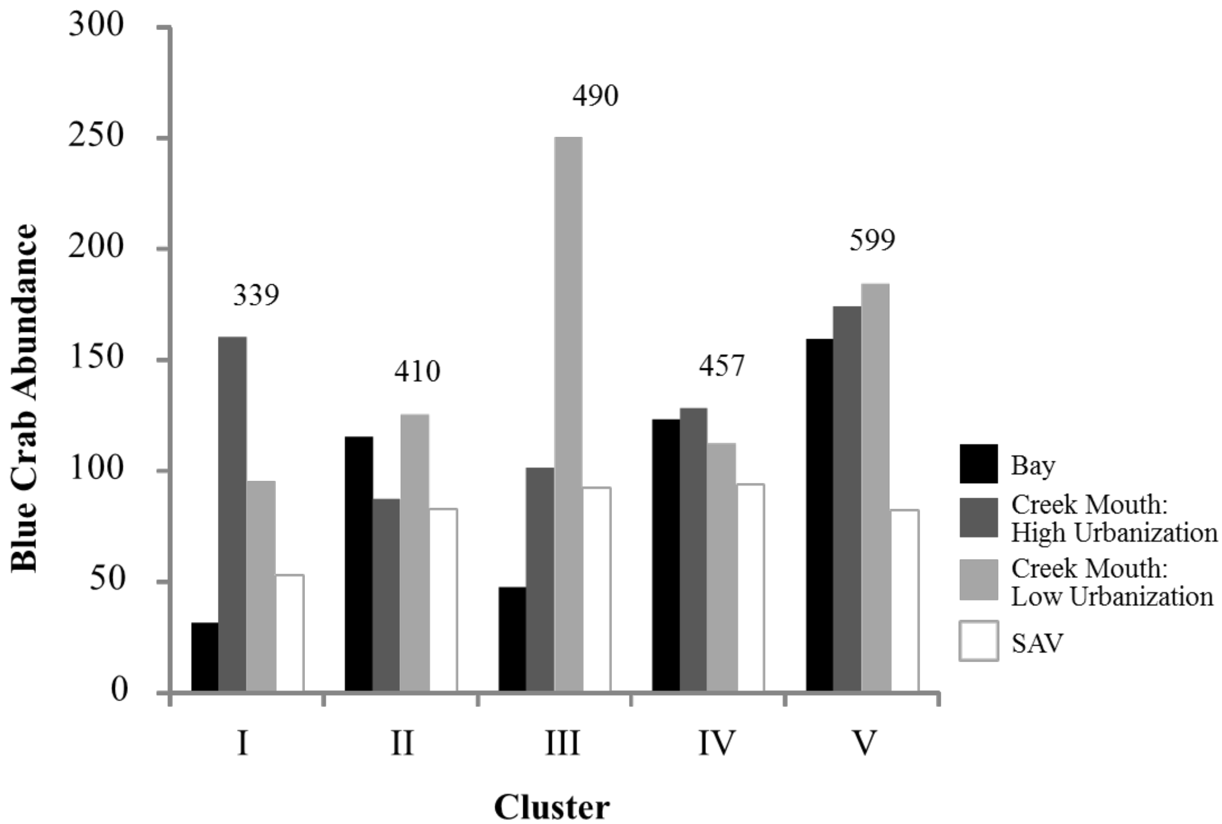


Figure 15. Size frequency distributions in 10mm size increments of blue crabs captured by two types of gear (trawl and trap) by habitat type in May, June and August 2012: A. Trawl in bay and SAV; B. Trawl in creek mouth-high urbanization and creek mouth-low urbanization; C. Trawl in creek upper-high urbanization and creek upper-low urbanization; D. Trap in bay and SAV; E. Trap in creek mouth-high urbanization and creek mouth-low urbanization. Total numbers of crabs captured per habitat are shown.

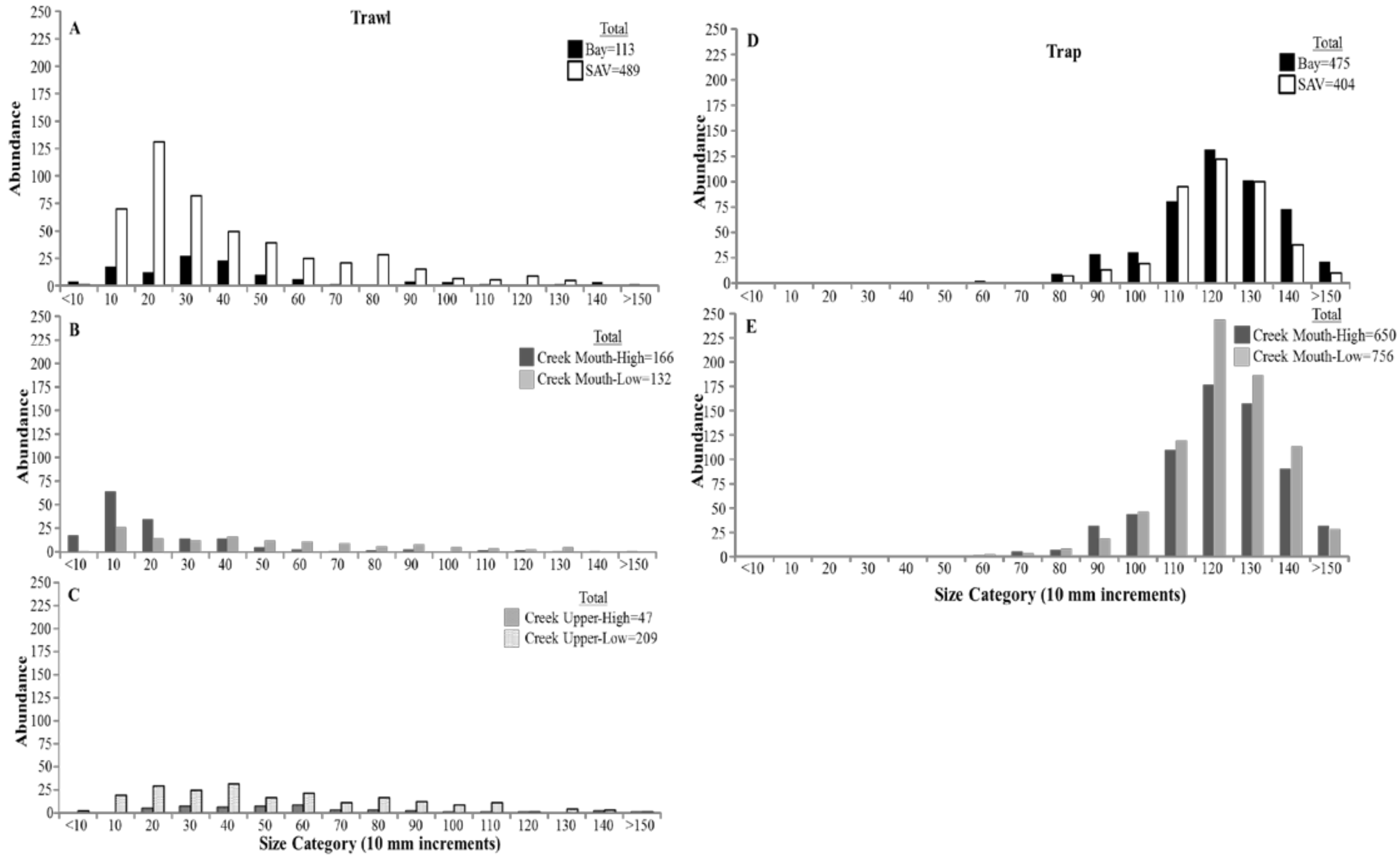


Figure 16. Number of crabs recaptured according to the cluster and creek type from which they were released, May-August, 2012. The numbers inside each bar indicate the number of crabs tagged at each creek. The numbers above the bars indicate the recapture percentage for each cluster.