Use of ocean and estuarine habitats by young-of-year bluefish (*Pomatomus saltatrix*) in the New York Bight*

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Abstract—Young-of-year (YOY) bluefish (*Pomatomus saltatrix*) along the U.S. east coast are often assumed to use estuaries almost exclusively during the summer. Here we present data from 1995 to 1998 indicating that YOY (30–260 mm FL) also use ocean habitats along the coast of New Jersey. An analysis of historical and recent data on northern and southern ocean beaches (0.1–2 m) and the inner continental shelf (5–27 m) during extensive sampling in New Jersey waters from 1995 to 1998 indicated that multiple cohorts occurred (June–August) in every year. When comparable collections of YOY were made in the ocean and in an adjacent estuary, the abundance was 1–2 orders of magnitude greater on ocean beaches during the summer. The YOY were even more abundant in ocean habitats in the fall (September–October), presumably as a result of YOY leaving estuaries to join the coastal migration south. During 1999 and 2000, YOY bluefish were tagged with internal sequential coded wire microtags in order to refine our understanding of habitat use and movement. Few (0.04%) of the fish tagged on ocean beaches were recaptured; however, 2.2% of the fish tagged in the estuary were recaptured from 2 to 27 days after tagging. Recaptured fish grew quickly (average 1.37 mm FL/d). On ocean beaches YOY fed on a variety of invertebrates and fishes but their diet changed with size. By approximately 80–100 mm FL, they were piscivorous and fed primarily on engraulids, a pattern similar to that reported in estuaries. Based on distribution, abundance, and feeding, both spring- and summer-spawned cohorts of YOY bluefish commonly use ocean habitats. Therefore, attempts to determine factors affecting recruitment success based solely on estuarine sampling may be inadequate and further examination, especially of the contribution of the summer-spawned cohort in ocean habitats, appears warranted.

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Bluefish (*Pomatomus saltatrix*) are an important component of recreational, and to a lesser degree, commercial fisheries along the east coast of the U.S. Catches of this species peaked in the late 1970s and early 1980s and have declined consistently since then (Klein-MacPhee, 2002). As a result, the Atlantic States Marine Fisheries Commission has established priority research needs for this species, including studies of recruitment (Kline[1]).

The available literature indicates that there are multiple cohorts of young-of-year (YOY) bluefish, which result from spring spawning in the South Atlantic Bight (south of Cape Hatteras) and summer spawning in the Middle Atlantic Bight (between Cape Hatteras and Cape Cod), but their relative contribution is variable and still under discussion (see review by Juanes et al., 1996; McBride et al., 1993; Smith et al., 1994; Hare and Cowen, 1996; Able and Fahay, 1998; Munch and Conover, 2000). The YOY are assumed to be estuarine-dependent (McHugh, 1966) and a worldwide review also indicates that estuaries are important for this widely distributed species (Juanes et al., 1996) although little is known of their movements within estuaries and between estuaries and the adjacent ocean (Lund and Maltezas, 1970; Morton et al., 1993). Along the east coast of the U.S., numerous studies have demonstrated that YOY of spring- and summer-spawned cohorts use estuaries as habitat, including those from Rhode Island (McBride et al., 1995), Long Island (Nyman and Conover, 1988; McBride and Conover, 1991), New Jersey (McBride and Conover, 1991; Rountree and Able, 1992a, 1992b, 1993; Able and Fahay, 1998), and North Carolina and South Carolina (McBride et al., 1993), and that size at estuarine ingress is at approximately 40–100 mm FL. However, one of the most comprehensive treatments of

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[1] Kline, L. L. 1997. Atlantic State Marine Fisheries Commission prioritized research needs in support of interjurisdictional fisheries management, 189 p. Atlantic States Marine Fisheries Commission, Washington, D.C.

bluefish suggests that those spawned during the summer might remain at sea and never enter estuaries (Kendall and Walford, 1979). Thus, it is useful to assess whether YOY bluefish use ocean habitats. To this end, the purpose of this paper is to summarize data from extensive collections and multiple sources for YOY bluefish along the coast of New Jersey in order to help determine the relative contributions of oceanic habitats by comparing them with an adjacent estuary. Further, we conducted tag and recapture studies to begin to further assess habitat use and movements.

Materials and methods

Study sites

The study area encompassed four distinct regions along the New Jersey coast (Fig. 1). First, the inner continental shelf (5–27 m), from the northern coast of New Jersey to the mouth of Delaware Bay (Fig. 1). Much of this area slopes gently offshore; however, the surface has a complex topography, as evidenced by convoluted isobaths (Uchupi, 1970). At the margins of the study area are two major shelf valleys, Hudson and Delaware. In between are numerous linear sand ridges (McBride and Moslow, 1991). Bottom salinities and temperatures in this region during the study period ranged from 27.1‰ to 33.4‰ and from 7.7° to 25.4°C, respectively. The second region was located in northern New Jersey along a 25-km stretch of ocean beach between Deal and Manasquan Inlet (Fig. 1). These beaches are divided at frequent intervals by groins. The third region consisted of sampling sites located in southern New Jersey on relatively undeveloped (few groins) beaches in the vicinity of Little Egg Inlet and more developed (abundant groins) beaches on the central portion of Long Beach Island (Fig. 1). The sandy beaches in both of these areas are steeply sloping and exposed to high wave energy (wave heights of 0.3–1.2 m and durations of 5–9 seconds and tidal range is approximately 1.4 m, Nordstrom et al., 1977). Salinities on these beaches during the study period were 26–32‰, and temperatures ranged from 13° to 27°C. A fourth region comprised estuarine beach sites in Great Bay and Little Egg Harbor (Fig. 1). These sites had sandy bottoms, a shallow profile with sandy fringing beaches, and a 1.1-m tidal range typical of these bays (Able et al., 1999). Salinities were 22–32‰ and temperatures were 10.5–30°C during the sampling period.

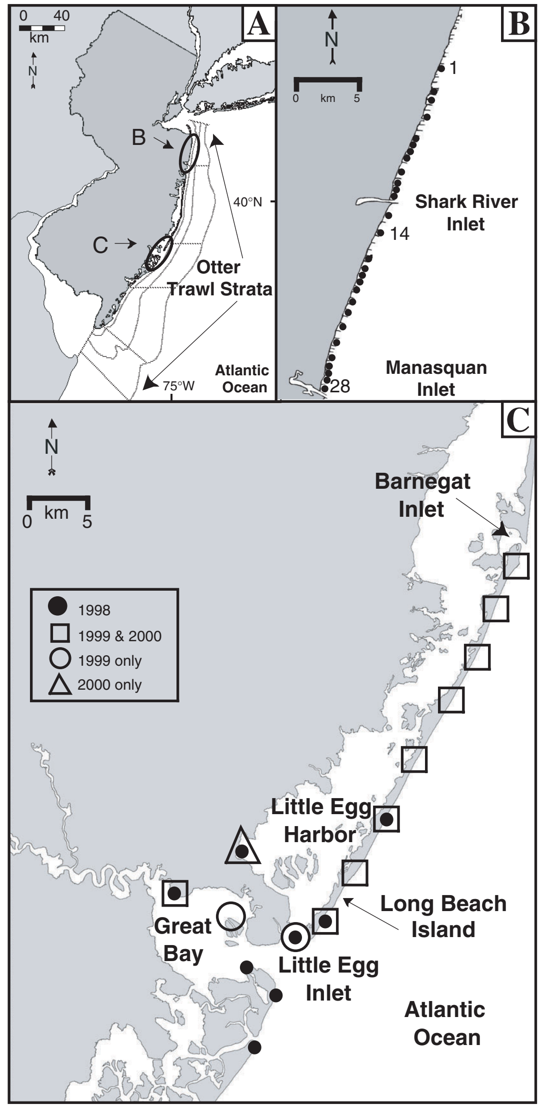

Figure 1

Study area along the Atlantic Ocean coast of New Jersey (**A**). Strata (5–10, 11–20, 21–27 m) for inner continental shelf collections, and location of ocean and estuarine beach sampling sites are indicated, including northern New Jersey ocean beaches (sites numbered 1–28 from north to south) (**B**) and southern New Jersey ocean and estuarine beaches (**C**) for 1998–2000. Additional information concerning these sites can be found in Table 1.

Sampling techniques

Young-of-year bluefish were sampled as part of several programs off the coast of New Jersey during 1995–98 (Fig. 1, Table 1). In all surveys, YOY were defined by characteristic lengths (<200 mm FL) from earlier studies in the region (see Able and Fahay, 1998). Individuals from inner continental shelf waters were collected by the New Jersey Department of Environmental Protection with 20-min duration otter trawl (30-m head rope, 6-mm codend) tows during daylight in stratified random sampling over an area of 4600 km^2 from the entrance to New York Harbor to the entrance of Delaware Bay in depths from 5 to 27 m (Byrne[2]). This sampling occurred seasonally and bluefish were available during the June, August, and October cruises.

[2] Byrne, D. 1994. Stock assessment of New Jersey's nearshore recreational fisheries resources. *In* Proceedings of the workshop on the collection and use of trawl survey data for fisheries management (T. Berger, ed.), p. 36–42. Atlantic States Marine Fisheries Commission, 1444 Eye St. NW, 6th Floor, Washington D.C. 20005.

Table 1

Summary of available data used to evaluate habitat use for young-of-year bluefish. NJDEP = New Jersey Department of Environmental Protection, Division of Fish and Wildlife; ACE = Army Corps of Engineers; RUMFS = Rutgers University Marine Field Station.

Sampling location	Habitat	Depths sampled (m)	Sampling duration	Sampling frequency	Gear	Number of samples	Source
Off New Jersey	inner continental shelf	5–27	1995–98	five times per year	otter trawl	480	NJDEP
Northern New Jersey	ocean beaches	0–2	1995–98	bimonthly (June–October)	seine	1926	ACE
Southern New Jersey	ocean and estuarine beaches	0–2	1998	weekly (May–Nov)	seine	387	RUMFS

On ocean beaches along northern New Jersey, sampling was conducted biweekly by the U.S. Army Corps of Engineers at 28 stations with a 15.2 × 1.8 m beach seine with a 1.8-m^2 bag (6-mm mesh) during one-week periods from August through October 1995–98 (Fig. 1, Table 1). At each location three seine hauls were completed during daylight, two near the groins bordering each site and one between the groins. Comparisons between ocean and estuarine beaches (Fig. 1) were conducted during 1998 with seasonal sampling in the Great Bay–Little Egg Harbor estuary and adjacent ocean by the Rutgers University Marine Field Station. All of these samples were collected with a 30 × 1.8 m bag seine with 6-mm mesh in the wings and 2-mm mesh in the bag.

For all of these sampling programs bluefish were enumerated and measured to either total length, standard length, or fork length, but for purposes of consistency, all lengths were converted to fork length (FL) for ease of comparison with earlier studies by using the regressions in Able and Fahay (1998).

Tag and recapture

The spatial and temporal components of this study were part of a larger sampling program to compare habitat use of YOY fishes on ocean and estuarine beaches. During this program, YOY bluefish were sampled during daylight hours with beach seines (30 m × 1.8 m, 2-mm mesh bag, 6-mm mesh wings) from 18 May to 28 October 1999 and from 22 May to 9 October 2000. The beach seines were deployed in depths <1.5 m, 10–40 m from shore depending on beach slope, tidal stage, wave and current conditions, and spread parallel to the beach, and then pulled back to shore. Seining on ocean beaches—Tuckers Island and Seven Islands (Fig. 1)—typically occurred between the two hours before and after low tide, whereas seining at Graveling Point occurred at various times in the tidal cycle, but mostly during the 4-hour window around high tide. At ocean sites, sampling at all but two sites (Barnegat Light and Holgate) occurred up to about 50 m from each side of groins that were present at most sites. At Graveling Point, hauls were made down the length of the beach. Regular, biweekly sampling across all 11 sites consisted of three standardized tows at each site. Additional sampling at these same sites used the same techniques but consisted of 1–20 seine hauls per site to collect YOY bluefish for tagging and recapture. Data from the regular sampling are presented as catch per unit of effort (CPUE) and data from both sampling programs were used for construction of length-frequency distributions that are available elsewhere (Rowe et al.[3]).

Young-of-year fish were tagged as they became available. Individuals caught in the seines were transported in buckets of water to shallow, 112-cm diameter circular tanks filled to a depth of 10–15 cm with aerated seawater and held at ambient conditions, typically below 25°C with bottles of ice used to maintain water temperature. Then they were anesthetized in a 65 mg/L solution of MS-222 (3-aminobenzoic acid ethyl ester methanesulfonate salt, Sigma Inc., St. Louis, MO), measured to the nearest millimeter and a sequential coded wire tag (1×0.25 mm) was injected dorsolaterally behind the head and anterior to the dorsal fin by using a hand-held multishot injector (Northwest Marine Technology, Shaw Island, WA). Each fish was checked for the presence of the tag with a hand-held "wand" tag detector before being released. Tagged fish were allowed to recover for 1–4 hours in holding tanks and were then released within the area of capture.

This approach yielded a high rate of tag retention and low mortality. In 1998, we tagged 25 fish (115–170 mm FL) and had 10 fish (130–188 mm FL) as controls, which were all held in 930 liter containers with ambient flow-through water from Great Bay. One mortality occurred in a tagged fish on the first day after tagging and the remainder (96%) survived for 30 days. Tag retention during this period was 100%. In 1999, we tagged 16 fish (16–92 mm FL) and had 6 control (77–101 mm) fish. There was no mortality after 45 days, in either group, and tag retention was 100%. At this time a power failure in the seawater system caused some mortality. The surviving 8 fish had 100% tag retention to 65 days when the experiment was terminated.

[3] Rowe, P. M., K. W. Able and M. J. Miller. In review. Distribution, abundance and size of young-of-the-year bluefish (*Pomatomus saltatrix*) in ocean and estuarine habitats in southern New Jersey during 1999–2000.

All YOY fish caught after tagging began were checked for tags with the hand-held "wand" detector during all sampling events. Recaptured fish were measured to the nearest mm FL and then preserved in 95% ETOH in the field. Tags were dissected out of each recaptured fish in the laboratory and read with a dissecting scope to identify each individual. The growth of each recapture was then calculated by dividing the difference in length at recapture and at tagging by the number of days between tagging and recapture.

Food habits

Young-of-year bluefish collected by seine in 1998 from northern (n=581 stomachs with prey) and southern (n=667) New Jersey ocean beaches and from the Great Bay–Little Egg Harbor estuaries (n=72) were analyzed for food habits. Emphasis was placed on food habits on ocean beaches because little is known about this aspect of their life history. Samples were immediately preserved in 10% formalin and, in the laboratory, were measured and divided into 10-mm FL size classes, and the analysis was performed on up to 12 individuals in each size class from 30–39 mm FL to ≥150 mm FL. The gastro-intestinal tract was dissected from each fish and all contents removed from the esophagus to the pylorus. Prey items were identified to the lowest possible taxon and their relative contribution based on percent frequency of occurrence.

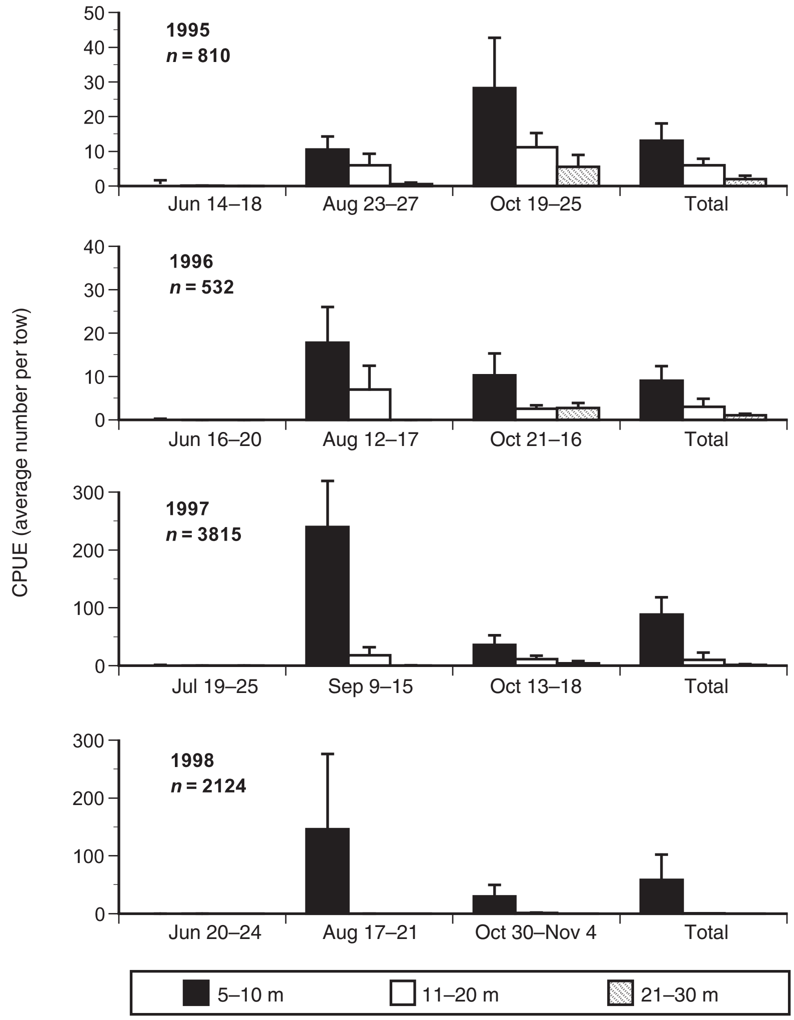

Figure 2

Abundance (CPUE) by depth of young-of-year bluefish on the inner continental shelf off New Jersey during 1995–98. None were collected during other periods of the year. Note differences in y-axes. See Figure 1 for sampling strata.

Results

Seasonal occurrence and abundance

Young-of-year bluefish were consistently collected in the ocean during summer and early fall from inner continental shelf waters to beaches along the New Jersey coast. On the inner shelf, in depths between 5 and 27 m, YOY were collected from June through October; greatest abundance occurred in August, September, and October during 1995–98 (Fig. 2). Abundance varied between years and average CPUE was an order of magnitude lower in 1995–96 than in 1997 and 1998. During the periods of peak abundance, catches averaged greater than 100–200 individuals/tow. The seasonal pattern of abundance varied between years and the peaks occurred in October in 1995 and in August–September in 1996–98. In every year the greatest abundance typically occurred in the shallowest nearshore stations (5–10 m), and the lowest value were at the deepest stations (21–27 m).

The YOY were consistently present on ocean beaches in northern New Jersey during the summer and fall sampling period in 1995–98 (Fig. 3). Interestingly, the pattern of annual abundance was consistent with the otter trawl sampling, i.e. peak CPUE was lower in 1995–96 and an order of magnitude higher in 1997–98. Seasonal abundance on these beaches varied between these high and low abundance periods and peaks in from late July through early August in 1995–96 and in late August–September in 1997–98. In all four years abundance was very low by mid-October. On smaller spatial scales on ocean beaches the pattern of occurrence was quite variable, regardless of year (Fig. 4); thus there were no sampling locations where catches were consistently high and instead peaks in abundance continually shifted.

The seasonal pattern of abundance on ocean beaches in southern New Jersey in 1998 differed from those elsewhere

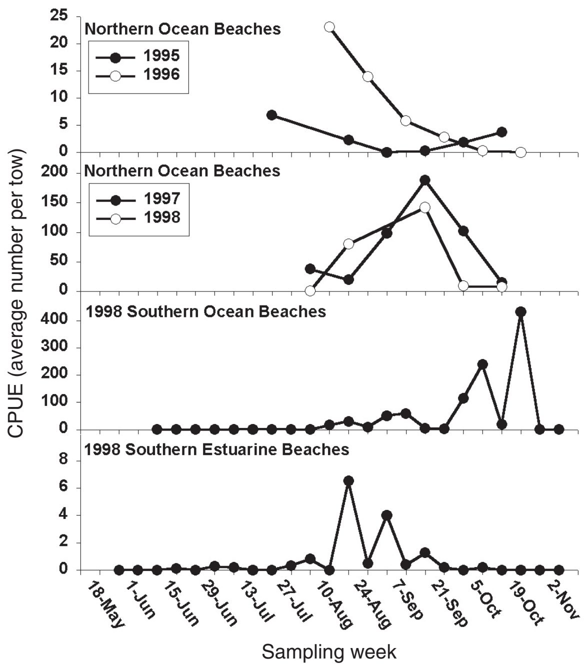

Figure 3

Abundance (CPUE) of young-of-year bluefish on northern New Jersey ocean beaches during 1995–98 and southern New Jersey ocean beaches and estuarine beaches during 1998. See Figure 1 for sampling locations.

(Fig. 3). Peaks occurred much later in October in relation to northern beaches in all years and, compared to the estuary, relative abundance was much higher than in the adjacent estuary during the entire sampling period, with peak abundance reaching approximately 400 individuals/tow (in the estuary only 6 individuals/tow were collected). Both ocean and estuarine beaches had very small numbers in late June and July, and abundance peaks in August and early September. Although estuarine catches declined by late September, with zero catches continuing through the end of the sampling period, catches on ocean beaches were highest in late September and early October and did not decline until October or early November.

Size composition

Young-of-year bluefish were represented by different size classes or cohorts and these varied between years and locations (Figs. 5–7). The size at first occurrence in the ocean was as small as approximately 20 mm FL in some years and around 50 mm FL in other years. Largest YOY were collected in otter trawl collections on the inner continental shelf where individuals >19 cm were common (Fig. 5). In 1995 several size classes were evident in August and three in October; the largest, in the latter, was approximately 17–26 cm FL, the smallest was 6–9 cm FL, and an intermediate group was 10–16 cm FL (Fig. 5). In 1996, only one size class was represented in August and only two in October. The larger mode in October approximated the size of the larger mode in October 1995, and the smaller mode resembled that of the intermediate mode during the same month. In September 1997 there was a single size mode, and perhaps two in October, and the latter were similar in size to the largest and intermediate modes in 1995. In 1998 the YOY were represented by a small size mode similar to that in August 1995 and the dominant size class in October was similar to the intermediate group in October 1995; thus the larger mode, that was present in other years was not present in 1998. Over the same time period, there appeared to be some relationship between distance offshore, depth, and size (Fig. 5). When fish occurred in the deepest strata sampled they were often the largest individuals and this was especially evident in 1995 and 1996.

Young-of-year on northern New Jersey beaches had similar mean sizes but fewer large and small fish than in inner continental shelf collections (Fig. 6). Often two modes were represented but these did not occur consistently in all collections. In early fall one mode often consisted of very small fish (<4–7 cm FL). This was obvious in early October 1995, September and October 1996, October 1997 and 28 September–1 October 1998. Large fish (>17 cm FL) were also represented in the fall, especially in October 1995 and 1998.

The average size of YOY on ocean beaches in southern New Jersey in 1998 was similar to those collected on the inner continental shelf, on northern New Jersey beaches, and in the estuary (Fig. 7). In most instances a single mode was evident, with the exception of October when few larger fish were present.

Residency and movements

The results from the tag and recapture experiments differed markedly between the estuary and the ocean and in no instance were fish from the estuary or the ocean captured in the other area (Fig. 8). Of the fish tagged in the ocean during 1999 (n=4987, 50–202 mm FL) only two (0.04%) were recaptured, whereas in 2000 (n=649, 55–241 mm FL) none were recaptured. The number of tag returns was much higher in the estuary during 1999 (n=856, 59–250 mm FL) with 29 (3.4%) recaptured; whereas in 2000 (n=661, 55–244 mm FL) only five (0.8%) were recaptured. In the ocean, the two fish recaptured were both at liberty for 15 days. In fact, they were tagged on the same day at the same location and recaptured together on the same day and at the same location, suggesting that they were traveling together. Over that period they traveled a minimum of 17 km from the tagging location at Surf City south to the recapture location at Holgate (Fig. 1). In the estuary the number of days at liberty ranged from 2 to 18 days in 1999 and 5–27 days in 2000 (Fig. 8). All of the fish tagged in the estuary at Graveling Point in both years were captured at the same location, indicating a much higher period of residency than could be demonstrated in the ocean.

Growth

Maximum growth rates for bluefish are among the highest recorded for the YOY of any fish species. Values for tagged and

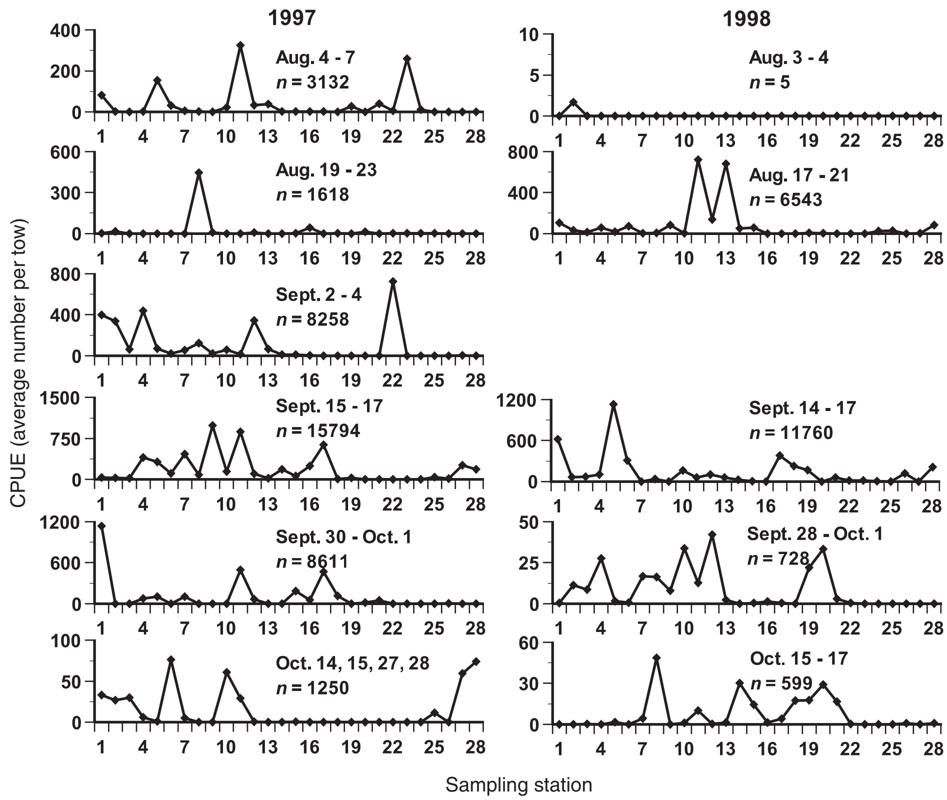

Figure 4

Spatial variation in abundance (CPUE) of young-of-year bluefish by sampling period on northern New Jersey beaches by collection date during 1997 and 1998. See Figure 1 for sampling locations.

recaptured individuals ranged from 0.1 to 2.2 mm FL/day with a mean value of 1.4 mm FL/day across all habitats (Fig. 9). The differences between years in the estuary and between the estuary and the ocean were not significantly different. Growth rates, in length, did decline slightly over the summer with the highest individual growth occurring in July and August and lower values in late August or September through October regardless of how the growth is expressed (Fig. 9).

Food habits

Fish dominated the stomach contents of YOY bluefish from ocean beaches in northern and southern New Jersey and in the estuary, occurring in more than 60% of the stomachs in both areas (Table 2). Prey fish species in the ocean included bay anchovy (*Anchoa mitchilli,* 27.6% and 24.7% frequency of occurrence on northern and southern beaches, respectively), silversides (*Menidia* spp., <2%), northern kingfish (*Menticirrhus saxatilis*, <0.5%), and northern pipefish (*Syngnathus fuscus*, <0.2%), with about 40% of the fish in both areas unidentified. Evidence of cannibalism was rare, with only 2.3% (northern) and 0.3% (southern) incidence. Other important prey categories (>10% frequency of occurrence) included gammarid amphipods and a variety of decapod crustaceans. The occurrence of empty stomachs was infrequent. In the estuary, stomach contents were somewhat different: the dominant prey fish species consisted of *Menidia* spp. (22.0% frequency of occurrence), smaller numbers of *Fundulus majalis* less frequently (5.1%), and a large proportion of unidentified fish (55.9%). *Anchoa* spp. were notable by their absence in relation to diets in the ocean. Other important categories included decapod crustaceans, which were mostly unidentified shrimp. Empty stomachs represented 18% of the total examined, as a result of this and the relatively small number examined, the effective sample size was much smaller than those from ocean beaches.

The relative contribution of fish and invertebrates in the diet changed with size and to some degree location (Fig. 10). Fish from the ocean beaches were consumed by virtually all size classes of YOY bluefish, including some of the smallest individuals in our collections (<40 mm FL), but fish occurrence in the diet became more frequent beginning at sizes of approximately 80–100 mm FL, depending on area. In northern New Jersey beaches, invertebrates dominated the diet at sizes of 30–>70 mm FL, whereas fish occurred in >70% of stomachs at sizes >80 mm FL, which increased to >80% in sizes >90 mm FL. In southern New Jersey beaches, where smaller bluefish (<50 mm FL) were not captured, invertebrates dominated the diets of bluefish up to 80–90 mm,

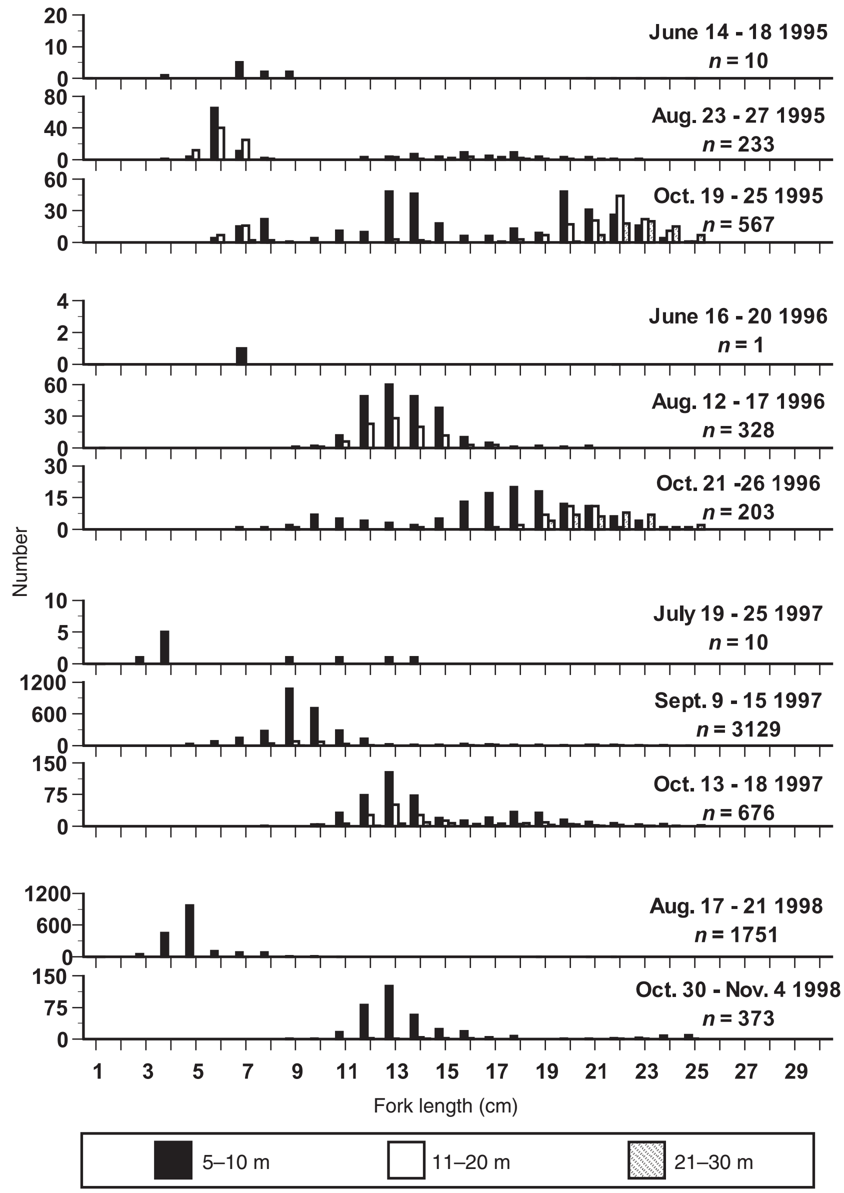

Figure 5

Size composition of young-of-year bluefish from inner continental shelf collections by collection date during 1995–98.

and fish occurred in over 70% of the diet at larger sizes. In the estuary, fish were consumed at smaller sizes, 50–60 mm FL, where they made up 100% of the diet. At larger sizes they continued to be of considerable importance.

Discussion

Habitat use in the ocean

Our results indicated that YOY bluefish use the inner continental shelf and ocean beaches in the New York Bight during summer and fall. They occurred consistently and abundantly in these habitats during July through mid-September during 1995–98, at a period when bluefish populations were at very low levels. In addition, an extensive analysis of bluefish from the Middle Atlantic Bight from 1973 through 1995 indicated that YOY were consistently collected in the summer in nearshore waters (Munch and Conover, 2000). Young-of-year have also been found on ocean beaches in the summer on the south shore of Long Island (Schaefer, 1967) and southern New Jersey (McDermott, 1983). These should be distinguished from the collections on ocean beaches in the fall when other

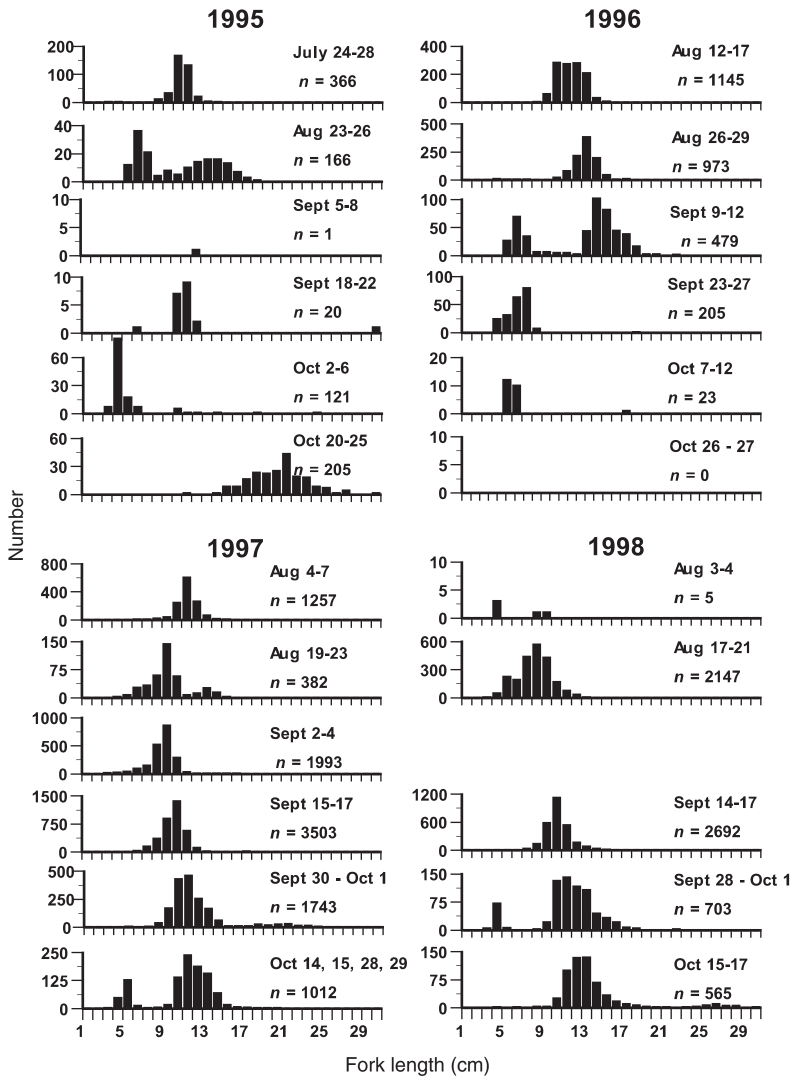

Figure 6

Size composition of young-of-year bluefish by collection date during 1995–98 from northern New Jersey ocean beaches.

YOY leave estuaries and join those in the ocean and make a southerly migration to overwintering habitats (Kendall and Walford, 1979; and see Able and Fahay, 1998) as water temperatures decline to below 15°C (Lund and Maltezos, 1970; Olla and Studholme, 1971). The occurrence of YOY in ocean waters in the fall has been reported elsewhere (Chiarella and Conover, 1990; McBride and Conover, 1991; McBride et al., 1993; Creaser and Perkins, 1994; Able and Fahay, 1998).

It is clear that YOY bluefish in the New York Bight use estuaries extensively (Kendall and Walford, 1979) and this use has been reported for a number of locations including Rhode Island (McBride et al., 1995), Long Island (Nyman and Conover, 1988; McBride and Conover, 1991), New Jersey (Fig. 3 in this paper; McBride and Conover, 1991; Rountree and Able, 1992a, 1992b, 1993; Able and Fahay, 1998) and North and South Carolina (McBride et al., 1993). As a result, YOY bluefish have been considered estuarine dependent (McHugh, 1966). However, it is not surprising that they also occupy other habitats such as ocean beaches because bluefish are widely distributed (Juanes et al., 1996), and YOY elsewhere have been found in the surf (Bennett, 1989; Ayvazian and Hyndes, 1995), along exposed coasts (van der Elst, 1976; Smale, 1984; McBride et al., 1993; Lenanton et al., 1996; Young et al., 1999) and shallow reefs (Bennett, 1989) in the South Atlantic Bight of the United States, Australia, and South Africa.

This annual pattern of abundance in the ocean in the study area could be dependent on the relative contribution of different cohorts. Although there has been much discussion of the importance of spring- versus summer-spawned individuals to the YOY population in estuaries in the

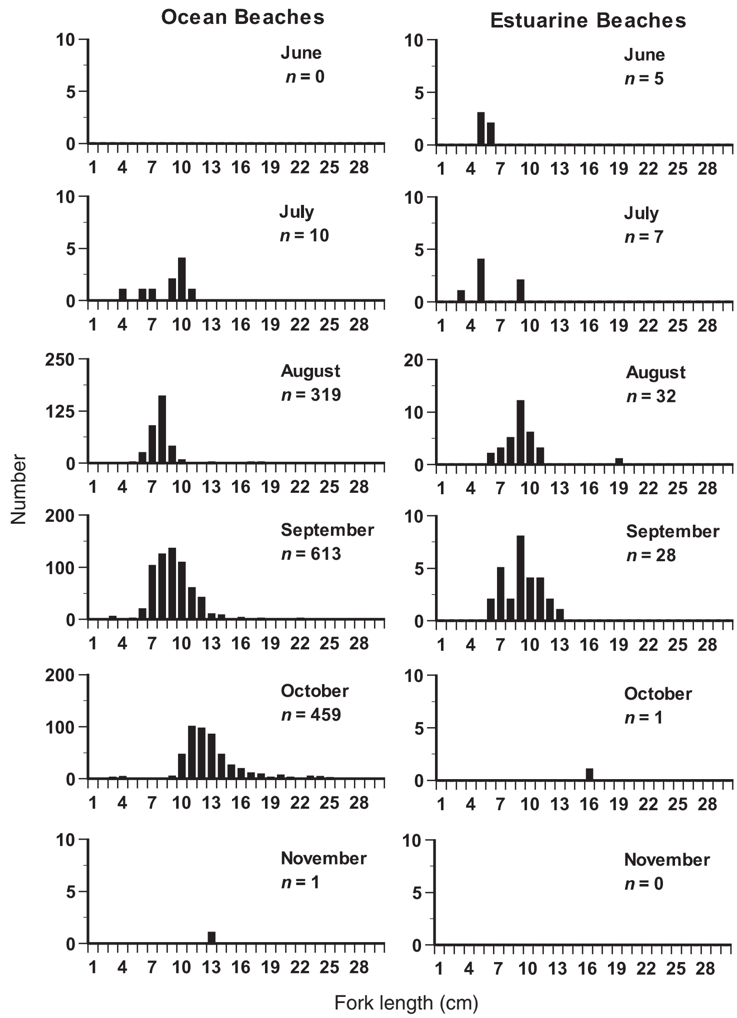

Figure 7

Size composition of young-of-year bluefish from southern New Jersey ocean beaches and the adjacent Great Bay estuary by month during 1998.

Middle Atlantic Bight (McBride et al., 1993; Hare and Cowen, 1996; Juanes et al., 1996; Able and Fahay, 1998), it appears that multiple cohorts occur in ocean habitats as well, based on the occurrence of the appropriate-size individuals in inner continental shelf (Fig. 5) and ocean beach (Figs. 6 and 7) sampling sites and in many of the same sites in the study area based on further extensive collections in 1999 and 2000 (Rowe et al.[3]).

In most years the smaller individuals of the presumed summer-spawned cohort were more abundant in ocean habitats. Others have suggested that summer-spawned individuals may be more abundant in the ocean (Kendall and Walford, 1979; Wilk, 1982) than in the estuary. Gear biases could influence the size of the YOY collected, as indicated by McBride and Conover (1991) for beach seines; therefore it is difficult to separate the effects of gear versus habitat to determine what is responsible for the average larger YOY collected in the ocean by otter trawl from the smaller average-size individuals collected on ocean beaches with seines. However, the occurrence of the largest fish in the deepest waters (21–27 m) suggests that habitat preference may be involved. A similar pattern was observed by Munch and Conover (2000), who found that the larger spring-spawned individuals were usually found in deeper waters than those for smaller summer-spawned individuals.

The contribution of the smaller bluefish cohort(s) to the population dynamics of the species in the Middle Atlantic Bight is unknown. The occurrence of very small (<50 mm) YOY bluefish in late summer occurred in a number of years during the study and subsequently (Rowe et al.[3]). These fish may represent late spawning or slow growth. They, along with the relatively small pelagic juveniles present in the water column in inner continental shelf waters in the study area at the same time (Rowe and Able, unpubl. data), may not contribute to the adult population because they enter the fall at relatively small sizes and may not survive

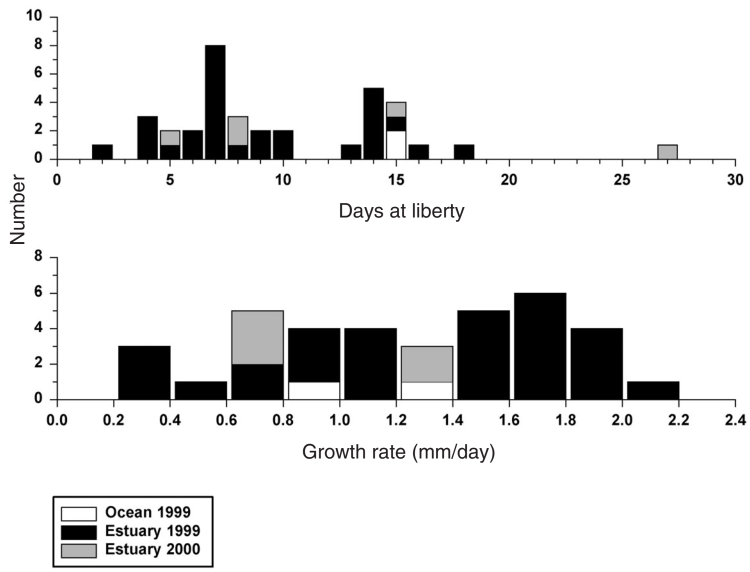

Figure 8

Summary of tag-recapture data from YOY bluefish during 1999 and 2000 at southern New Jersey estuarine and ocean beaches, including days at liberty and growth rate.

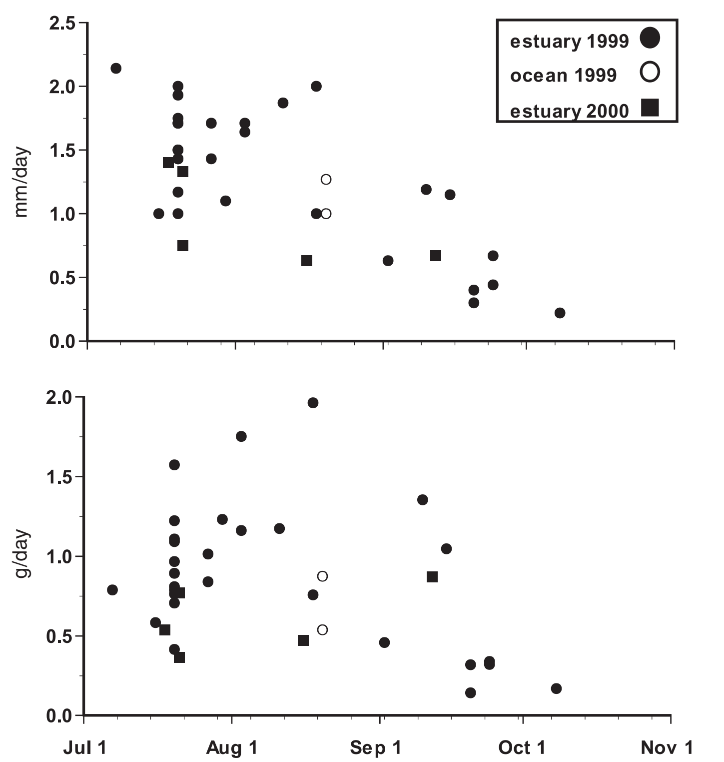

Figure 9

Growth rate by length and weight of tag-recapture fish during 1999 and 2000 at southern New Jersey estuarine and ocean beaches.

the overwinter period because of size-selective mortality (see Sogard, 1997; Hales and Able, 2001). Alternatively, the relatively large numbers of presumed summer-spawned YOY in collections implies that they could contribute substantially to the adult population. The only prior analysis, that we are aware of, suggested that the spring-spawned contingent was the principal contributor to the adult population (Chiarella and Conover, 1990). Regardless of the habitats used, the relative contribution by the summer-spawned individuals to the adult population could vary over annual or decadal scales. More attention to broad geographical responses over longer temporal periods is probably necessary to resolve the relative contribution issue of the different cohorts.

Residency and movements

Our understanding of the importance of ocean habitats to YOY bluefish is confounded by a lack of information about the movements of these fast-swimming fishes. Collections at northern New Jersey beaches suggests their occurrence and abundance may be sporadic based on the lack of consistent catches over time at the sites sampled (Fig. 4). The same pattern was observed in the study area during 1999 and 2000 (Rowe et al.[3]). This sporadic abundance could be due to several factors including inshore-offshore movements from the beaches to deeper water beyond the reach of seine samples, as appears to occur on estuarine beaches on a diel period (Buckel and Conover, 1997), or movements along the beach. A similarly variable pattern of occurrence has also been noted for beaches in South Africa (van der Elst, 1976).

The results of the tag and recapture efforts indicated that at least some of the YOY were resident on an estuarine beach for a considerable portion of the summer. Perhaps the number of recaptures (0.76–3.4%) would have been higher if not for the three hurricanes that occurred in the region during September 1999 that could have contributed to movement from shallow beaches into deeper waters of the estuary or into the ocean. The only other tag-recapture study of YOY (<270 mm FL) bluefish, of which we are aware, occurred in Moreton Bay, Queensland, Australia (Morton et al., 1993). The high rate of returns (11%) from the externally tagged fish in that study was attributed to the intensive fishery for this species and the fact that sheltered estuaries within the study area presumably provided

Table 2

Diet composition for young-of-year bluefish (*Pomatomus saltatrix*) collected on ocean beaches in southern and northern New Jersey during 1998. Percent frequency of occurrence based on number of stomachs with prey. The miscellaneous category includes macroalgae, detritus, shell fragments, and sand. See Figure 1 for sampling locations.

	Southern beaches		Northern beaches		Estuary	
Prey category	Total number of prey	Percent frequency of occurrence	Total number of prey	Percent frequency of occurrence	Total number of prey	Percent frequency of occurrence
Annelida (Polychaeta)	14	1.8	7	1.0	0	0
Crustacea	3560	45.7	8463	42.5	46	33.9
Amphipoda (Gammaroidea)	938	16.9	513	18.6	2	1.7
Cladocera	151	0.3	3961	6.9	0	0.0
Copepoda	447	3.8	3449	15.7	15	3.4
Calanoida	268	2.3	2165	8.2	0	0.0
Harpacticoida	0	0.0	12	0.5	0	0.0
Unidentified	179	1.5	2417	8.9	0	0.0
Decapoda	1830	27.9	296	10.1	29	28.8
Megalopa	476	11.4	35	3.0	0	0.0
Zoea	406	4.1	83	3.2	0	0.0
Emerita talpoida	251	7.2	160	2.2	0	0.0
Ovalipes ocellatus	5	0.7	6	1.0	0	0.0
Pagurus spp.	1	0.1	0	0.0	0	0.0
Unidentified crabs	9	0.7	1	0.2	2	3.4
Crangon spp.	13	1.3	1	0.2	0	0.0
Palaemonetes spp.	588	6.3	6	0.5	0	0.0
Thalassinoidea	18	1.2	0	0.0	0	0.0
Unidentified shrimps	63	3.5	4	0.5	27	25.4
Mysidacea	47	1.9	210	4.7	0	0.0
Stomatopoda	14	0.6	1	0.2	0	0.0
Unidentified	133	7.2	33	3.9	0	0.0
Larvacea	91	0.6	287	1.2	0	0
Mollusca	96	4.5	10	1.2	0	0.0
Bivalvia	95	4.4	5	0.5	0	0.0
Cephalopoda	1	0.1	5	0.7	0	0.0
Pisces	786	64.1	533	70.0	57	83.0
Anchoa spp.	414	25.1	248	27.6	0	0.0
Clupeidae	3	0.4	0	0.0	0	0.0
Fundulus majalis	0	0	0	0	3	5.1
Menidia spp.	15	1.6	11	0.5	17	22.0
Menticirrhus saxatilis	3	0.4	0	0.0	0	0.0
Pomatomus saltatrix	2	0.3	14	2.3	0	0.0
Syngnathus fuscus	6	0.1	0	0.0	0	0.0
Unidentified	343	39.7	260	39.7	37	55.9
Unidentified	134	12.3	65	6.4	14	23.7
Miscellaneous	160	21.5	61	9.7	—	—

optimal habitats where YOY bluefish may choose to remain resident for longer periods of time. The lower rates of recapture in both years and areas (estuary and ocean) in our study may in part be attributable to the fact that coded wire tags are not detectable by fishermen.

The very low level of tag returns from the ocean in our study (0.04%) makes it difficult to discern patterns of habitat use with this approach. This may be due to the fact that sampling with seines in the ocean was largely limited to the relatively shallow portions of the surf zone and it appears that YOY bluefish also use deeper portions of the coastal ocean (Fig. 2). In addition, the lack of returns could be due to more extensive movements on ocean beaches in relation to the estuary—a point supported by the fact that the sporadic nature of bluefish captures during the intensive sampling in 1997 and 1998 (Fig. 4) and in subsequent years (Rowe et al., in review). In addition, the same pattern of reasonable recapture rates in this estuary and low or no recaptures in

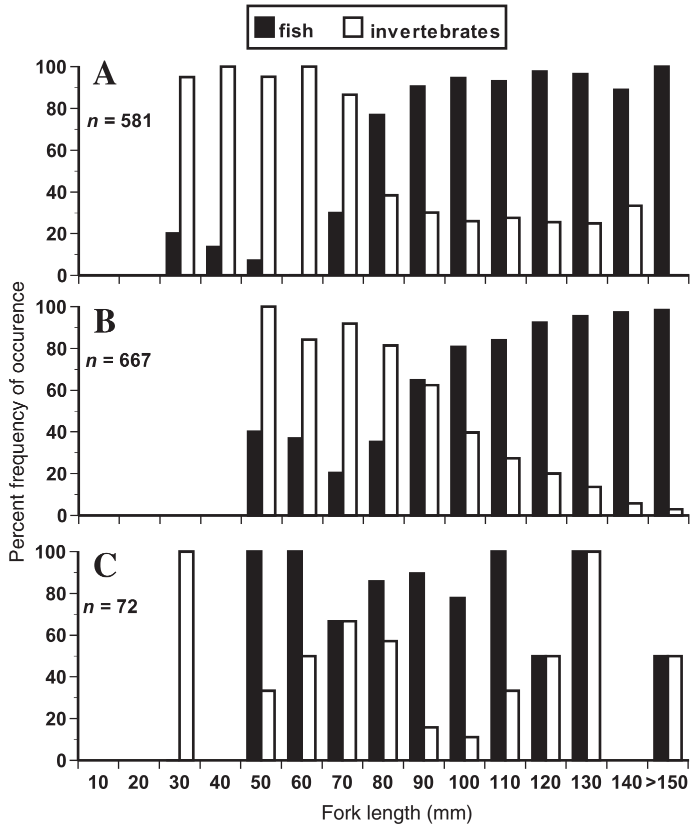

Figure 10

Ontogenetic changes in diet of YOY bluefish based on percent frequency of occurrence of fish and invertebrate prey for individuals collected on ocean beaches in northern (**A**) and southern (**B**) New Jersey and on estuarine beaches (**C**) in southern New Jersey during summer and fall 1998. See Figure 1 for location of beaches.

the ocean also occurred for another species, *Menticirrhus saxatilis*, during the same period with exactly the same tag and recapture techniques (Miller et al., 2002).

Growth

Earlier estimates for the same and other estuarine systems indicated an average growth rate of 0.9–2.1 mm/day for YOY bluefish (McBride and Conover,1991; McBride et al., 1995; Juanes et al., 1993, 1996). Another species, *Menticirrhus saxatilis*, that occurred in the same estuarine habitat, had slightly higher growth rates (Mean 1.8 mm/day, range 0.7–2.8 mm/day) (Miller et al., 2002). These estimates of growth for bluefish average greater than that for YOY of most other estuarine fish, at least in the Middle Atlantic Bight, where most nonresident, i.e. the fastest-growing species, range from 0.3 to 1.1 mm/day (Able and Fahay, 1998).

Food habits

Just as an understanding of YOY bluefish distribution and abundance in the New York Bight has been largely based on estuarine collections, so has the knowledge of their food habits. The ontogenetic shift reported in the diet of YOY bluefish during the transition from pelagic juveniles in the ocean to larger juveniles in estuarine habitats (Marks and Conover, 1993) also occurs on ocean beaches. Observations on northern and southern New Jersey beaches indicate that this transition, from invertebrates to fishes, occurs at approximately the same sizes (80–100 mm FL) as reported elsewhere (Marks and Conover, 1993; Juanes and Conover, 1994a, 1994b; Creaser and Perkins, 1994).

The diet of YOY bluefish in the coastal ocean is similar to that reported elsewhere in the world. The selection of engraulids and atherinids, as occurs on New Jersey beaches, is similar to that for other populations (Juanes et al., 1996), except that atherinids made up a much smaller percentage of the diet (Table 2). This difference is not easily explained because atherinids are a large component of the surf zone fish assemblage on New Jersey beaches during the summer and fall (Rowe and Able, unpubl. data).

In summary, ocean beaches and deeper waters of the inner continental shelf are used continuously by YOY bluefish from summer through the fall migration. Bluefish in these habitats appear to share some characteristics with estuarine bluefish, such as monthly occurrence in the summer, size composition, growth, and food habits. The exception is that the smaller, summer-spawned cohort may be relatively more abundant in ocean habitats. This possible distinction should be considered when assessing the importance of different cohorts to recruitment. Another exception is that the degree of residency varied between the estuary and the ocean with higher recapture rates on at least one estuarine beach. Further study is necessary, however, to resolve the degree to which ocean bluefish are resident there. The available data suggest that their movements may be much more dynamic in the ocean.

Although YOY bluefish are clearly not obligate estuarine users because of the large numbers found in coastal waters, it will take more detailed studies of bluefish and other "estuarine-dependent" species to determine if their use of estuarine or ocean habitats is facultative, varies annually or varies with different cohorts. This view is in keeping with the "basin model" of MacCall (1990), which recognizes a variety of factors that may influence habitat use.

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