FISHES OF TEMPERATE ESTUARIES: ASPECTS OF LARVAL SUPPLY AND DEVELOPMENT

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Abstract

Despite a century of interest in the early life history of fishes we still need descriptive studies of many aspects including larval supply and development. To that end, we note that little has been published on the larval distribution in the surfzone and adjacent nearshore waters. In a study in these habitats in northern New Jersey we found that the larvae are surprisingly abundant. Those sampled over a five year period in the spring and summer were dominated by individuals <5 mm although some as large as 15 mm were captured. These early stages of development were represented by 51 species in 35 families. They were derived from multiple sources including from spawning in the ocean, estuaries and some that may have originated from both.

In another aspect of the early life history, we determined the pattern of scale formation from onset to the adult condition for species from a variety of families. These and other of our published studies suggest that scale formation is length related, is completed later for larger species, and that, in general, the larval – juvenile transition occurs later in development than previously recognized.

Introduction

Despite nearly a century of study of the early life history of fishes there are important and very basic patterns of development and larval supply that are lacking in order to effectively manage and conserve these populations. This lack of understanding extends to
temperate estuary fishes in the northeastern U.S. To enhance our understanding of ocean beach/surfzone and shallow nearshore larval fish assemblages we examined the summer larval fish assemblages off northern New Jersey beaches from 1995 – 1999. Particular attention was paid to temporal and spatial patterns of distribution, abundance, size, stage and species composition. A synthesis of these data, with more focus on assemblage structure relative to environmental factors, provides additional interpretation (Able et al. in review). Also, in an attempt to improve our understanding of developmental morphology, we determined the patterns of scale formation in a variety of estuarine fishes. Both of these aspects are meant to provide complementary information for a broader study of the ecology of estuarine fishes (Able and Fahay in press).

Materials and Methods

Larval fish distribution

Site Description

The study area is located on a 15 km stretch of beach on the coast of New Jersey in the Middle Atlantic Bight between the Townships of Deal and Manasquan (Fig. 3-1). The beaches in this region are typically high energy, exposed and steeply sloped. Wave heights average 0.3 to 1.2 m with a period of 5 to 9 seconds and a tidal range of approximately 1.4 m. The beach is divided at regular intervals by groin structures (Nordstrom et al. 1977). Within the study area are two inlets, one at the southernmost extent, Manasquan Inlet, and one located roughly in the center, Shark River Inlet.
**Sampling Technique**

Sampling occurred monthly from May to July, 1995 through 1999 with each sampling event occurring over a week-long period (Table 3-1). Sampling was conducted in two zones relative to the beach, surfzone (generally within 50 m of the MLW mark) and nearshore (along the 6-7 m depth contour). Surfzone sampling consisted of 22 sampling stations spaced fairly evenly throughout the area (Fig. 3-1). At each site a 0.5 m (505 mesh) plankton net with a three-point bridle was deployed 50 m from shore by a swimmer and then towed back in by a line by a team on the beach. Twenty-one daytime tows were performed in this manner to accumulate approximately 100 m$^3$ of water sampled. The contents of all the tows were pooled and fixed with 5% formalin.

Nearshore sampling consisted of five replicate 5-minute tows performed at nine sites (Fig. 3-1) along the 6.5 m depth contour with two 1.0 m (505 mesh) bongo nets. Surface and bottom tows were made at each site, with bottom tows approximately 1 - 2 m off the bottom. Samples from each of the two nets were pooled and fixed with 5% formalin. A General Oceanics flow meter was attached to each net. Larval abundance is expressed as number per 100 m$^3$.

For both nearshore and surfzone samples, contents were transferred from formalin solution and placed into 95% ethanol in the laboratory prior to removal of fishes. In instances where there was a great deal of detritus or amphipods that hindered sorting, the samples were split with a standard plankton splitter. The sorted samples were then separated by species, enumerated, and 20 individuals of each species were measured to
the nearest millimeter. Individuals < 10 mm were measured with an ocular micrometer, whereas those > 10 mm were measured with a dial caliper. For those individuals that were measured, flexion stage was also recorded (Kendall et al. 1984). Standard length was recorded for postflexion individuals and notochord length was recorded for preflexion and flexion individuals.

At the beginning of sampling at each surfzone station, a HydroLab® data logger was deployed 50 m from the beach and was removed at the end of the sampling period. Data were recorded at 10-minute intervals and then averaged for each sampling site.

**Scale Formation**

Specimens for this examination were collected with a variety of techniques (plankton nets, trawls, seines, dipnets), primarily in New Jersey estuaries and on the adjacent continental shelf. Effort was made to examine a length series from hatching to full coverage of scales as occurs in the adult condition. Care was taken during all stages of collection, preservation and examination to prevent scale loss. However, some species were more likely to lose scales than others. For those which tended to lose scales we examined them for the presence of scale pockets to help define their distribution. Sample sizes examined varied between species. See Able and Lamonaca and Able et al. (2009) for additional details.

Individuals were stained to better visualize scales. They were preserved for at least 48 hours in either 95% ethyl alcohol (ETOH), or 10% formalin which was switched to ETOH then treated with a solution containing Alizarin red S to elucidate scales, as
adapted from Taylor (1967) and Pothoff (1984). See Able and Lamonaca (2006) and Able et al. (2008) for additional details. Subsequently, these specimens were visually examined with a stereomicroscope and patterns of scale formation were illustrated on blank templates for individual species primarily adapted from illustrations in Able and Fahay (1998). The illustrations were then transferred to a digital medium via illustration in Adobe Photoshop. Area covered by scales was calculated from these illustrations using the Image J software package (Rasband, 2003) and expressed as percent of body and percent of body and fins covered relative to the adult condition of scale coverage (100%). The adult condition is based on the smallest size at which scales are no longer being formed.

The illustrations of representative stages of scale formation were standardized across all species. For example, the location of the lateral line is shown with a thin line, even before it is formed, to provide a local landmark. In addition, the margin of the dorsal and anal pterygiophores is also noted with a thin line for some flatfishes. The area behind the pectoral fins is not shaded to indicate the location of the pectoral fins in order to provide another local landmark. The darkly shaded areas indicate scale formation on the body; the gray shaded areas indicate where scales occur on the fins of some species.

**Results and Discussion**

**Larval fish distributions**

*Physico-chemical characteristics*

Many of the variables measured were similar over the study area and between years during the May - July sampling period. Salinity was consistently high with an
average of 28.2 ppt with a range of 20.9 - 33.4 ppt over 1996 - 1999 (Fig. 3-2). However, values averaged lower in 1998 (mean = 25.3 ppt). There was little spatial variation in salinity as well and Shark River Inlet had no apparent effect on salinities at stations in proximity to the inlet. Temperature was similarly consistent across temporal and spatial scales (Fig. 3-3). Temperatures during the summer averaged 18.0°C with a range of 9.4 - 24.4°C, with somewhat lower values (mean = 17.4°C, range = 9.4 - 24.4°C) in 1996. Dissolved oxygen values were consistently high in the study area across all years with an average of 9.08 mg/l and a range of 5.32 - 15.9 mg/l. However, in 1998 oxygen levels appeared much higher (mean =10.5 mg/l, range = 6.1 - 15.9 mg/l) at most stations south of Shark River Inlet during 1998 (Fig. 3-4). Turbidity varied between years with values averaging higher in 1996 (mean = 17.0 NTU, range = 0 - 340.0 NTU) and 1997 (mean =10.4 NTU, range = 0 - 39.4 NTU) than in 1998 (mean = 7.2 NTU, range = 0 - 44.2 NTU) and 1999 (mean = 4.2 NTU, range = 0 - 90.2 NTU) (Fig. 3-5).

The relatively uniform physio-chemical features of the study area during the summer months may reflect the absence of a well-defined Hudson River plume, which is typically pushed offshore by westerly winds under summertime conditions (Bowman 1978, Cowen 1996).

**Larval Abundance**

The density of larvae in the study area varied across years over the area from Long Branch to Manasquan Inlet during 1996-1999. Larvae were more abundant in nearshore versus surfzone samples in every year (Table 3-1). The larvae were most
abundant in the surfzone in 1998 and in the nearshore samples in 1996. There was no obvious correspondence between larval density in nearshore versus surfzone samples in any given year (Fig. 3-6). In addition, there was no general pattern of overall greater abundance at any one location, either for nearshore or surfzone collections. Possible exceptions were that larval density was high at some of the northernmost nearshore stations (NR3, NR2 and NR1) in 1999, 1997 and to some degree in 1996, however this was not the case in 1998 (Fig. 3-6). During two of the five years (1997 and 1999) values were among the highest at Station 10, just south of Shark River Inlet, but this was not the case in the other three years.

The summer sampling for this study was near or during the peak in larval abundance as a result of a typical mid- to late-summer peak in reproduction in the Middle Atlantic Bight (Able and Fahay 1998). The lack of consistency in larval abundance in surfzone versus nearshore samples may be due to complex circulation, both on large regional or small against the shoreline spatial scales, or species specific differences in the timing of larval occurrence and transport or retention. Some of these same characteristics may account for the lack of distinct spatial patterns in the abundance of any of the species that we examined in detail.

**Size and stage composition**

While the sampling nets in the nearshore and surfzone collections differed in size and mode of deployment, the size and stage of larval development appeared to be similar across years. The composite (Fig. 3-7) and annual (Fig. 3-8 to 3-11) size frequency
distributions were similar with most individuals < 5 mm, but individuals up to 15 mm were fairly equally represented, and some individuals > 20 mm were also collected. For these composite samples the means were nearly identical, i.e. 5.7 mm in the surfzone and 4.8 in the nearshore collections. The annual pattern of size distribution did vary somewhat with relatively more individuals in the 5 – 15 mm range in the nearshore collections in 1998 (Fig. 3-10) and a larger proportion of larger individuals, i.e. > 5 mm in both nearshore and surfzone collections in 1999 when the mean sizes were 6.9 and 8.8 mm, respectively (Fig. 3-11). The relatively small sizes across habitats and gears are supported by the fact that, for many of the species, the average size at collection (both gears combined) approximated the size at hatching (Fig. 3-12). This was evident for *Brevoortia tyrannus*, *Cynoscion regalis*, *Lophius americanus*, *Scophthalmus aquosus*, *Sphoeroides maculatus*, and *Tautogolabrus adspersus*. The possibility that many of these species spawn in relatively shallow waters is supported by prior studies (see Able and Fahay 1998 for a review; Berrien and Sibunka 1999). Spawning by *L. americanus* in these nearshore waters has not previously been reported, but seemed evident in a number of years. For other species that were represented by two size modes, the smallest mode also represented the size at hatching, including *Hippoglossina oblonga*, *Pomatomus saltatrix*, *Pseudopleuronectes americanus* and *Tautoga onitis*. Most of these species are reported to reproduce in coastal waters (Grosslein and Azarovitz 1982). The exception is *P. americanus*, which is presumed to spawn in adjacent estuaries (Able and Fahay 1998), but some of the larvae are presumably transported out of the estuary (Able and Fahay 1998, Chant et al. 2000). In other instances, the smallest individuals collected were larger than the size at hatching, e.g., *Etropus microstomus*, *Prionotus carolinus*, and *P.*
*evolans.* This may be due to spawning over the continental shelf, as occurs for the *Prionotus* species (McBride and Able 1994). The overall small size of the larvae collected is reflected in the dominance of preflexion stage individuals in most years and in both gears/habitats (Fig. 3-13). A possible exception is in 1997 and more clearly in 1999 when relatively larger numbers of postflexion larvae were collected.

**Species composition**

Species richness, based on combined nearshore and surfzone collections, was relatively high with 51 species represented over the five years from 1995-1999 (Table 3-2). Species richness varied between years with 28 taxa represented in 1996 and 38 in 1997 and 1999. We have excluded 1995 because there was no nearshore sampling performed that year. The number of species also varied between habitats with a larger number of species in nearshore (46) than in surfzone (38) collections.

The composite nearshore and surfzone larval collection was dominated by a diverse assemblage of fishes from 33 families (Table 3-2). Of these the sciaenids, gadids, engraulids, scombrids and bothids were the most speciose. The sciaenids had four species (*Bairdiella chrysoura, C. regalis, Menticirrhus saxatilis* and *Micropogonias undulatus*), the gadids had four species (*Enchelyopus cimbrius, Pollachius virens, Urophycis chuss* and *U. regia*), the engraulids had three species (*Anchoa hepsetus, A. mitchilli* and *Engraulis eurystole*), the scombrids had three species (*Auxis sp., Scomber scombrus* and *Scomberomorus maculatus*) and the bothids had three species (*Bothus ocellatus, E. microstomus* and *H. oblonga*). Several species were among the most
abundant in both nearshore and surfzone collections. These included *Anchoa* sp. (most likely *A. mitchilli* given the dominance of this form over other engraulids among those identified to species), *B. tyrannus, S. scombrus, S. aquosus*, and *L. americanus*.

Some relatively abundant (>10 in total catch) species were restricted in the habitats in which they occurred (Table 3-2). Those only collected in the nearshore included *A. hepsetus, Opisthonema oglinum, E. eurystole, U. regia*, and *Gasterosteus aculeatus*. Species that appeared disproportionately abundant in the nearshore were *Anchoa* sp., *T. onitis* and *P. saltatrix*. There were no abundant species that were only found in the surfzone, however several were relatively more abundant there including *Menidia menidia, S. aquosus*, Atherinidae and *Peprilus triacanthus*. Many of these species are typical larvae from the central part of the Middle Atlantic Bight based on an 11-year data set from NMFS-MARMAP surveys (Able and Fahay 1998, Table 4.1). Also, many species from the study area overlap with the inshore larval assemblage reported from slightly deeper water in the Middle Atlantic Bight (Cowen et al. 1993).

The catches of selected species varied by year (Table 3-3). In the nearshore collections the abundance of *Anchoa* sp. was much greater in 1996 and 1997, perhaps because the smallest individuals are difficult to identify to species and small individuals were very abundant in those years. This pattern was similar for the surfzone except that 1998 collections were abundant as well. The pattern of relative abundance observed for this taxon in the nearshore collections was consistent with that for *A. mitchilli*, suggesting again that unidentified specimens may be this species. *Scomber scombrus* was very
abundant in 1996 and 1998 in both nearshore and surfzone collections, but virtually absent in 1997 and at a low level in 1999. *Tautogolabrus adspersus* was especially abundant in 1998, while another labrid, *T. onitis*, was abundant in 1997 and 1999. *Cynoscion regalis* was consistently present, but was most abundant in 1997. *Pomatomus saltatrix* was abundant in nearshore collections in every year except 1998, but seldom occurred in surfzone collections. *Lophius americanus* was most abundant in 1996 and 1997.

The sources of the larvae in the coastal ocean, i.e. nearshore and surfzone combined, seemed to vary between years (Table 3-4). In 1995, a high percent composition of species of estuarine origin, i.e. presumably spawned there (see Table 3-2), was evident, implying that surfzone collections are dominated by species of estuarine origin. This may simply reflect the absence of nearshore collections during that year. In most other years the contribution of estuarine species was relatively low. In 1997, the percent composition of estuarine/oceanic species was high in both nearshore and surfzone collections.

**Spatial Distribution by Species**

For the large majority of species examined, there were no consistent spatial patterns in larval abundance across years over the 15 km of the study area between Long Branch and Manasquan Inlet (Fig. 3-14 to 3-35). For example, while *H. oblonga* were most abundant at four stations (PR2, 3, 6, 7) north of Shark River Inlet in 1996, they were never abundant there again and in 1998 they were most abundant at three stations (SR12,
13, 14) south of Shark River Inlet (Fig. 3-14). Many species such as *S. aquosus* were distributed widely across the entire sampling area (Fig. 3-15). Some species of presumed estuarine origin were most abundant in surfzone collections including atherinid sp. (Fig. 3-16) and *Syngnathus fuscus* (Fig. 3-17). For some species such as *C. regalis* (Fig. 3-18) there were distinct periods in a single year, such as the consistent occurrence of larvae north of Shark River Inlet in 1997, but this pattern was not repeated in other years.

The spatial distribution relative to the source of the larvae did not show any clear patterns (Fig. 3-36 to 3-38). One exception is that most of the estuarine species (Table 3-2) were found almost exclusively in the surfzone samples, indicating that they preferred or were constrained by circulation patterns within the shallow waters in the study area. In addition, there appeared to be a tendency for more estuarine larvae downstream of Shark River Inlet, perhaps because that was a major source for this group (Fig. 3-36).

These results also present, for the first time, an extensive examination of surfzone ichthyoplankton on the northeast coast of the U.S. This unique contribution is largely due to the difficulty of sampling in high energy surf zones. Additionally, this study included sampling in slightly deeper, nearshore waters that had not been conducted previously in New York Bight waters. As a result, we now have an improved appreciation of the extent to which these shallow coastal waters are used for reproduction and as larval habitat. This is especially striking for some species of economic (e.g., *L. americanus, C. regalis, S. scombrus, T. onitis, P. saltatrix, B. tyrannus*) and ecological (*A. mitchilli, E. microstomus, Prionotus* spp.) importance.
Our studies are complemented by examination of ichthyoplankton from adjacent estuaries (Croker 1965, Witting et al. 1999, see Able and Fahay 1998 for a listing of unpublished studies) and the deeper waters of the continental shelf (Cowen et al. 1993, Cowen 1996, Berrien and Sibunka 1999). These, in combination with the analysis of juvenile fish assemblages on the same beaches as the ichthyoplankton collections (Wilber et al. in review), provide for an enhanced understanding of fishes in the summer surf zone. As a result of the above, we have new insights into the early life history of fishes in these shallow waters.

**Scale Formation**

As a result of this study on a variety of estuarine species (Fig. 39 – 44 and Able and Fahay in press), including recently published results from an examination we now have detailed information on scale formation for representative species from numerous species from several families. These include data from onset of scale formation to the size at which they reach the adult condition. Prior emphasis was on families such as from the cyprinodontids and fundulids (Able et al. 2009) and flatfishes from several families including scopthalmids, paralichthyids, pleuronectids, and achiroids (Able and Lamonaca 2009). Additional families represented include sciaenids, engraulids, atherinids, belonids, tetrodontids, moronids, serranids, pomatomids, and labrids. All of these suggest that scale formation is a length related feature, i.e. not age related (Able and Lamonaca 2006) and, further, the pattern appears similar regardless of whether the fish were raised in the laboratory or captured in the field (Able et al. 2009). Also, it appears
that completion of scale formation occurs later in development for larger species. Most importantly, the relative large size at completion of scale formation implies that development during the larval – juvenile transition continues much beyond the size at notochord flexion or fin ray formation. Additional details of scale formation of these and other species are available in Able and Fahay (in press).

Acknowledgments

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Table 1. Overall abundance and average density of larvae from nearshore and surfzone ichthyoplankton collected from ocean beaches in northern New Jersey from 1995 through 1999. See Fig. 6.1 for sampling locations.

<table>
<thead>
<tr>
<th>Species</th>
<th>Origin</th>
<th>Nearshore</th>
<th>Surfzone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abundance</td>
<td>Density (SE)</td>
<td>Abundance</td>
</tr>
<tr>
<td><strong>Anchoa sp.</strong></td>
<td>Estuarine/Oceanic</td>
<td>71304</td>
<td>29.54(5.53)</td>
</tr>
<tr>
<td><strong>Brevoortia tyrannus</strong></td>
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<td>28393</td>
<td>12.20(2.31)</td>
</tr>
<tr>
<td><strong>Scomber scombrus</strong></td>
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<td>8726</td>
<td>3.84(0.92)</td>
</tr>
<tr>
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<td>Estuarine/Oceanic</td>
<td>5942</td>
<td>3.91(1.12)</td>
</tr>
<tr>
<td><strong>Scophthalmus aquosus</strong></td>
<td>Estuarine/Oceanic</td>
<td>5507</td>
<td>2.55(0.52)</td>
</tr>
<tr>
<td><strong>Tautogolabrus adspersus</strong></td>
<td>Oceanic</td>
<td>4560</td>
<td>2.08(0.42)</td>
</tr>
<tr>
<td><strong>Cynoscion regalis</strong></td>
<td>Estuarine/Oceanic</td>
<td>3623</td>
<td>1.88(0.29)</td>
</tr>
<tr>
<td><strong>Unidentified fish</strong></td>
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<td>1.28(0.38)</td>
</tr>
<tr>
<td><strong>Pomatomus saltatrix</strong></td>
<td>Oceanic</td>
<td>2431</td>
<td>1.34(0.32)</td>
</tr>
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<td><strong>Lophius americanus</strong></td>
<td>Oceanic</td>
<td>1828</td>
<td>0.66(0.11)</td>
</tr>
<tr>
<td>Species</td>
<td>Origin</td>
<td>Nearshore</td>
<td></td>
</tr>
<tr>
<td>--------------------------</td>
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</tr>
<tr>
<td></td>
<td>Abundance</td>
<td>Density (SE)</td>
<td>Abundance</td>
</tr>
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<td>1003</td>
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<td>701</td>
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<td>688</td>
<td>0.33(0.06)</td>
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<td>600</td>
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<td>0.19(0.05)</td>
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<td>386</td>
<td>0.19(0.04)</td>
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<td>379</td>
<td>0.16(0.02)</td>
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<td>0.13(0.02)</td>
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<td>316</td>
<td>0.17(0.04)</td>
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<td>0.10(0.03)</td>
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<td>109</td>
<td>0.15(0.11)</td>
</tr>
<tr>
<td>Species</td>
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<td>Surfzone</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Abundance</td>
<td>Density (SE)</td>
</tr>
<tr>
<td>Anchoa hepsetus</td>
<td>Oceanic</td>
<td>90</td>
<td>0.05(0.02)</td>
</tr>
<tr>
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<td>Surfzone</td>
</tr>
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<tr>
<td></td>
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<td>Abundance</td>
<td>Density (SE)</td>
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<td><em>Ophidion sp.</em></td>
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</tr>
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<td><em>Micropogonias undulatus</em></td>
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<td><em>Pollachius virens</em></td>
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<td><em>Stichaeidae sp.</em></td>
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<td>Species</td>
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<td>Surfzone</td>
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<td>Abundance</td>
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<td><em>Bothus ocellatus</em></td>
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<td><em>Auxis sp.</em></td>
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<td><em>Gobiosoma sp.</em></td>
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<tr>
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</tr>
<tr>
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<td>Density (SE)</td>
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<td><strong>Grand Totals</strong></td>
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Nearshore
n = 4997
Mean = 4.0
range - 1.0 to 102.1

Surfzone
n = 512
Mean = 5.3
range - 1.1 to 86.1

Figure 9 Composite lengths for (surfzone and nearshore) ichthyoplankton samples from northern New Jersey beaches for 1997.
**Nearshore**
n = 2111
mean = 5.5
range - 1.2 to 106.5

**Surfzone**
n = 1061
mean = 4.68
range - 1.3 to 76.2

*Figure 10* Composite lengths for (surfzone and nearshore) ichthyoplankton samples from northern New Jersey beaches for 1998.
Nearshore
n = 2737
mean = 6.92
range - 1.2 to 62.5

Surfzone
n = 668
mean = 8.81
range - 1.2 to 64.5

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