Abstract—The goal of this study was to provide insight into habitat use of the inner continental shelf off southern New Jersey by summer-spawned bluefish (*Pomatomus saltatrix*). Throughout the August–October 1998 sampling period, a total of 1071 bluefish were collected from shelf surface waters, during which the mean density and body size was 3.7 bluefish/1000 m^3 and 13.7 mm standard length (SL), respectively. Spatiotemporal variability in bluefish density was explained by an inverse relationship with Secchi depth, and body size was explained by water temperature and depth. Bluefish size-structure in August was bimodal and comprised larval, transitional, and juvenile stages (3–48 mm SL). Size frequencies in subsequent months were unimodal and consisted of bluefish <25 mm SL. Synoptic sampling of multiple habitats indicated that the earliest life stages of bluefish extensively, and perhaps exclusively, use inner continental shelf surface waters. Summer-spawned bluefish numerically dominated the population across all habitats and temporal scales examined.

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Habitat use of the inner continental shelf off southern New Jersey by summer-spawned bluefish (*Pomatomus saltatrix*)*

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Bluefish (*Pomatomus saltatrix*) is a coastal marine species that is common in temperate and subtropical waters worldwide (Juanes et al., 1996). Bluefish support extensive fisheries throughout their distribution (Juanes et al., 1996), including the western north Atlantic where this species has historically accounted for the greatest catch by weight in the recreational fishery (Pottern et al., 1989). Along the eastern coast of the United States, for example, bluefish landings in 1985 contributed to over 24% of the total marine recreational catch (U.S. Department of Commerce, 1986). Since the mid-1980s, however, bluefish landings in this area have declined precipitously and have yet to rebound in the last two decades (Klein-MacPhee, 2002). As a result, the Atlantic States Marine Fisheries Commission (ASMFC) established bluefish as a priority research subject and further recommended that research provide a better understanding of the early life history and recruitment patterns of this species.

Recruitment dynamics of bluefish along the eastern coast of the United States are intrinsically linked to annual spawning migrations of the adult population. Bluefish spawning migrations move northward into the Middle Atlantic Bight (MAB; Cape Hatteras, North Carolina, to Cape Cod, Massachusetts) during the spring and summer following an overwintering period in the South Atlantic Bight (SAB; Cape Canaveral, Florida to Cape Hatteras) (Klein-MacPhee, 2002) or at the edge of the continental shelf in the MAB (Miller, 1969; Wilk, 1982; Shepherd et al., in press). Pelagic eggs are spawned offshore during the spring and summer as bluefish migrate northward along the continental shelf. The planktonic eggs of bluefish experience a brief incubation period (48 hours; Deuel et al., 1966) that is followed by a larval stage that concludes 18–25 days after hatching and once the bluefish are 10–12 mm standard length (SL) (Hare and Cowen, 1994). Bluefish then undergo a transitional period, ending with the

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onset of the juvenile stage at 34–37 mm SL (Silverman, 1975). Juveniles remain oceanic for an additional 15–45 days before passively or actively recruiting to estuarine habitats at 40–80 mm fork length (FL) (Nyman and Conover, 1988; McBride and Conover, 1991; Hare and Cowen, 1993).

Along the U.S. northeastern coast, juvenile bluefish recruit to estuaries and have a consistent intra-annual and bimodal length-frequency distribution: the first cohort enters estuaries from late May to early June (spring-spawned cohort), and a second cohort enters from July to October (summer-spawned cohort) (Nyman and Conover, 1988; McBride and Conover, 1991; McBride et al., 1993; Creaser and Perkins, 1994). This is consistent with previous studies that indicate that juveniles of both spring and summer cohorts are estuarine dependent (Juanes et al., 1996; Able and Fahay, 1998). There is recent evidence, however, that select cohorts of bluefish may exclusively use alternative habitats, such as ocean beaches, during the juvenile stage (Able et al., 2003; Wilber et al., 2003). In addition, samples of larval and juvenile bluefish from surface waters on the inner continental shelf have indicated at least two cohorts of presumably summer-spawned fish that may not recruit to estuaries (Kendall and Walford, 1979; Rowe et al.[1]; Taylor and Able, in press).

Spring-spawned bluefish historically dominate juvenile year-class strength and were therefore assumed to determine adult population dynamics (Nyman and Conover, 1988; McBride and Conover, 1991; Munch and Conover, 2000). This assertion, however, is based primarily on estimates of juvenile abundance in MAB estuaries (Nyman and Conover, 1988; McBride and Conover, 1991) and failed to consider contributions from alternative habitats, including the inner continental shelf. A more recent evaluation of bluefish collected from the MAB also has indicated a shift in the cohort-specific production of juveniles over the last decade (Conover et al., 2003), such that summer-spawned fish numerically dominate recent year classes. Despite the apparent switch in the relative dominance of the two cohorts, bluefish successfully recruiting to the adult population remain the products of spring-spawning events (Chiarella and Conover, 1990; Conover et al., 2003). The factors underlying the apparent failure of the summer-spawned cohort to contribute substantially to the adult population are unknown. This failure is due, in part, to insufficient information that would otherwise enable a critical evaluation of each cohort's role in regulating year-class strength. Attempts to determine factors affecting recruitment patterns should include an evaluation of the cohort dynamics of summer-spawned bluefish that utilize inner continental shelf habitats.

The goal of our study was to provide greater insight into the habitat use by summer-spawned bluefish in a localized area in the MAB. In 1998, young-of-the-year (YOY) bluefish were sampled during the summer and fall on the inner continental shelf off southern New Jersey. Spatial and temporal abundance and distribution patterns were used to evaluate the potential importance of continental shelf waters as habitats for YOY bluefish. Observations from the 1998 study were then analyzed and compared to observations from other field surveys of habitat use by YOY bluefish in the same geographic region and time: inshore and other continental shelf waters of southern New Jersey in 1998 (Able et al., 2003).

Material and methods

Sampling of surface waters over the inner continental shelf

Bluefish were sampled at the water surface along the inner continental shelf off the southern coast of New Jersey (Fig. 1). Specifically, a 4×4 station grid (total area ~825 km^2) was sampled on ten dates between 11 August and 9 October 1998. Stations were grouped into four transects that were aligned parallel to the coastline (Fig. 1A). Transects closest and farthest from the coastline were 3 km and 18 km offshore, respectively. Water depths ranged between 6 and 29 m, and the shallowest depths generally occurred near the shore.

Bluefish were collected during daylight with a Methot trawl deployed at the surface (Methot, 1986; Oozeki et al., 2004). The frame trawl had a mouth area of 5 m^2, leading to an 11-m-long net (6-mm mesh) that tapered to a 2-m-long plankton net (0.5-m diameter, 500-μm mesh). One tow was performed at each of the 16 stations per sampling date, with the exception of 11 August and 9 October when only four and eight stations were sampled, respectively (n=140 total tows). At each station, the trawl was towed for four minutes in an arc (tow speed ~2.5–3.5 knots) to avoid the wake of the research vessel. All tows were made at the surface (0–2 m depth) with the top of the frame approximately 0.25 m out of the water. Samples were immediately processed after collection, and bluefish were preserved in 95% ethanol for subsequent laboratory analysis.

A General Oceanics flowmeter (General Oceanics, Inc., Miami, FL) was attached to the Methot trawl frame along a lower corner so that the volume of water sampled could be determined (~2000 m^3 per tow). Surface salinity, surface water temperature, water depth, Secchi depth, and wind speed and direction were recorded at all stations. Additional wind data were available as a time series (15-minute sampling interval) from a meteorological platform located at the Rutgers University Marine Field Station (Tuckerton, NJ; Fig. 1A; K. W. Able, unpubl. data).

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[1] Rowe, P. M., K. W. Able, and M. J. Miller. 2002. Distribution, abundance, and size of young-of-the-year bluefish (*Pomatomus saltatrix*) in ocean and estuarine habitats in southern New Jersey during 1999–2000, 54 p. Jacques Cousteau Technical Report no. 100-16. Rutgers University, Institute of Marine and Coastal Sciences, Marine Field Station, 800 c/o 132 Great Bay Boulevard, Tuckerton, NJ 08087-2004.

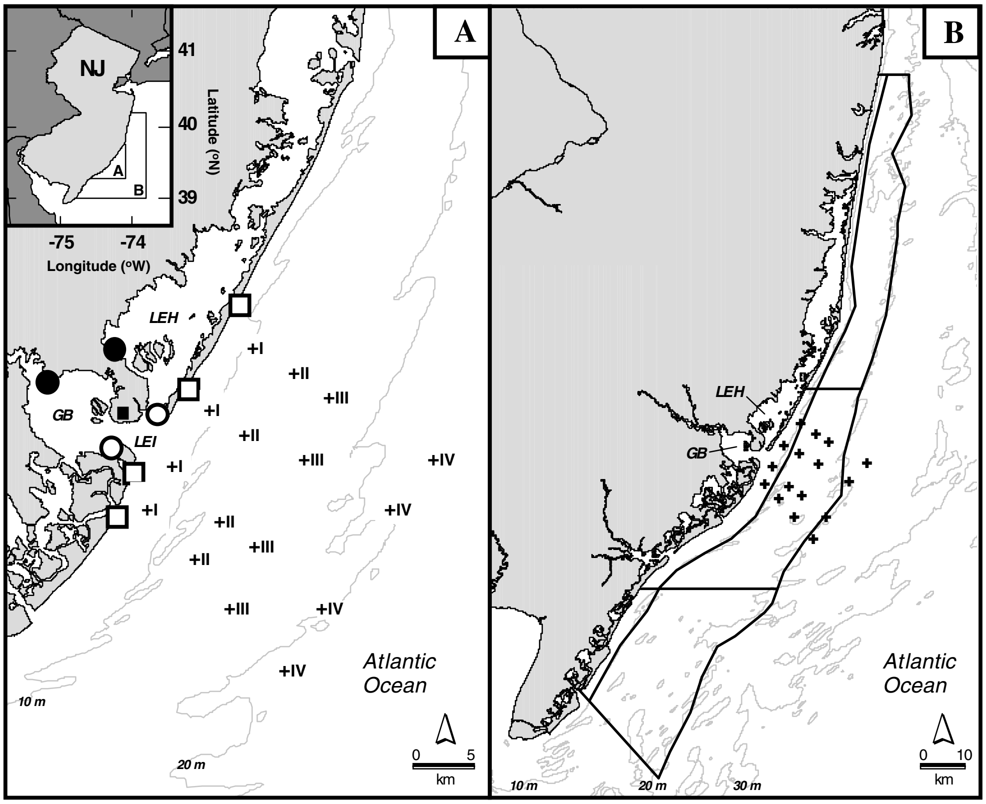

Figure 1

Map of inshore and inner continental shelf habitats off southern and central New Jersey. Plus symbols (✚) demarcate the 4×4 station grid (total area ~825 km^2) sampled with a surface-deployed Methot trawl on the inner continental shelf between 11 August and 9 October 1998. (**A**) Inner continental shelf sampling sites were grouped into four transects (I–IV) aligned parallel to the coastline. Estuarine (●), inlet (○), and ocean beach (□) sites sampled with a beach seine were located at the margins of Great Bay (GB), Little Egg Harbor (LEH), and Little Egg Inlet (LEI). (**B**) Solid lines (—) demarcate six depth strata sampled with an otter trawl on the inner continental shelf. Location of the Rutgers University Marine Field Station (Tuckerton, NJ; ■) and depth contours of 10, 20, and 30 m are provided.

Bluefish collected with Methot trawls were counted to estimate fish density (no. of bluefish/1000 m^3), measured to the nearest mm SL, and classified into distinct ontogenetic stages based on the individual's body size and presumed scale development (Silverman, 1975; Able and Lamonaca, in press). For the purposes of our investigation, several life history stages were demarcated: larval, transitional, and juvenile. The onset of scale development was recognized as the end of the larval stage and the beginning of the transitional period (12 mm SL; Silverman, 1975; Hare and Cowen, 1994). The transitional period in bluefish development, in turn, concluded with complete scale formation and the juvenile stage began at 34 mm SL (Silverman, 1975).

Spatial and temporal patterns of bluefish density and mean size were analyzed independently with multivariate repeated-measures analysis of variance (ANOVA) models by using station transects (transects I–IV; Fig. 1A) and sampling date (day of year) as the between-subject and within-subject factors, respectively. Profile transformation of the within-subject factor was used in the repeated-measures ANOVA model, and statistical significance was estimated from the Greenhouse-Geisser–adjusted probability to avoid violating the assumption of circularity (sphericity) of the within-subject variance-covariance matrix (von Ende, 1993). The mean density and body size of bluefish across four levels of transects and ten levels of sampling dates were contrasted with a Ryan-Einot-Gabriel-Welsch (Ryan's Q) multiple comparison test (Day and Quinn, 1989). Moreover, natural log (x+1) and natural log (x) transformations were performed on bluefish density and mean-size data, respectively, to meet assumptions of normality and homogeneity of variance. When data transformations did not achieve homoscedasticity, hypotheses were rejected at alpha values lower than the P-values of Levene's test for homogeneity of variance (Underwood, 1981).

The effects of several environmental parameters on the spatial and temporal distribution of bluefish density and mean size were analyzed with a stepwise multiple regression. The variables included in the regression

Table 1

Summary of field sampling protocols, habitat characteristics, and bluefish (*Pomatomus saltatrix*) catch and size data across multiple areas of southern and central New Jersey in the summer and fall of 1998. Bluefish catch data are reported as catch per unit of effort (CPUE). Temperature, salinity, and size data within parentheses represent minimum and maximum values observed on a given date, and NM and NA signify "no measurement" and "not applicable," respectively. Additional information regarding habitat location and sampling protocols is found in the text and Figure 1.

Habitat	Sampling gear	Sampling effort (no. of tows)	Depth (m)	Temperature (°C)	Salinity (‰)	CPUE (no. per tow)	Size (mm SL)
Continental shelf (surface waters)							
11–20 Aug 1998	Methot trawl	68	6–28	25.5 (16.5–27.3)	30.7 (30.0–31.1)	4.4	18.7 (3–48)
1–11 Sep 1998	″	32	6–29	24.0 (21.8–25.5)	30.6 (30.3–30.7)	2.3	10.1 (5–25)
18–25 Sep 1998	″	32	6–27	22.5 (21.0–23.6)	30.7 (30.3–31.0)	21.7	12.0 (4–24)
6 Oct 1998	″	8	9–29	19.5 (18.7–20.3)	30.7 (30.6–30.9)	0.6	18.7 (18–22)
Estuary							
13–24 Aug 1998	Beach seine	8	0–2	25.0 (24.0–26.0)	28.5 (28.0–29.0)	0.3	116.0 (60–172)
9 Sep 1998	″	5	″	19.9 (19.5–20.5)	28.0 (28.0–28.0)	0.4	111.0 (104–118)
21 Sep 1998	″	5	″	27.0 (27.0–27.0)	NM	0.2	116.0
5 Oct–3 Nov 1998	″	15	″	16.0 (10.5–19.0)	27.8 (26.0–29.0)	0.1	147.0
Inlet							
4–21 Aug 1998	Beach seine	9	0–2	25.7 (25.0–26.0)	29.3 (28.0–30.0)	3.3	83.1 (59–103)
3–4 Sep 1998	″	5	″	25.6 (25.0–26.0)	28.8 (28.0–30.0)	4.0	78.9 (55–113)
14–29 Sep 1998	″	10	″	21.7 (20.0–23.0)	29.7 (29.0–30.0)	0.5	96.2 (91–99)
13–29 Sep 1998	″	12	″	15.0 (13.0–17.0)	29.3 (29.0–30.0)	0.0	NA
Ocean beach							
3–25 Aug 1998	Beach seine	32	0–2	25.4 (23.0–27.0)	30.1 (28.0–31.0)	14.1	73.3 (51–168)
2–8 Sep 1998	″	16	″	24.4 (23.0–26.0)	30.4 (30.0–31.0)	53.7	76.5 (53–123)
14–30 Sep 1998	″	26	″	22.6 (20.0–26.0)	30.1 (29.5–31.0)	50.2	96.6 (27–205)
6 Oct–4 Nov 1998	″	41	″	15.6 (13.0–18.0)	30.0 (30.0–30.0)	93.2	118.5 (32–225)
Continental shelf (bottom)							
17–20 Aug 1998	Otter trawl	17	6-18	19.6 (12.3–25.4)	30.9 (28.3–31.5)	10.5	63.8 (30–200)
30 Oct–4 Nov 1998	″	17	″	14.4 (12.6–15.4)	31.4 (30.1–31.9)	21.6	125.6 (80–220)

model were sampling date (day of year), sampling time of day (sine-transformed), station distance from coastline (km), surface temperature (°C), surface salinity (‰), Secchi depth (m; a coefficient of light extinction or water clarity), water depth (m), and cross- and long-shelf wind speed (positive east and north, respectively). The significance level for entry into the regression model was set at $P<0.05$. Environmental variables that significantly affected the spatial and temporal distribution of bluefish density and mean size (i.e., those parameters incorporated into regression models) were also analyzed with an analysis of covariance (ANCOVA) model, with sampling date as the covariate and station transects as the discrete explanatory variable.

Synoptic analysis of habitat use by summer-spawned bluefish

Several other sampling programs initiated in 1998 monitored the distribution and size composition of YOY bluefish across multiple habitats in southern and central New Jersey (Table 1, Fig. 1) and the data from these programs were then compared to our data from surface waters on the inner continental shelf. A complete description of the sampling protocols and schedules for monitoring YOY bluefish in these habitats is provided elsewhere (Able et al., 2003; Rowe et al.[1]). Habitat use by different ontogenetic stages was ascertained from the size and stage (larval, transitional, juvenile) composition of bluefish observed in estuaries, inlets, ocean beaches, and the inner continental shelf. Accordingly, length-frequency histograms of bluefish were created for each habitat over four time periods (August, early to mid-September, mid-to-late September, and from October to November) by using class intervals of 5.0 mm SL for Methot trawl and beach seine samples, and 10.0 mm SL intervals for otter trawl samples. Moreover, a length-based key derived by McBride and Conover (1991) and adopted by others (Juanes and Conover, 1995; Wilber et al., 2003) was used to delineate between spring- and summer-spawned bluefish in length-frequency histograms. Summer-spawned bluefish were defined as <100 mm SL in August, <125 mm SL from early to mid-September, <150 mm SL from mid-to-late September, <175 mm SL from October to November. Bluefish at body sizes larger then these groupings were designated as spring-spawned individuals.

Results

Bluefish density and mean size on the inner continental shelf

A total of 1071 bluefish were collected from surface waters off the southern coast of New Jersey during the survey. Throughout the August–October sampling period, bluefish were found in 71% of the tows (99 out of 140), during which the mean density was 3.7 bluefish/1000 m^3 (range=0–57.9 bluefish/1000 m^3). Bluefish density differed significantly by transect and sampling date (multivariate repeated-measures ANOVA; transect: F=9.39, df=3,12, P<0.005; date: F=16.09, df=9,88, P<0.0001). However, the transect-sampling date interaction effect was significant and precluded direct conclusions about the main effects (multivariate repeated-measures ANOVA; transect × date: F= 1.95, df=27,88, P<0.05) (Fig. 2). The interaction effect was attributed to significantly higher densities of bluefish at transect II on days 226 and 268 (in comparison to transects I, IV, and transect I on these days, respectively (Ryan's Q multiple comparison test). Bluefish densities were also significantly greater at transect III on days 226 and 244 than at transect I for both dates (Ryan's Q multiple comparison test).

In the stepwise multiple regression, Secchi depth explained the most variability in bluefish density with an r^2 of 0.078 (stepwise multiple

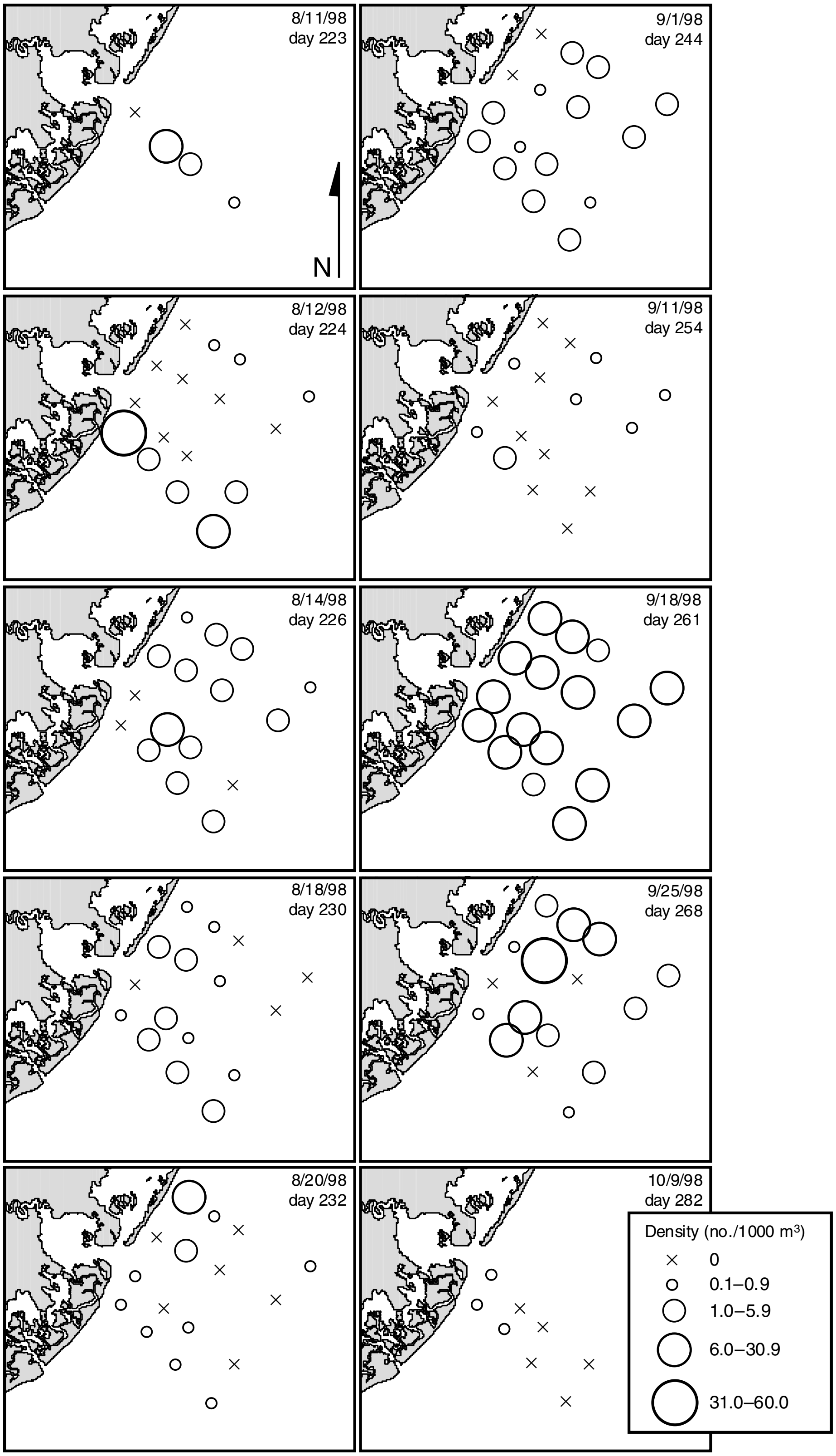

Figure 2

Spatial distribution of the density (no. of fish/1000 m^3) of bluefish (*Pomatomus saltatrix*) collected with a Methot trawl between 11 August and 9 October 1998 off the southern coast of New Jersey. Stations were located at approximately 39°27′N, 74°11′W.

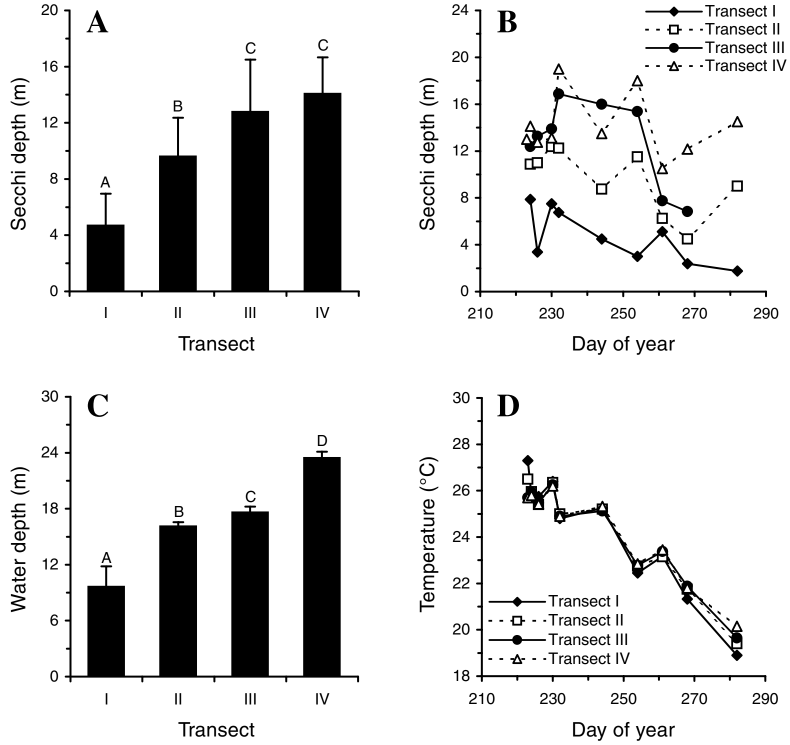

Figure 3

Spatial and temporal distribution (**A** and **B**) of Secchi depth (m), (**C**) water depth (m), and (**D**) surface water temperature (°C). Mean (±1 standard deviation) Secchi depth and water depth are displayed as a function of station transects (I–IV; Fig. 1A), calculated from ten sampling dates between 11 August and 9 October 1998 (days 223–282). Means with the same upper case letters are not significantly different (Ryan's Q multiple comparison test). Secchi depth and surface water temperature are also displayed as function of station transects and sampling date (days 223–224).

regression; F=11.34, df=1,135, P<0.001), and remaining parameters were not significant at P<0.05 and therefore not included in the model. The estimated coefficient for Secchi depth was negative (parameter estimate=−0.436), indicating an inverse relationship between bluefish density and water clarity. Before analyzing spatial and temporal variations in Secchi depths with an ANCOVA model, we examined the interaction effect between transect and sampling date. There was no significant transect-date interaction effect (two-way ANOVA; transect×date: F=2.47, df=3,124, P=0.065), and the assumption of equal slopes was met in the full data set (Underwood, 1981). Secchi depth differed significantly as a function of transect position (ANCOVA; F=63.34, df=3,127, P<0.0001), whereby distance from the coastline was positively correlated with Secchi depth (Fig. 3A). Furthermore, Secchi depth significantly decreased throughout the sampling period (ANCOVA; F=30.20, df=1,127, P<0.0001) (Fig. 3B).

The mean body size of bluefish collected from August to October was 13.7 mm SL (range=3–48 mm SL) (Table 1; Fig. 4). Similar to spatial and temporal density patterns, bluefish mean body size differed significantly by transect and sampling date (multivariate repeated-measures ANOVA; transect: F=6.16, df=3,12, P<0.01; date: F=7.50, df=9,50, P<0.0001) (Fig. 4). The transect-sampling date interaction effect was again significant (multivariate repeated-measures ANOVA; transect×date: F=3.50, df=24,50, P<0.0001), thereby precluding contrasts across main effects. The interaction effect was caused by significantly larger bluefish at transects I and II on day 254 compared to transects III, IV, and transect III, respectively (Ryan's Q multiple comparison test). On day 268, significantly larger bluefish were collected at transect IV than at all other transects (Ryan's Q multiple comparison test).

Surface water temperature and water depth were the most significant factors affecting the size distribution of bluefish (stepwise multiple regression; temperature: F=14.07, df=2,94, P<0.0005; depth: F=5.50, df=2,94, P< 0.05), such that temperature and depth accounted for a partial r^2 of 0.129 and 0.048, respectively (cumulative r^2=0.177). Moreover, estimated coefficients for both variables were negative (parameter estimates=−1.121

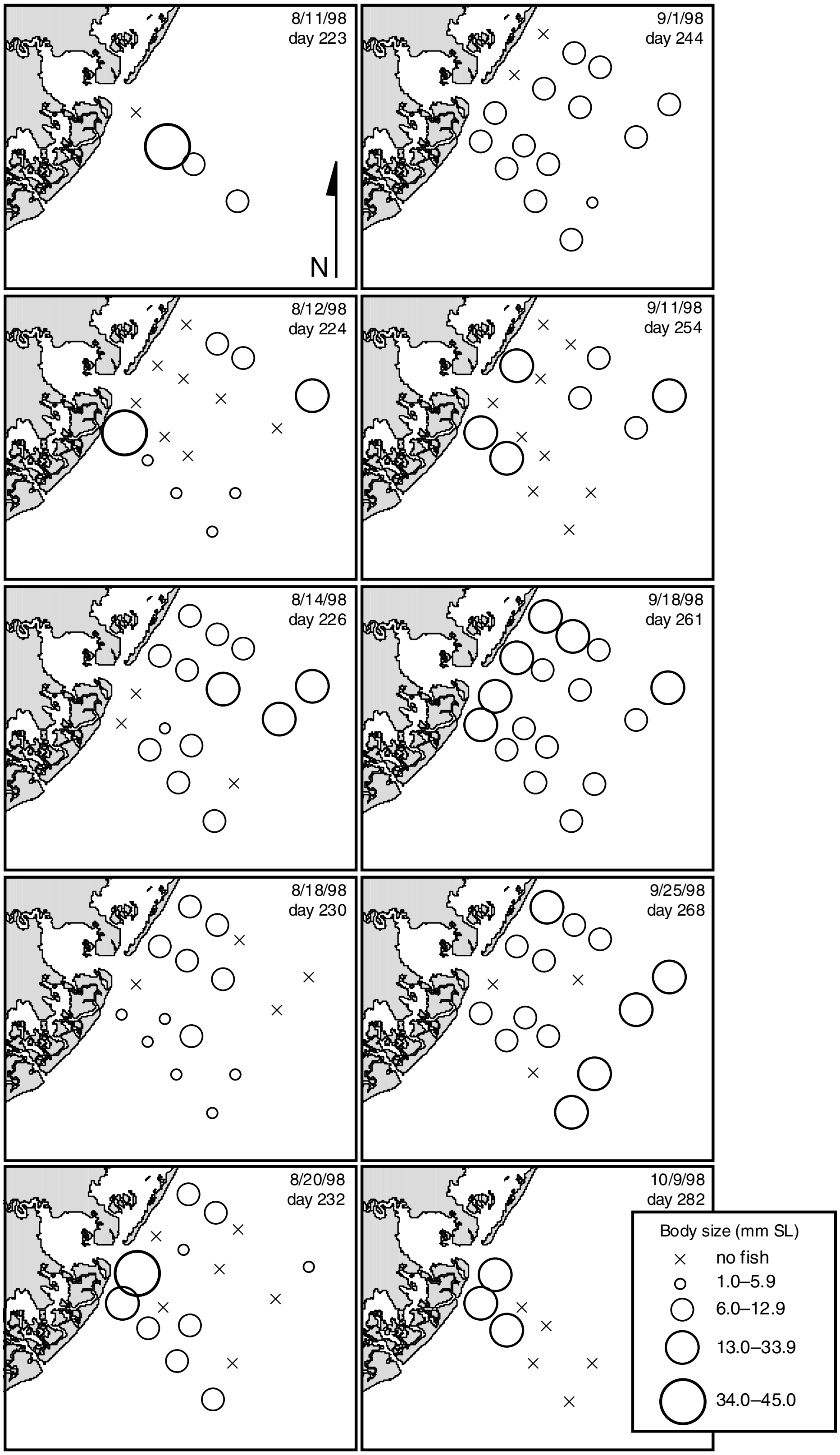

Figure 4

Spatial distribution of the mean size (mm SL) of bluefish (*Pomatomus saltatrix*) collected with a Methot trawl between 11 August and 9 October 1998 off the southern coast of New Jersey. Stations are located at approximately 39°27′N, 74°11′W.

and −0.254 for temperature and depth, respectively) indicating that larger bluefish were associated with relatively cool surface water and shallow water depths. Before analyzing spatial and temporal variations in temperature and depth with an ANCOVA model, we examined the transect-sampling date interaction effect. There were no significant interactions between transect and date for both analyses (two-way ANOVA; depth−transect×date: F=0.72, df= 3,132, P=0.5401: temperature−transect×date: F=1.87, df=3,132, P= 0.1385). Water depth significantly increased as distance from the coastline increased (ANCOVA; F=231.24, df=3,135, P<0.0001) (Fig. 3C), and surface temperature significantly decreased during the sampling period (ANCOVA; F=916.49, df=1,135, P<0.0001) (Fig. 3D).

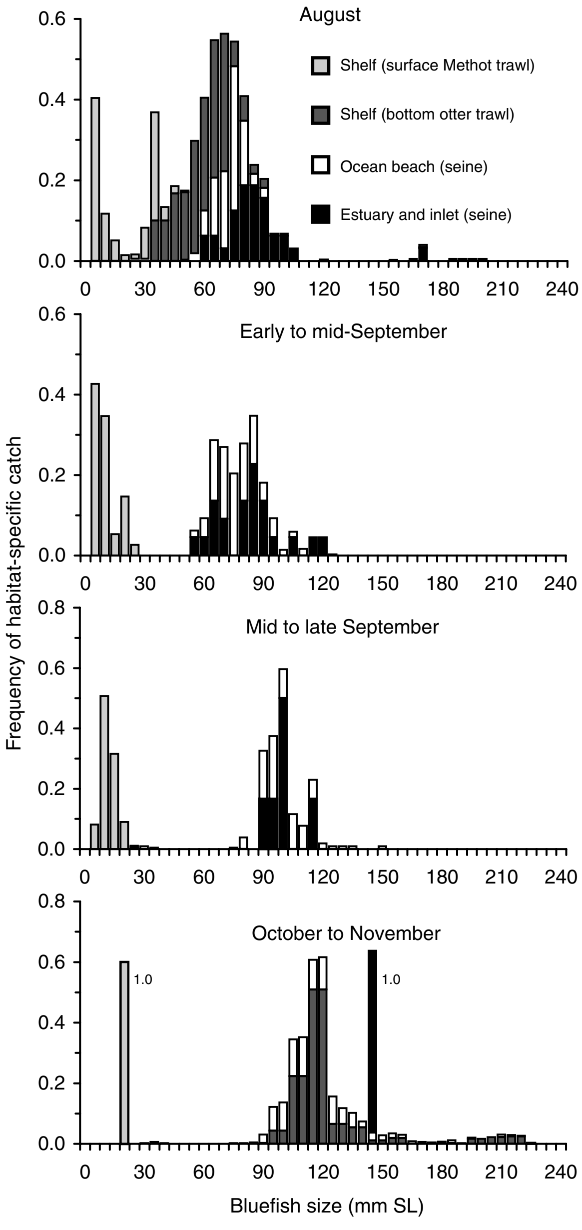

Figure 5

Composite length-frequency histograms for bluefish (*Pomatomus saltatrix*) collected from multiple habitats in summer and early fall (1998) in southern and central New Jersey. Additional information regarding habitat location and sampling protocols is found in the text, Table 1, and Figure 1.

Transitional bluefish (25–34 mm SL) and juveniles (35–50 mm SL) were a major portion of the overall size composition of bluefish collected in August (Fig. 5). For example, bluefish 25–50 mm SL constituted 40.1% of the individuals collected during this time period. In subsequent months, however, these bluefish were absent from remaining survey tows. Conversely, larval bluefish (3–11 mm SL) and small transitional bluefish (12–24 mm SL) were collected on all sampling dates and were numerically dominant in August and thereafter (Fig. 5). From August to late September, length-frequency distributions of bluefish <25 mm SL generally broadened in range and shifted to larger body sizes.

Synoptic analysis of habitat use by summer-spawned bluefish

Bluefish abundance and size-structure were compared among diverse inshore and coastal habitats in an effort to provide a more synoptic examination of summer habitat use across ontogenetic stages. In the process, bluefish were examined from shallow estuarine, inlet, and ocean beaches to surface and deeper waters on the inner continental shelf. As previously discussed, all individuals collected by Methot trawl tows from shelf surface waters were <50 mm SL, and therefore defined as summer-spawned larval, transitional, or juvenile bluefish (Fig. 5).

Bluefish catches in the Great Bay estuary were low; 33 seine hauls collecting five bluefish from August to October (0.1–0.4 bluefish/haul) (Table 1). With the exception of one bluefish, all individuals in the estuary were designated as summer-spawned fish (Fig. 5). Relatively few bluefish were collected in seine hauls at inlet sites located at the margin of Little Egg Inlet (55 bluefish from 36 hauls) that were primarily summer-spawned (Table 1; Fig. 5). In contrast to estuarine and inlet sites, substantial numbers of bluefish were collected from August to early November along ocean beaches north and south of Little Egg Inlet (6440 bluefish from 115 hauls) (Table 1). Spring-spawned bluefish were consistently collected along ocean beaches during the survey, but abundances were low compared to those of summer-spawned individuals that represented 98.4% of the total catch (Fig. 5). Compared to the sizes of bluefish collected from surface waters of the inner continental shelf, the sizes of the overwhelming majority (99.4%) of fish collected at inshore sites (estuary, inlet, and ocean beaches) were >50 mm SL (i.e., the sizes of juvenile fish). The only exception to this pattern occurred along ocean beaches from mid-September to early November (Fig. 5).

Sampling of bottom waters on the inner continental shelf during the same time period collected 179 and 367 bluefish in August and October–November, respectively (Table 1; Fig. 5). The size composition of bluefish collected from otter trawl tows was comparable to that observed at inshore sites (particularly ocean beaches), but distinctly different from that of fish captured in continental shelf surface waters. For example, 96.5% of the bluefish captured during sampling of shelf bottom waters were >50 mm SL (mean size=63.8 and 125.6 mm SL in August and October–November, respectively). Of the remaining individuals that were <50 mm SL, all were collected during the August otter trawl survey. Spring-spawned bluefish were collected in August and October–November by otter trawl tows, but again these bluefish represented a small portion of the total sampled population (5.1%).

Discussion

In our study, summer-spawned larval, transitional, and juvenile bluefish used the inner continental shelf extensively and represented a major portion of the entire fish assemblage collected in surface waters off the southern coast of New Jersey. For example, summer-spawned bluefish were the most frequently encountered species within the surface fish assemblage and ranked fourth in numerical dominance during the summer and early fall. Moreover, patterns of bluefish density observed in this study are consistent with those seen in other ichthyoplankton surveys in the MAB. Kendall and Walford (1979) found that bluefish larvae <4 mm SL were widely distributed in the MAB in August (Long Island, New York, to Virginia) and that peak concentrations occurred on the inner continental shelf in the vicinity of New Jersey and Delaware. Similarly, Smith et al. (1994) observed high densities of bluefish eggs in June and July and that centers of abundance occurred in mid-shelf waters off Delaware Bay and New Jersey (Berrien and Sibunka, 1999). Subsequent months were characterized by relatively broad spatial distributions of bluefish larvae from the central MAB to southern New England and by dense concentrations off New Jersey in July and August, followed by decreased abundance over the entire continental shelf in October (Kendall and Walford, 1979; Smith et al., 1994). These observations from the inner continental shelf, in conjunction with the reported use of inshore habitats by summer-spawned juveniles (McBride and Conover, 1991; Able et al., 2003; Wilber et al., 2003), indicate that coastal regions of New Jersey and adjacent areas are important summer-spawning sites for bluefish and, moreover, represent an appropriate location for synoptic comparisons of bluefish abundance and size-structure across habitats.

Empirical observations indicate that summer-spawned bluefish may use inner continental shelf habitats and, to a lesser extent, ocean beaches during their earliest life history stages (larval, transitional, and small juveniles). As surmised from this and previous studies, bluefish <50 mm SL are prominent constituents of the ichthyoplankton assemblage in the MAB (Kendall and Walford, 1979; Hare et al., 2001), but the these life stages are found rarely in estuaries and inlets. Field collections from our study indicated an abundant supply of larval to small juvenile bluefish in the vicinity of Little Egg Inlet from August to October, yet these particular life stages were not observed during concurrent sampling at estuarine sites. Moreover, larval fish assemblages were monitored over 16 years (1989–2004) inside Little Egg Inlet (Fig. 1), and bluefish were found in only 0.8% of the total 640 plankton tows performed between July and September (25 total bluefish, size range: 7.6–57.0 mm SL) (Witting et al., 1999; K. W. Able, unpubl. data).

In another study, juvenile bluefish were conspicuous members of the pelagic fish assemblage in Great Bay (Fig. 1), ranking fifth in frequency of occurrence and tenth in numerical dominance (Hagan and Able, 2003). The mean body size of bluefish collected in Great Bay, however, was 87.4 mm FL—a size that indicates that bluefish may not use estuaries during the earliest life history stages. More likely, YOY bluefish recruit to estuarine and ocean beach habitats as small juveniles (40–80 mm FL), as has previously been reported (McBride and Conover, 1991; Hare and Cowen, 1993; Able et al., 2003). This assertion was reconfirmed in our study by the synoptic examination of summer-spawned bluefish across multiple habitats, where the smallest bluefish collected in estuarine, inlet, and ocean beaches averaged 47.3 mm SL.

In contrast to the size-composition of bluefish inhabiting estuarine and coastal ocean sites, bluefish in surface waters on the inner continental shelf were strictly larval, transitional, and small juveniles <50 mm SL (Fig. 5). The paucity of juvenile bluefish >50 mm SL off the southern coast of New Jersey may be attributed to several factors including gear avoidance, size-dependent depth and habitat distributions, and active or passive emigration. First, gear avoidance appears unlikely because of the speed (~2.5–3.5 knots), duration (4 minutes), and frequency (140 tows) at which tows were performed (Norcross et al., 1974). For example, the approximate swimming speed of a 50-mm bluefish is 10 cm/s (Olla et al., 1985; Hare and Cowen, 1993) under the assumption that the fish swims at 2 body length/s (Hunter, 1981). At this rate, it is improbable that juvenile bluefish could actively avoid a Methot trawl being towed at 128–180 cm/s (1 knot=51.44 cm/s). Secondly, larval-to-juvenile bluefish are surface oriented (0–6 m), as indicated by collection efforts across different water depths (Norcross et al., 1974; Kendall and Walford, 1979; Kendall and Naplin, 1981; Shima, 1989) and by morphometric characteristics (e.g., silver and dark blue counter-coloration) of pelagic juveniles that indicate that they are adapted for a surface oceanic existence. Sampling in our study, however, was limited to the immediate surface layer (0–2 m), and therefore the current sampling design would not detect size-dependent depth distributions >2 m. In Virginian coastal waters, Norcross et al. (1974) did not collect bluefish >22 mm total length in near-surface waters and attributed the absence of this fish to a lack of samples at depths where larger bluefish were presumably concentrated. In our study, continental shelf bottom waters were sampled with otter trawls (trawl vertical opening ~2 m), and the size of first occurrence was 30 mm SL. This finding indicates that juveniles may seek deeper water as body size increases and swimming ability improves (Norcross et al., 1974). Alternatively, small bluefish collected with otter trawl tows may have been concentrated in surface waters and were incidentally captured during initial gear deployment and final retrieval (i.e., under conditions when the otter trawl was inadvertently fishing the upper water column). Third, recruitment of juvenile bluefish >50 mm SL to estuarine or coastal habitats is another plausible explanation for their absence in continental shelf waters. As previously mentioned, bluefish actively or passively migrate inshore at 40–80 mm FL (McBride and Conover, 1991; Able et al., 2003). The size at which bluefish enter inshore habitats may be the result of biological timing and morphological constraints. These two factors are consistent with the fact that inshore recruitment co-occurs with a switch in diet from copepods to available piscine prey (Marks and Conover, 1993; Juanes and Conover, 1995). Correspondingly, bluefish may not enter estuaries until swimming ability improves and morphological development is complete, i.e., when fin ray development and scale formation (between 34 and 37 mm SL) are complete (Silverman, 1975). Swimming ability in many fish species dramatically improves after the transformation from larval to juvenile stages (Hunter, 1981; Stobutzki and Bellwood, 1994). If morphological development is coupled with improved swimming ability in bluefish, juveniles most likely have the physical ability to actively recruit to estuarine habitats from inner continental shelf waters (Shima, 1989; Hare and Cowen, 1993, 1996). This study provides cursory evidence that summer-spawned juveniles move inshore during August and early September. Furthermore, the disappearance of bluefish of 25–50 mm SL from continental shelf surface waters coincided with the appearance of somewhat larger fish (~50–60 mm SL) at estuarine and coastal ocean sites in late August and early September.

Along the northeastern coast of the United States (Cape May, New Jersey, to Long Island, New York), ingress of juvenile bluefish to inshore habitats presumably occurs as two distinct episodes (McBride and Conover, 1991 and references therein); which are consistent with intra-annual and bimodal length-frequency distributions. This bimodality in bluefish size-composition is a result of a first cohort recruiting inshore from late May to early June (spring-spawned cohort), and a second cohort entering the same geographic region from July to October (summer-spawned cohort) (Nyman and Conover, 1988; McBride and Conover, 1991; McBride et al., 1993). In our study, the size-composition of bluefish across habitats was multimodal, yet length-based information indicated that the overwhelming majority of YOY bluefish had been summer-spawned. Similarly, recent investigations of the inshore and continental shelf regions of the MAB also documented the numerical dominance of summer-spawned bluefish in late summer and early fall (Able et al., 2003; Conover et al., 2003; Wilber et al., 2003).

Although summer-spawned bluefish presumedly dominated the catches of YOY across all habitats and temporal scales examined in our study, the recruitment success and contribution of these cohorts to year-class strength is unknown. The abundance of these fish, compared to that of spring-spawned individuals, implies that they potentially make important contributions to bluefish year-class strength (Able et al., 2003); yet it is unknown whether the area sampled in this survey is indicative of bluefish abundance along other portions of the U.S. northeastern coast or whether this survey is representative of other years. Moreover, bluefish spawned later in the season (e.g., those encountered on the shelf in late September and October) may not achieve a size permitting either movement into estuaries or successful seasonal migrations. These bluefish, along with relatively small juveniles, may fail to contribute to the adult population because of size-selective mortality and decreased survival during overwintering periods (Hare and Cowen, 1997; Sogard, 1997; Hales and Able, 2001). There is also a consensus that spring-spawned juveniles frequently dominate the emigrating population in the fall, and therefore, are the key contributors to year-class strength (Nyman and Conover, 1988; Chiarella and Conover, 1990; Munch and Conover, 2000). This assertion has been recently contested, however, because other studies have indicated that summer-spawned bluefish contribute equally, if not exceedingly, to the YOY population (Able et al., 2003; Conover et al., 2003; Wilber et al., 2003). It is probable that bluefish population dynamics along the coastal United States are a function of the combined recruitment success of spring- and summer-spawned cohorts and that contributions vary annually or over decadal scales (McBride and Conover, 1991; Munch and Conover, 2000). As a result, future research must focus on broad geographical areas over sufficiently long temporal periods in order to adequately resolve the contribution of the different bluefish cohorts.

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