Seasonal changes of the pelagic fish assemblage in a temperate estuary

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Abstract

The pelagic (i.e. fishes that spend most of their time swimming and feeding in the water column) fish assemblage was examined within a temperate estuary to determine the seasonal patterns of abundance, biomass, richness, and species composition. These measures were related to abiotic measures including temperature, salinity, water transparency, and depth. Pelagic fish \( n < 350,000 \) were sampled weekly from August 1995 through December 1996 in Great Bay in New Jersey, USA, with a pop net (5 m diameter, 5 m length, 3 mm cod end). The most frequently occurring and abundant species included *Clupea harengus* (frequency of occurrence \( = 27.4\% \); abundance \( = 80.5\% \) of total catch), *Menidia menidia* (83.5, 10.6%), *Anchoa mitchilli* (66.5, 6.0%), and *Anchoa hepsetus* (23.1, 1.9%). There were strong seasonal trends in species richness, total abundance, and total biomass with peaks in spring, summer, and autumn, and very low values for these parameters in winter. In addition, there were five seasonal groupings within this pelagic fish assemblage that were primarily, but not exclusively, represented by young-of-the-year (age 0+) species. Winter (December–March) was represented by adult *Gasterosteus aculeatus* and age 1+ by *M. menidia*. Spring (April–early June) was overwhelmingly dominated by age 0+ *C. harengus*. Early summer (late June–early July) was relatively species rich and characterized by age 0+ of *Brevoortia tyrannus*, *Pomatomus saltatrix*, *Alosa pseudoharengus*, and age 1+ of *Anchoa mitchilli*. Late summer (late July–August) remained relatively species rich and included mostly age 0+ of *A. mitchilli*, *A. hepsetus*, and *M. menidia*. Autumn (September–November) continued to have high catches of age 0+ of *M. menidia* and *A. mitchilli*. As expected for temperate estuaries, the best of the measured abiotic predictors of these groupings included temperature, salinity, and degree of change in temperature. However, timing of life history characteristics, such as location, and timing of reproduction and migration also influenced the seasonal occurrence of these pelagic species. The large abundance and biomass of a relatively few species, as observed in this study, are typical of estuaries, although this is one of the few studies that have focused solely on the pelagic component of estuarine fish assemblages.

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1. Introduction

Pelagic fish, especially the young-of-the-year (age 0+), are often extremely abundant in estuaries and may be an integral link in estuarine food webs acting both as predator and prey. Pelagic fish have been shown to be significant predators of zooplankton, and fish eggs and larvae (Baird & Ulanowicz, 1989; Blaxter & Hunter, 1982). In fact, two pelagic fishes, bay anchovy, *Anchoa mitchilli* and Atlantic menhaden, *Brevoortia tyrannus*, when found in high densities in estuaries, have been correlated with short-term, local reduction of zooplankton (Durbin & Durbin, 1998; Johnson, Allen, Ogburn, & Stancyk, 1990). In estuaries along the east coast of the United States, pelagic fish are themselves major prey items of piscivorous fish, including many commercially and recreationally important fish, such as bluefish, *Pomatomus saltatrix*, striped bass, *Morone saxatilis*, and weakfish, *Cynoscion regalis* (Friedland, Garman, Bejda, Studholme, & Olla, 1988; Hartman & Brandt, 1995b; Nemerson & Able, in press; Safina & Burger, 1989; Tupper & Able, 2000). Furthermore, it has been suggested that seasonal fluctuations of prey fish abundance and biomass may determine the distribution of some dominant piscivorous predators (Greenstreet,
McMillan, & Armstrong, 1998; Hartman & Brandt, 1995a). However, we often lack details of their occurrence and abundance, which would allow an improved understanding of these linkages and a better understanding of marine ecosystems as a whole (Springer & Speckman, 1997; Underwood, Chapman, & Connell, 2000). In fact, we have found few studies that investigated the complete assemblage. Most of the available literature either focused on coastal oceanic assemblages (Allen & DeMartini, 1983; Moreno & Castro, 1994; Parrish & Mallicoate, 1995; Sanchez & Ciechomski, 1995) or selected species within an estuary (Allen, Johnson, & Ogburn-Matthews, 1995; Castillo-Rivera, Moreno, & Iniesta, 1994; Castro & Cowen, 1991; Conover & Ross, 1982; Elliott, O’Reilly, & Taylor, 1990; Newberger & Houde, 1995; Vouglioitis, Able, Kurtz, & Tighe, 1987; Wang & Houde, 1995) or ocean (Clay, Stobo, Beck, & Hurley, 1989; Conover & Murawski, 1982). In addition, estuarine-wide sampling programmes, which were designed to evaluate total species composition in a variety of habitats, may include data on some pelagic fishes (e.g. Able & Fahay, 1998; Ayvazian & Deegan, 1996; Pearcy & Richards, 1962; Szedlmayer & Able, 1996; and others), but these do not provide a comprehensive view of this component of the fauna.

A significant limiting factor in studying pelagic fish assemblages is the traditional sampling techniques, i.e. nets hauled behind vessels, often underestimate and are unable to quantify the abundance of pelagic fish. This difficulty is related to a combination of factors including their position in the water column, patchy distribution, and fast swimming speed (Blaxter & Hunter, 1982). Through acoustic and visual techniques, researchers have observed that pelagic fish, including Atlantic herring (Clupea harengus), mackerel (Scomber scombrus), and sprat (Sprattus sprattus), avoid capture by increasing both vertical and horizontal swimming speeds in areas where vessels and/or trawls are approaching (Blaxter & Hunter, 1982; Misund & Aglen, 1992; Misund, Luyeye, Coetzee, & Boyer, 1999; Wardle, 1993). Conversely, enclosure devices (e.g. purse seine, pop net, lift net) may be more appropriate to collect pelagic fish because the design of these gears is not disruptive to the schooling behaviour of pelagic fish (Misund, 1993; Rozas & Minello, 1997; Wardle, 1993; Wickham, 1970). Many studies of pelagic fish have been carried out in deeper water where hydro-acoustic techniques were effective (Allen & DeMartini, 1983; Freon, Gerlatto, & Soria, 1996; Koslow, Kloer, & Williams, 1997; Petitgas & Levenez, 1996; Safina & Burger, 1988); however, this technique is not available in shallow waters (<2 m) typical of estuaries (Trevorrow, 1998). For these reasons, the pelagic fish assemblage in estuaries has rarely been the focus of research.

As a result of the above, the specific objectives of this study were to determine: (1) the seasonal patterns of species composition, species richness, abundance, and biomass of the pelagic fish assemblage within a temperate estuary, and (2) whether selected environmental variables including water temperature, salinity, water transparency, and depth could predict seasonal species groupings. The data for this study were collected with a newly designed pop net, which proved effective in the collection of pelagic fish.

2. Methods and materials

2.1. Study area

The study was conducted within Great Bay (39°31’N; 74°19’W), a temperate, polyhaline, estuary in southern New Jersey, USA (Fig. 1) with a wide seasonal temperature range (−0.1 to 25.2°C), relatively stable salinities (23.6 to 34.5) and a moderate tidal range (1.1 m), which is typical of estuaries within the Middle Atlantic Bight (Able & Fahay, 1998; Able, Hoden, Witting, & Durand, 1992). Great Bay is relatively pristine compared with other estuaries along the northeastern Atlantic coast of the United States, due primarily to a relatively undeveloped and protected watershed in the Jacques Cousteau National Estuarine Research Reserve at Mullica River-Great Bay (Able, Lathrop, & DeLuca, 1996; Psuty, DeLuca, Lathrop, & Able, 1993).

Sampling was carried out in a protected embayment, which is approximately 2 km from Little Egg Inlet and the Atlantic Ocean (Fig. 1). Portions of this embayment, which was last dredged in 1994, ranged from intertidal to 2 m depths and served as the Rutgers University Marine Field Station boat basin. Piers provided access to the deeper, central portion of the embayment where sampling occurred. The embayment is broadly connected to Schooner Creek, a subtidal creek (depths to 2 m) and Shooting Thoroughfare, a channel (depths to 11 m) leading from Little Egg Inlet into Great Bay (Fig. 1). The embayment was fringed with unaltered marsh, dominated by salt marsh cordgrass (Spartina alterniflora), while intertidal and subtidal substrata were dominated by brown (Fucus vesiculosus and Ascophyllum nodosum), and green (Ulva lactuca) algae.

2.2. Sampling technique

A conical-shaped pop net with a rigid mouth of 5 m diameter and an overall length of approximately 5 m was constructed with a white, large, outer mesh with a gradient of mesh sizes from 25 cm² at the mouth to 3 cm² at the cod end, an inner lining of green 6 mm mesh and a black cod end of 3 mm mesh (Fig. 2). The pop net was lowered until the body of the net was collapsed, and the mouth was resting on the bottom of the embayment. After 15 min, the net was manually retrieved vertically through the water column. The large white outer mesh...
was designed to be easily visible to pelagic fish and thus work as a visual barrier to herd the fish into the centre of the net (see Blaxter & Hunter, 1982). This large mesh also provided little resistance so it could be retrieved quickly (c. 0.2–0.4 m s\(^{-1}\); total recovery time = 5–10 s). The inner lining, starting approximately a third of the way down the net, retained the fish. As the net moved through the water column the fish were funnelled down to the cod end where they were captured. This net was functionally similar to that used by previous investigators sampling pelagic fishes (Bagenal, 1974; Connolly, 1994; Dewey, Holland-Bartels, & Zigler, 1989; Espegren & Bergersen, 1990; Rooker, Dennis, & Goulet, 1996; Wickham, 1970).

Lights have been successful in attracting and maintaining pelagic fish at night for harvesting in the Gulf of Mexico (Wickham, 1971, 1973) and enhancing the collections of a variety of species and stages at the study site (Able, Hales, 1997). In an attempt to enhance fish capture with the pop net, an electric-powered halogen lamp (300 W) was suspended and centred approximately 0.5 m above the water surface in the sampling area. Light meter readings taken directly under the light at night were 40 microeinsteins at the water surface and nearly 1 microeinstein at the substratum (depth = 2 m). Readings taken at the edge of the sampled area, 2.5 m from the light, were 1 microeinstein at the surface and 0 microeinstein at the substratum (depth = 2.5 m). These readings indicate that the light did not penetrate the perimeter of the sampling area; however, attraction rate for each species towards the light is unknown.

![Fig. 1. General study area in Great Bay estuary in New Jersey, USA.](image)

![Fig. 2. Diagram of pop net, which has a diameter of 5 m at the mouth and an approximate length of 5 m.](image)
Fish were collected weekly, without replacement, on night mid-flood tides (i.e. predicted low tide plus 3 hours) with four consecutive hauls of the pop net from August 1995–December 1996 (n = 53 dates). There was no evidence to suggest that abundance decreased with each successive sampling (Hagan, pers. comm.). Sampling was less frequent from December 1995 through March 1996, and July through August 1996 due to ice formation and lack of flooding tides occurring during darkness, respectively (Table 1). For each sample, all fish were identified to the lowest possible taxa, enumerated, and a sub-sample (n = 30) of each fish species from each net haul was measured to the nearest millimetre fork length (FL), if available, or total length (TL). In 1996, all the pelagic fish species were weighed to the nearest 5 g with a mechanical counter balance to determine fish biomass. Unidentified fish were recorded, measured and preserved in 95% ETOH for later identification.

Water temperature (°C), salinity, water transparency (Secchi depth, m), and water depth were recorded at the end of each sampling event. Change in temperature was calculated by determining the directional change in water temperature since the previous sampling date.

2.3. Gear evaluation

Understanding the effectiveness of a chosen sampling technique is necessary in understanding the usefulness of data collected (Rozas & Minello, 1997). To determine the aspects of the capture efficiency of this pop net and to determine the effectiveness of the gear to collect Atlantic silverside, *Menidia menidia*, two mark-recapture experiments were conducted. These fish were appropriate test subjects because they were a dominant component of the fish assemblage. On the day of the experiments, fish were collected by seine in the embayment, were placed in an aerated cooler, counted, measured, and were marked subcutaneously with nontoxic acrylic paint. Marked fish (36–85 mm FL, mean = 60.8) were released into the centre of the sampling area by sliding them from an adjacent dock through a long tube (15 cm diameter, 5 m). There was no evidence of mortality after release because all fish swam out of sight. Approximately one min after release, the net was retrieved with the typical protocol and marked fish were re-counted and measured. The recapture rate for the two experiments (67 and 73 fish released) averaged 89.4% (91.0 and 87.7%, respectively), and thus the gear appeared to be efficient, at least for this species, based on this technique.

2.4. Analysis

Due to the inherent biases (i.e. attraction, avoidance) associated with use of the light over the net, abundance (number per haul), biomass (g per haul), and species richness (number of species per haul) are relative estimates for this sampling technique and were denoted as catch per unit effort (CPUE). To determine size frequency distribution of fish collected by the pop net, all measured lengths were converted into TL using the length relationships in Able and Fahay (1998).

### Table 1

Sampling effort, mean species richness (number of species per haul), mean abundance (number per haul), and mean biomass (gram per haul) by month for pelagic fish collected by pop net during the night in Great Bay estuary in southern New Jersey during 1995 to 1996. Different letters within each measure indicate significant differences among sampling months for log-transformed data. Biomass measurements were done in January through December 1996.

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of dates</th>
<th>Number of hauls</th>
<th>Mean species richness ±1 SE</th>
<th>Mean abundance ±1 SE</th>
<th>Mean biomass ±1SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>August</td>
<td>5</td>
<td>20</td>
<td>4.3 ± 0.3</td>
<td>418.5 ± 109.8</td>
<td>cde n/a</td>
</tr>
<tr>
<td>September</td>
<td>4</td>
<td>16</td>
<td>2.9 ± 0.2</td>
<td>78.9 ± 13.0</td>
<td>de n/a</td>
</tr>
<tr>
<td>October</td>
<td>5</td>
<td>20</td>
<td>2.8 ± 0.1</td>
<td>363.8 ± 102.1</td>
<td>cde n/a</td>
</tr>
<tr>
<td>November</td>
<td>3</td>
<td>12</td>
<td>1.7 ± 0.2</td>
<td>519.2 ± 157.0</td>
<td>cde n/a</td>
</tr>
<tr>
<td>December</td>
<td>2</td>
<td>8</td>
<td>0.4 ± 0.3</td>
<td>1.6 ± 0.4</td>
<td>h n/a</td>
</tr>
<tr>
<td>1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>1</td>
<td>4</td>
<td>2.0 ± 0.0</td>
<td>14.8 ± 4.9</td>
<td>fg 32.0 ± 9.8</td>
</tr>
<tr>
<td>February</td>
<td>2</td>
<td>8</td>
<td>1.6 ± 0.3</td>
<td>30.5 ± 17.9</td>
<td>g 70.9 ± 43.4</td>
</tr>
<tr>
<td>March</td>
<td>2</td>
<td>8</td>
<td>1.9 ± 0.3</td>
<td>17.9 ± 5.5</td>
<td>fg 44.1 ± 22.9</td>
</tr>
<tr>
<td>April</td>
<td>4</td>
<td>16</td>
<td>2.6 ± 0.2</td>
<td>1823.8 ± 826.7</td>
<td>cde 1040.3 ± 531.0</td>
</tr>
<tr>
<td>May</td>
<td>4</td>
<td>16</td>
<td>3.6 ± 0.4</td>
<td>12726.8 ± 2071.4</td>
<td>a 15091.3 ± 2084.0</td>
</tr>
<tr>
<td>June</td>
<td>4</td>
<td>16</td>
<td>4.1 ± 0.4</td>
<td>3529.1 ± 1167.7</td>
<td>b 6480.3 ± 2750.3</td>
</tr>
<tr>
<td>July</td>
<td>3</td>
<td>12</td>
<td>5.9 ± 0.2</td>
<td>656.6 ± 230.1</td>
<td>bcd 1216.4 ± 370.7</td>
</tr>
<tr>
<td>August</td>
<td>2</td>
<td>8</td>
<td>5.9 ± 0.3</td>
<td>860.6 ± 242.4</td>
<td>bc 990.6 ± 268.1</td>
</tr>
<tr>
<td>September</td>
<td>4</td>
<td>16</td>
<td>2.6 ± 0.3</td>
<td>58.8 ± 8.1</td>
<td>ef 63.4 ± 9.5</td>
</tr>
<tr>
<td>October</td>
<td>4</td>
<td>16</td>
<td>3.0 ± 0.2</td>
<td>418.5 ± 134.2</td>
<td>cde 447.4 ± 114.7</td>
</tr>
<tr>
<td>November</td>
<td>2</td>
<td>8</td>
<td>2.4 ± 0.2</td>
<td>218.9 ± 45.1</td>
<td>cde 413.1 ± 105.4</td>
</tr>
<tr>
<td>December</td>
<td>2</td>
<td>8</td>
<td>1.8 ± 0.4</td>
<td>1326.6 ± 852.4</td>
<td>bcd 735.0 ± 344.1</td>
</tr>
</tbody>
</table>
We used analysis of variance to test for significant differences in species richness, abundance and biomass among years and months. Values were log transformed to attain normality as identified by the Wilk–Shapiro test. If significant differences among years and months were detected \( (P \leq 0.05) \) a Student–Newman–Keuls multiple range test was used to identify specific differences (Zar, 1984). Because we were focusing on the pelagic fish fauna, any demersal fish \((n = 659)\), i.e. species primarily associated with substrata and/or structure (Hagan, unpub. data), were not considered in any analysis.

Principal components analysis (PCA) of the correlation matrix of log-transformed mean abundance of each dominant fish species, i.e. any species in which greater than 75 individuals were collected throughout the study, by date, was used to classify seasonal components of the pelagic fish assemblage. Prior to this analysis, \( M. \) menidia and \( A. \) mitchilli were broken into age-classes of young-of-the-year \((\text{age } 0+)\) and age \(1+\) through analysis of length frequency (see Able & Fahay, 1998). The correlation matrix of log-transformed data is a standardization process measuring the degree of relatedness between the two variables, thus preventing the variation of a few species to drive the analysis (Pielou, 1984). A scree plot of the eigenvalues was used to determine as to which components were important (Jackson, 1993). The important components were determined, the eigenvector loadings for each species were examined for significant correlation \( (P \leq 0.05) \) with each component and grouping.

Two methods were used to determine if seasonal species groupings were associated with abiotic variation. First, Spearman correlation among measured abiotic data \((\text{temperature, change in temperature, salinity, water transparency, and water depth})\) on each sampling date and each PCA factor scores \((\text{factor } 1 \text{ and factor } 2)\) was calculated. Second, to determine whether there was a unique combination of abiotic variables for each season, abiotic data were split into chronological groupings \((\text{seasons})\) as defined by PCA. A one-way ANOVA was performed separately on each abiotic variable with season as the main effect. If significant differences \( (P \leq 0.05) \) were detected a Student–Newman–Keuls multiple range test was used to identify specific differences (Zar, 1984). Finally, significant differences within each abiotic variable were examined across each seasonal grouping to determine whether each grouping was identified by unique abiotic parameters.

### 3. Results

#### 3.1. Abiotic variables

Water temperature varied seasonally ranging from 0–26°C and averaging 16°C \((\pm 1.0 \ \text{SE})\) (Fig. 3). Temperature was highest during August through September 1995 and June through September 1996 and lowest in December 1995 through March 1996 and December 1996. During December 1995, temperature reached its lowest value and ice formed over the sampling site, while temperatures in December 1996 remained relatively high. There was a trend for temperatures to increase in February through May 1996 and decrease in September through December in both years. There was not a strong seasonal trend in salinity, water transparency or water depth (Fig. 3). Salinity ranged from 22–34 and averaged 27 \((\pm 0.4 \ \text{SE})\) and was highest in August–September, October–November 1995 and September 1996. Water transparency ranged from 0.5 m to 1.8 m and averaged 1.1 m \((\pm 0.04 \ \text{SE})\) based on Secchi disk readings. Water depth ranged from 1.0 to 1.8 and averaged 1.4 \((\pm 0.02 \ \text{SE})\). Water depth varied less than 0.2 m on any sampling date. These differences in depth resulted in volume of water sampled by the pop net for each haul ranging between 17.9 and 37.1 m\(^3\) during the duration of sampling, and varying less than 3.1 m\(^3\) on any sampling date.

#### 3.2. Species richness, abundance, and biomass

Species richness on a given sampling date ranged from 0 to 7 and averaged 3.1 species per haul \((\pm 0.2 \ \text{SE})\) with a pronounced seasonal pattern (Table 1). Species richness was highest in August 1995 and July–August 1996 and reached its lowest levels from November 1995 through April 1996 and November through December 1996 \((F_{16,195} = 23.68, P < 0.0001)\) (Table 1; Fig. 4). Species richness gradually increased through spring into early summer \((\text{April through June 1996})\) and significantly decreased from late summer into autumn \((\text{August to September 1996})\), and although not significant, the pattern was similar in 1995. Species richness was consistent among similar months between the years except that it was higher in August and December 1996 compared with those same months in 1995 (Table 1).

Abundance of the dominant pelagic species on a given sampling date averaged 1639.77 fish per haul and ranged from 0 to 28 888 fish per haul (Table 1; Fig. 4). There was a strong seasonal trend in overall abundance with highest values in May through June 1996 and lowest December 1995 through March 1996 \((F_{16,192} = 22.68, P < 0.0001)\). Abundance significantly increased through spring \((\text{March through May 1996})\) and significantly decreased through autumn of both the years, similar to the patterns observed in species richness. During both the years, abundance increased slightly from September to October and densities remained relatively consistent among other similar months between years. One exception was December 1995, which had a significantly lower mean abundance than December 1996.
Biomass of the dominant components of the pelagic fauna averaged 2961.2 g per haul and ranged from 0 to 40135 g per haul with a seasonal pattern similar to that of fish abundance ($F_{11,124} = 13.46$, $P < 0.0001$) (Table 1; Fig. 4). Biomass was highest in May 1996 and lowest in January through April 1996. Biomass significantly increased through spring (April to May 1996) and remained relatively high until significantly decreasing from late summer into autumn (August to September 1996). Although not significant, biomass increased from September to October 1996 and remained high until the sampling was discontinued in December 1996.

3.3. Species composition

Approximately 350,000 pelagic fish were collected over the study period and these represented 12 families and 21 species. Dominant families represented in the catch included clupeids (Clupea harengus, Alosa pseudoharengus, and Brevoortia tyrannus), engraulids (Anchoa...
mitchilli, A. hepsetus, and Engraulis eurystole), and an atherinid (M. menidia). Twelve species collected were considered dominant (i.e. greater than 75 individuals collected) and these made up nearly 100% of the total catch (Table 2). Clupea harengus was the most abundant species (80.5% of total catch) in terms of abundance and biomass with catches as high as 28,872 fish and 39,895 g per haul during the peak abundance. Menidia menidia, representing 10.6% of total catch, occurred most frequently in samples (frequency of occurrence = 83.5%). Other dominant fish included Anchoa mitchilli (6% of total catch), and Anchoa hepsetus (1.9% of total catch). Fishes ranged in size from 5–1200 mm TL with a mean length of 60 mm TL (Fig. 5). Over 90% of the fish measured were age 0+ based on comparisons with size compositions in Able and Fahay (1998).

3.4. Assemblage structure

Seasonal components of assemblage structure were defined with PCA with the first two principal components of the matrix, i.e. mean abundance against sampling date most important. Factor 1 (eigenvalue = 4.0) explained 29% of the variation and Factor 2 (eigenvalue = 2.9) explained 21%. These two axes separated the samples into five seasonal groupings: winter, spring, early summer, late summer, and autumn (Fig. 6a). Factor 1 separated winter and spring (negative) from early summer, late summer, and autumn (positive). Species or year classes of species negatively correlated to Factor 1 included Menidia menidia (age +1), Clupea harengus, and Pollachius virens, while those positively correlated included Menidia menidia (age 0+), Anchoa mitchilli (age 0+), and Anchoa hepsetus (Table 3).
Factor 2 separated winter and autumn (negative) from all other seasons (positive). Species or year classes of species negatively correlated to Factor 2 included *A. mitchilli* (age 0+), while those positively correlated included *A. mitchilli* (age 1+), *Pomatomus saltatrix*, and *Brevoortia tyrannus* (Table 3).

To determine the species composition in each seasonal grouping, two measures were examined. First, eigenvectors for each species were plotted on Factor 1 (PC1) and Factor 2 (PC2) to examine which species characterized the seasonal groupings in PCA (Fig. 6b). Direction of each species vector is correlated with placement of seasonal groupings as shown in Fig. 6a. Secondly, the dominant species were determined for each seasonal grouping (Fig. 7). Winter was characterized and dominated by *Gasterosteus aculeatus* (adults). Although *M. menidia* (age 1+) were relatively abundant in winter, this species also occurred in the spring and therefore was characteristic of both the seasons. Spring was overwhelmingly dominated by age 0+ *C. harengus*, but *P. virens* were also present in this grouping. *Anchoa mitchilli* (age 1+) were collected in spring and early summer and therefore characterized both the seasons. Early summer was dominated by *M. menidia* (age 0+); however other important species during this season included *P. saltatrix*, *B. tyrannus*, *Alosa pseudoharengus*, and *Sphyraena borealis*. Late summer was represented by age 0+ of *A. mitchilli*.

Table 2
Dominant fish species collected at night by pop net (frequency of occurrence, total number, mean abundance (number per haul), mean biomass (g per haul) and length (mm) based on samples collected from August 1995 through December 1996. Mean biomass based on samples collected from January through December 1996. Life history stage was determined from length range in samples (y, age 0+; all, all stages). Nd, no data collected; n/a, species never weighed more than 5 g in any haul.

<table>
<thead>
<tr>
<th>Species</th>
<th>Frequency of occurrence</th>
<th>Total number</th>
<th>Mean abundance ±(1 SE)</th>
<th>Mean biomass ±(1 SE)</th>
<th>Length mean (range)</th>
<th>Life history stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clupea harengus</td>
<td>27.4</td>
<td>279915</td>
<td>1320.4 (297.3)</td>
<td>2579.2 (580.7)</td>
<td>53.3 (31–95)</td>
<td>FL y</td>
</tr>
<tr>
<td>Menidia menidia</td>
<td>83.5</td>
<td>36752</td>
<td>173.4 (39.7)</td>
<td>240.3 (106.1)</td>
<td>58.2 (13–115)</td>
<td>FL all</td>
</tr>
<tr>
<td>Anchoa mitchilli</td>
<td>66.5</td>
<td>21395</td>
<td>100.9 (15.1)</td>
<td>130.8 (23.5)</td>
<td>54.0 (19–104)</td>
<td>FL all</td>
</tr>
<tr>
<td>Anchoa hepsetus</td>
<td>23.1</td>
<td>6722</td>
<td>31.7 (12.5)</td>
<td>71.4 (34.0)</td>
<td>51.4 (26–103)</td>
<td>FL all</td>
</tr>
<tr>
<td>Pollachius eirens</td>
<td>17.0</td>
<td>975</td>
<td>4.6 (1.4)</td>
<td>24.0 (7.4)</td>
<td>67.1 (28–200)</td>
<td>FL y</td>
</tr>
<tr>
<td>Gasterosteus aculeatus</td>
<td>11.3</td>
<td>312</td>
<td>1.5 (0.7)</td>
<td>5.4 (2.7)</td>
<td>61.2 (17–71)</td>
<td>TL all</td>
</tr>
<tr>
<td>Cynoscion regalis</td>
<td>10.8</td>
<td>201</td>
<td>0.9 (0.3)</td>
<td>n/a</td>
<td>57.7 (34–360)</td>
<td>TL all</td>
</tr>
<tr>
<td>Sphyraena borealis</td>
<td>15.6</td>
<td>182</td>
<td>0.9 (0.3)</td>
<td>nd</td>
<td>86.0 (52–180)</td>
<td>FL y</td>
</tr>
<tr>
<td>Brevoortia tyrannus</td>
<td>12.3</td>
<td>142</td>
<td>0.7 (0.2)</td>
<td>5.7 (3.2)</td>
<td>74.4 (28–145)</td>
<td>FL y</td>
</tr>
<tr>
<td>Pomatomus saltatrix</td>
<td>17.0</td>
<td>126</td>
<td>0.6 (0.1)</td>
<td>4.3 (1.3)</td>
<td>87.4 (32–204)</td>
<td>FL all</td>
</tr>
<tr>
<td>Alosa pseudoharengus</td>
<td>11.3</td>
<td>99</td>
<td>0.5 (0.2)</td>
<td>1.6 (0.9)</td>
<td>76.5 (49–142)</td>
<td>FL y</td>
</tr>
<tr>
<td>Engraulis eurystole</td>
<td>5.7</td>
<td>79</td>
<td>0.4 (0.2)</td>
<td>n/a</td>
<td>54.7 (29–74)</td>
<td>FL y</td>
</tr>
<tr>
<td>Other (n = 9 species)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5. Size distribution of all (age 0+ and age 1+) pelagic fish collected by pop net from August 1995–December 1996.
M. menidia, and A. hepsetus and included Cynoscion regalis and Engraulis eurystole. Autumn was characterized by only age 0+ of A. mitchilli and M. menidia.

Timing of seasonal groupings was similar but not predictable by date between the years. Groupings included spring (April through early June 1996) early summer (late June through early July 1996) and late summer (August 1995 and late July through August 1996). Variation between years in timing of seasonal groupings was evident during the autumn (September through November 1995 and September through December 1996) and winter (December 1995 through March 1996). Samples collected from December 1995 grouped with winter, while December 1996 grouped with autumn. This difference in assigned season resulted from differences in abiotic variables, especially temperature, between these 2 years (Fig. 3).

Abiotic variables explained some of the seasonal groupings of species defined by PCA. Factor 1 had a positive correlation with temperature (Spearman correlation = 0.50; P < 0.001) and with salinity (Pearson correlation = 0.32; P = 0.02), while Factor 2 had a negative correlation with salinity (Pearson correlation, −0.41; P = 0.002). Change in temperature, depth and
water clarity were not significantly ($P < 0.05$) correlated with either factor. There was a unique combination of abiotic variables for some seasons (Fig. 8). Water temperature, change in temperature, and salinity were significantly different between some seasons, while depth and water clarity were not significantly different between any season. Winter water temperature was significantly different from all other seasons. Water temperature separated spring from late summer, while change in temperature separated spring from autumn. However, spring was not significantly different from early summer in any abiotic variable measured. Change in temperature separated early summer from autumn, however it was not significantly different from spring and late summer for all the abiotic variables. Late summer was significantly different from autumn in temperature, however it was similar to early summer in all other measures. Finally, the combination of temperature, change in temperature, and salinity made autumn uniquely relative to all other seasons.

![Table 3](image)

**Table 3**

Loadings (i.e. eigenvector) on, and correlation coefficients for, each species with principal components 1 and 2. (**$P < 0.001$, *$P < 0.05$**). Age classes (age 0+ or age 1+) indicated for selected species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Eigenvector</th>
<th>Correlation</th>
<th>Eigenvector</th>
<th>Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menidia menidia (age 0+)</td>
<td>0.398</td>
<td>0.795**</td>
<td>-0.125</td>
<td>-0.213</td>
</tr>
<tr>
<td>Anchoa hepsetus</td>
<td>0.298</td>
<td>0.596**</td>
<td>-0.057</td>
<td>-0.097</td>
</tr>
<tr>
<td>Sphyraena borealis</td>
<td>0.296</td>
<td>0.591**</td>
<td>0.145</td>
<td>0.247</td>
</tr>
<tr>
<td>Anchoa mitchilli (age 0+)</td>
<td>0.287</td>
<td>0.573**</td>
<td>-0.263</td>
<td>-0.447**</td>
</tr>
<tr>
<td>Brevortia tyrannus</td>
<td>0.271</td>
<td>0.542**</td>
<td>0.393</td>
<td>0.668**</td>
</tr>
<tr>
<td>Pomatomus saltatrix</td>
<td>0.262</td>
<td>0.524**</td>
<td>0.422</td>
<td>0.716**</td>
</tr>
<tr>
<td>Alosa pseudoharengus</td>
<td>0.256</td>
<td>0.511**</td>
<td>0.327</td>
<td>0.555**</td>
</tr>
<tr>
<td>Cynoscion regalis</td>
<td>0.197</td>
<td>0.394*</td>
<td>-0.134</td>
<td>-0.228</td>
</tr>
<tr>
<td>Engraulis eurytote</td>
<td>0.147</td>
<td>0.295*</td>
<td>0.021</td>
<td>0.036</td>
</tr>
<tr>
<td>Anchoa mitchilli (age 1+)</td>
<td>0.093</td>
<td>0.185</td>
<td>0.476</td>
<td>0.809**</td>
</tr>
<tr>
<td>Gasterosteus aculeatus</td>
<td>-0.153</td>
<td>-0.306*</td>
<td>-0.047</td>
<td>-0.079</td>
</tr>
<tr>
<td>Menidia menidia (age 1+)</td>
<td>-0.302</td>
<td>-0.604**</td>
<td>0.136</td>
<td>0.232</td>
</tr>
<tr>
<td>Pollachius virens</td>
<td>-0.305</td>
<td>-0.609**</td>
<td>0.281</td>
<td>0.477**</td>
</tr>
<tr>
<td>Clupea harengus</td>
<td>-0.315</td>
<td>-0.629**</td>
<td>0.326</td>
<td>0.555**</td>
</tr>
</tbody>
</table>

Fig. 7. Mean percent relative abundance of dominant pelagic fish (age 0+ and age 1+) species by season. All other pelagic fish collected are combined in the ‘other’ category.
4. Discussion

There are two important potential limitations of this study that must be addressed in order to properly interpret the data collected. The first is the lack of any spatial component. Previous studies have used this site for observing fish populations and/or communities (Able & Hales, 1997; Able et al., 1997; Rountree & Able, 1992, 1993; Sogard & Able, 1994; Szedlmayer & Able, 1993) and all of these studies have considered this site typical of the polyhaline portion of the Great Bay-Little Egg Harbor estuary. Moreover, concurrent studies that focused on habitat-specific fish assemblages within this estuary using otter and beam trawls and seines found a similar temporal occurrence for selected pelagic fish species as in this study (Haroski, pers. comm.; Able, unpubl. data). As a result, we have every indication that the temporal occurrence of pelagic species at this study site is representative of the rest of the estuary. The second potential limitation of this study is the bias associated with the use of an artificial light. Although the effect of the artificial light on the behaviour of the fish is unknown, the light did not penetrate the perimeter of the sampling area of the net. As a result, fish attracted to the light probably came within a small area around the net and thus did not attract fishes that were not typical of the area. Additionally, during spring, early summer, and late summer of 1996, tests that evaluated the effect of the artificial light (artificial vs. ambient light) indicated that the light did enhance species richness (ANOVA, $F_{1,45} = 27.0, P < 0.001$), total abundance (ANOVA, $F_{1,45} = 47.1, P < 0.001$), and total biomass (ANOVA, $F_{1,45} = 68.5, P < 0.001$); however the assemblage structures of samples collected under artificial and ambient light conditions were similar (Mantel test, Rho, $0.712; P < 0.001$). Therefore, the use of the artificial light did not affect the seasonal assemblage structure. As a result, we feel that these data are representative of the seasonal occurrence and relative abundance of species in this estuary.

4.1. Seasonal patterns of abundance, biomass, and species richness

Previous studies of demersal and pelagic fishes within this estuary had slightly different seasonal patterns of overall abundance relative to this study while seasonal patterns in biomass and species richness were similar. In these studies, overall abundance of fish was low during the spring, high during the summer and low through the autumn into winter (Able, Witting, McBride, Rountree, & Smith, 1996; Rountree & Able, 1992; Sogard & Able, 1991; Szedlmayer & Able, 1996; Haroski, unpubl. data). Our results indicated that overall abundance and biomass of estuarine pelagic fish peaked during the spring and remained relatively high into the autumn. However, seasonal patterns of biomass in this study were similar to biomass of demersal and pelagic fish in subtidal marsh creeks (Rountree & Able, 1992). Seasonal patterns of species richness were similar to the formerly mentioned studies in this estuary, with highest values in the summer and lowest values in the winter.

Other studies of estuarine fish assemblages along the east coast of the US had patterns of abundance, biomass, and species richness that differed from this study primarily due to the latitudinal differences. In Maine, abundance, biomass, and species richness of estuarine fish were highest in the summer and relatively low during the rest of the year, especially in the winter when fish were nearly absent from collections (Ayvazian & Deegan, 1992). Farther south in Massachusetts, a similar pattern was present, however estuarine fish
depicted higher abundance, biomass, and species richness earlier in the spring and further into the autumn (Ayvazian & Deegan, 1992). This same pattern of abundance and species richness was also observed in Connecticut (Peary & Richards, 1962), Maryland (McErlean, O’Connor, Mihursky, & Gibson, 1973), and Virginia (Richards & Castagna, 1970). Because this is one of the few studies designed to exclusively sample the estuarine pelagic fish assemblage, direct comparisons of these measures between this and other estuarine studies should be treated with caution.

4.2. Species composition

The pop net proved to be an effective gear in collecting small (<100 mm) pelagic (over 99%) fish (Hagan, unpubl. data). Other studies within the same estuary, which focused on the overall estuarine fish assemblage, had a much lower representation (10 to 45%) of pelagic species (Able et al., 1996b; Rountree & Able, 1992; Sogard & Able, 1991; Szedlmayer & Able, 1996; Haroski, unpubl. data). Other estuarine fish assemblage studies elsewhere found a similar range of pelagic species (Ayvazian & Deegan, 1992; Richards & Castagna, 1970). In this study, some species (e.g. age 0+ Clupea harengus, age 0+ Pollachius virens, age 0+ and adult Anchoa hepsetus, and age 0+ Sphyraena borealis), which were not well represented in catches by the other gears in the above-mentioned studies, were consistently collected with the pop net. However, gears that blocked off the entire water column, such as weirs, included some of these pelagic species (Rountree & Able, 1992); thus, the different species compositions are likely the result of biases due to the selectivity of gear used in each study. For instance, Clupea harengus, the dominant pelagic species collected in this study, were not effectively sampled by gears used in the other studies, and therefore accounted for higher spring estimates of fish abundance in this study relative to the other studies. However, the occurrence of large numbers of age 0+ C. harengus in this study relative to earlier studies may be in part an indication of recovery of this species (Able & Fahay, 1998; Smith & Morse, 1990; Witting, Able, & Fahay, 1999) in the Middle Atlantic Bight in recent years.

In this study, the five most abundant species made up over 99% of the total catch. The large abundance of a relatively few species is typical of temperate estuaries in North America (Able & Fahay, 1998; Haedrich, 1983), although comparisons are difficult because this is one of the few studies that has focused on the pelagic component of the estuarine assemblage. Other studies found other species of pelagic fish dominating the estuarine fish catch by number including engraulids, such as Anchoa mitchilli (51% of total catch in otter trawls in New Jersey, Szedelmayer & Able, 1996). In this and other estuaries, atherinids, such as Menidia beryllina (28% in seine and otter trawls in Massachusetts, Ayvazian & Deegan, 1992) and Menidia menidia (46% in otter trawls in Virginia, Richards & Castagna, 1970; 59% in throw traps in New Jersey, Sogard & Able, 1991; 86% in subtidal weirs and seines in New Jersey, Rountree & Able, 1992; > 90% in seines in New Jersey, Haroski, unpubl. data) accounted for a large proportion of the fauna. In one instance, Ammodytes americanus dominated the catch (41% in seines and otter trawls in Maine, Ayvazian & Deegan, 1992).

Nearly all of the pelagic fish collected in this study were age 0+ of estuarine transients, i.e. they were either utilizing the estuary as a nursery area or seasonal residents (see Able & Fahay, 1998). Many of the collected species moved into estuarine nursery areas from ocean-spawning grounds. Notable among these are Clupea harengus, Pollachius virens, Pomatomus saltatrix, Brevoortia tyrannus, and Sphyraena borealis. Other age 0+ were the result of local spawning and utilized the estuary as a nursery area, including A. mitchilli, Menidia menidia, and Alosa pseudoharengus. Finally, the last group included older individuals (age 1+) that seasonally moved from coastal waters to spawn in the estuary, including Gasterosteus aculeatus, M. menidia, and A. mitchilli.

4.3. Assemblage structure

In this study, there were distinct seasonal groupings in the estuarine pelagic fish assemblage primarily owing to the timing of large-scale species-specific life history characteristics, such as reproduction, immigration, and emigration of the dominant species. In the spring, abundance and biomass were high due to the ingress of age 0+ of a few species from ocean-spawning grounds into estuarine nursery areas. During this season, C. harengus overwhelmingly dominated the catch, although it was also the peak period for P. virens. Both of these species leave the estuary with rising water temperatures or as they reach larger sizes (Able & Fahay, 1998). Also occurring in spring and early summer were age 1+ of both A. mitchilli and M. menidia, which typically move into estuaries of the Middle Atlantic Bight during these seasons to reproduce (Able & Fahay, 1998; Conover & Ross, 1982; Newberger & Houde, 1995; Voughlitos et al., 1987; Wang & Houde, 1995). Abundance of pelagic species remained relatively high in the summer due to an increase of age 0+ of other transient species, including P. saltatrix, S. borealis, and B. tyrannus, and age 0+ from local spring and/or summer reproduction, including M. menidia, A. mitchilli, A. hepsetus and A. pseudoharengus. Autumn brought a decrease in species diversity; however, abundance and biomass remained relatively high. This resulted from increased catches of age 0+ of the dominant species during autumn migration out of the
estuary, including *A. mitchilli* and *M. menidia* as previously observed in this estuary (Rountree & Able, 1992) and elsewhere in the Middle Atlantic Bight (Conover & Murawski, 1982; Vouglitois et al., 1987). During the winter, catches were relatively low and depauperate in species, and consistent with the fact that many species leave the estuary during the winter (Able & Fahay, 1998) perhaps to avoid lethal temperatures (Hales & Able, 2001; Hoff & Westman, 1966). Regardless, adult *G. aculeatus* dominated the winter catch as they were presumably moving into estuarine-spawning areas (Able & Fahay, 1998).

Seasonal patterns of some of the dominant pelagic species within this study differed from other estuaries along the east coast of the US due primarily to latitudinal differences. In Connecticut, *M. menidia* occurred only from spring through the autumn (Pearce & Richards, 1962); whereas in this study, they also occurred in the winter, albeit in greatly reduced numbers. On the other hand, in South Carolina, *M. menidia* peaked during the winter (Allen et al., 1995); whereas in this study, they peaked during the summer, similar to patterns observed in a New England estuary (Conover & Ross, 1982). Along the eastern shore of Virginia and within the Chesapeake Bay, *A. mitchilli*, although peaking in abundance and biomass in summer and autumn, occurred throughout the year (Richards & Castagna, 1970; Wang & Houde, 1995); whereas in this study, they did not occur during the winter. However, despite the great latitudinal difference, collections of *Anchoa hepsetus* in South Carolina had a similar seasonal pattern in abundance to this study (Allen et al., 1995).

Larval supply patterns can explain some of the seasonal groupings of species observed within the estuarine pelagic fish assemblage. Long-term ichthyoplankton collections within this estuary have documented a consistent seasonal cycle of species occurrence over 6 years (1989–1994) (Witting et al., 1999). Similar to this study, there were a total of five distinct seasonal groupings within the larval fish assemblage; however, species composition of each of these groupings was not exactly the same. Comparison between larval occurrence in the ichthyoplankton collections and age 0+ abundance in pop net collections indicated that the latter often occurred during (e.g. *Anchoa mitchilli*, *Menidia menidia*, and *Cynoscion regalis*) or immediately following (e.g. *Clupea harengus*) peaks in larval abundance. One notable exception was *Brevoortia tyrannus*, which had two peaks in larval collections, autumn and early spring (Witting et al., 1999), which apparently originate from local and distant spawning sites in different seasons (Warlen, Able, & Laban). On the other hand, juveniles of this species were collected by pop net only during one peak, early summer. This may result from offshore migration of larval autumn-spawned *B. tyrannus* or high mortality of this cohort. Additionally, some dominant pelagic age 0+ collected in this study (*Anchoa hepsetus* and *Pollachius virens*) were not well represented in larval samples collected within this estuary indicating that they were the result of reproduction elsewhere or were not available to the plankton net; the former is more likely.

In general, timing of seasonal patterns in estuarine fish abundance, biomass, richness, and composition previously has been attributed primarily to abiotic influences. In this study, temperature, rate of temperature change, and salinity appeared to play a role in shaping seasonal groupings, however, none of these measures were able to completely predict the seasonal groupings of species in this assemblage. Temperature is often cited as a major factor affecting seasonal occurrence of species in estuaries (Livingston, 1976; Marshall & Elliott, 1998; Witting et al., 1999) determining timing of reproduction, immigration, and emigration. However, co-varying factors, such as salinity, dissolved oxygen, nutrient input, and freshwater discharge, often contribute, and make it difficult, to determine a driving factor (Fraser, 1997; Morin, Hudon, & Whoriskey, 1992; Potter, Claridge, & Warwick, 1986; Valiela, 1995). Furthermore, location and timing of large-scale life history characteristics such as reproduction and migration are probably triggered by abiotic conditions in the habitats/locations in which these activities are occurring. As a result, understanding these large scale life history characteristics is central to effective interpretation of the composition, seasonal occurrence, and abundance of pelagic species in estuaries.

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**References**


