Recruitment of bluefish *Pomatomus saltatrix* to estuaries of the U.S. South Atlantic Bight*

Richard S. McBride
Rutgers University Marine Field Station
Institute of Marine and Coastal Sciences
P.O. Box 278, Tuckerton, New Jersey 08087

Jeffrey L. Ross
North Carolina Division of Marine Fisheries
P.O. Box 1550, Manteo, North Carolina 27954

David O. Conover
Marine Sciences Research Center
State University of New York
Stony Brook, New York 11794–5000

The bluefish *Pomatomus saltatrix* is a pelagic species that is distributed circumtropically (Briggs 1960, Richards 1965, van der Elst 1976, Fable et al. 1981, Pollock 1984, Lenanton & Potter 1987). Ichthyoplankton surveys off the U.S. east coast indicate three separate spawning concentrations of bluefish, namely (1) a spring-spawned cohort produced between March and May in the South Atlantic Bight (SAB), (2) a summer-spawned cohort originating between June and August in the Middle Atlantic Bight (MAB), and (3) a fall-spawned cohort produced in the SAB between September and January (Norcross et al. 1974, Kendall & Walford 1979, Powles 1981, Collins & Stender 1987).

The abundance of bluefish has fluctuated widely along the Atlantic coast during the past century (Baird 1873, Bigelow & Schroeder 1953). Recently, population abundance increased steadily from the early 1960s to the late 1970s (Gilmore 1985) and remained relatively high during the 1980s (NMFS 1987, 1988). Chiarella & Conover (1990) speculated that increased recruitment success of the spring-spawned cohort is largely responsible for this recent increase in overall bluefish abundance. They demonstrated that bluefish off the New York coast during the 1980s were primarily spring-spawned fish, and this contrasts with a more equal proportion of spring-spawned and summer-spawned fish observed by Lassiter (1962) in the late 1950s, when overall bluefish abundance was lower.

Our understanding of how these three intra-annual cohorts contribute to the overall year-class strength of bluefish along the U.S. Atlantic coast, however, is still unclear. For example, Kendall & Walford (1979) hypothesized that spring-spawned bluefish were transported from the SAB northward into the MAB estuaries, but Collins & Stender (1987) postulated that spring-spawned fish were transported directly inshore to estuaries of the SAB. Otolith analyses of young recruits have confirmed the northerly dispersal of spring-spawned fish as proposed by Kendall & Walford (Nyman & Conover 1988, McBride & Conover 1991), but similar studies of recruitment to SAB estuaries are nonexistent. Length-frequency data for bluefish from SAB estuaries is also sparse, thus it has been difficult to evaluate if bluefish use estuaries in the SAB as nursery grounds. Here we present evidence of recruitment by three cohorts of young-of-the-year (YOY) bluefish to estuaries and nearshore habitats of the SAB.

Materials and methods

Field sampling

Bluefish <360mm fork length (FL) were collected from estuarine poundnet (a summer fishery) and oceanic trawl (a winter fishery) samples taken in North Carolina (Table 1). The upper limit of 360mmFL represents the largest size attained by young bluefish in their first year of life (Lassiter 1962). Additional data were also obtained from a variety of fishery-independent sources of sampling from North Carolina to Florida (Table 1).

Otolith aging

To avoid dissolution, sagittal otoliths were extracted directly in the field, or from frozen or preserved (95% ETOH) fish. Nyman & Conover (1988) validated that daily increments are present in otolith microstructure, and we followed their methods of preparation. Sagittae were chosen randomly from YOY specimens of the large fishery collections. Eight of the total 51 sagittae prepared were determined to be yearling fish and were excluded from further analysis. Daily sagittal increments were counted independently three times, and a mean count was considered valid if the range was <10% of the mean count. If the range was greater (11% of the time), then a fourth count was made and the outlier was discarded.

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Table 1
Sources of bluefish *Pomatomus saltatrix* samples examined in this study. Size range is given as mmFL. Larger datasets (n>500) were used to compile length-frequency distributions, and some fish from 1987–88 were used for otolith analyses. Other samples ($n \leq 13$) were obtained specifically for otolith analyses.

Sampling location	*Gear (size & mesh)*	*Sampling period*	*Sample size*	Bluefish *Length range*	*Source**
N.C. estuaries Pamlico and Core Sounds	Otter trawls (3.2 & 6.1m headrope)	March–November 1979–90	547	21–320	NCDMF (Phalen & Stephan 1984)
N.C. estuaries Pamlico Sound Oliver's Reef	Pound-net fishery (Lead 150mm mesh, Tunnel 50mm mesh)	May–November 1982–85	4484	100–360**	NCDMF
N.C. coast Oregon—Beaufort Inlets 4.5–18.5m depths	Trawl fishery (27–33m headrope 400–1400mm wing mesh 50mm cod end mesh)	November–April 1982–85	4466	150–360**	NCDMF
S.C. coast Stono Inlet	Otter trawl (6.1m headrope)	2 November 1988	1	101	NCDMF
S.C. coast Breech Inlet	1×2m neuston net (2 mm mesh)	April–June 1988	9	39–68	SCWMRD
S.C. North Inlet (Town Creek)	Surface trawl	26 July 1988	13	101–123	USC
Nearshore continental shelf Capes Hatteras—Canaveral 4.9–9.1m depths	Falcon trawl (9.1m Mongoose type, 39–45mm stretch mesh)	May–November 1987–88	2276	80–360**	SEAMAP (Wenner 1989)

* Most data and specimens supplied by the N.C. Dep. Mar. Fish. (NCDMF); additional material from S.C. Wildl. Mar. Resour. Dep. (SCWMRD), Univ. South Carolina (USC) Belle Baruch Lab., and the Southeast Area Monitoring and Assessment Program (SEAMAP).
** Data from these sources were truncated at 360mmFL.

Mean ring count (= daily age) was subtracted from date of capture to estimate birthdate, assuming no lag between birthdate and date of first ring deposition. Average growth rate was calculated as ([FL-2mm]/daily age); a 2mm constant represents the size-at-hatching (Deuel et al. 1966). Growth rate was also calculated using least-squares regression of FL on daily age.

Results

Evidence of spring-spawned juveniles Small bluefish (21–60mmFL) entered North Carolina estuaries in March and April (Fig. 1A). These fish were similar in size to spring-spawned bluefish collected by neuston nets on incoming tides at Breech Inlet (South Carolina) as early as 29 April 1988, and as late as 16 June 1988 (Table 2).

This spring-spawned cohort grew rapidly and recruited to the North Carolina pound-net fishery in July (Fig. 1B). These fish became progressively larger until the fishery ended in October. A July recruitment of spring-spawned fish was also evident in SEAMAP trawling (Fig. 1C).

Bluefish <175mmFL in July were YOY that had been spawned primarily in April (Table 2, Fig. 2). For example, a sample from 29 July 1987 had a mean birthdate of 19 April ± 13d (±1SD), and a sample for 26 July 1988 had a mean birthdate of 26 April ± 12d (Table 2). Bluefish observed in July, but >200mmFL, showed evidence of an overwinter growth mark on their otoliths. Very few specimens of 175–200mm were available for otolith analysis, which precluded a more precise separation of age from size modes. Bluefish juveniles were larger and older in August samples (Table 2). Spring-spawned YOY bluefish grew 1.2–1.9mm/d during this time-period (Fig. 3).

Evidence of summer-spawned juveniles Small bluefish (<150–170mmFL) appeared in North Carolina estuaries and in nearshore continental shelf waters of the SAB in October (Fig. 1). Small bluefish (<150mm) collected near Bogue and Stono Inlets in October and November 1988 had a mid-July birthdate (Table 2,

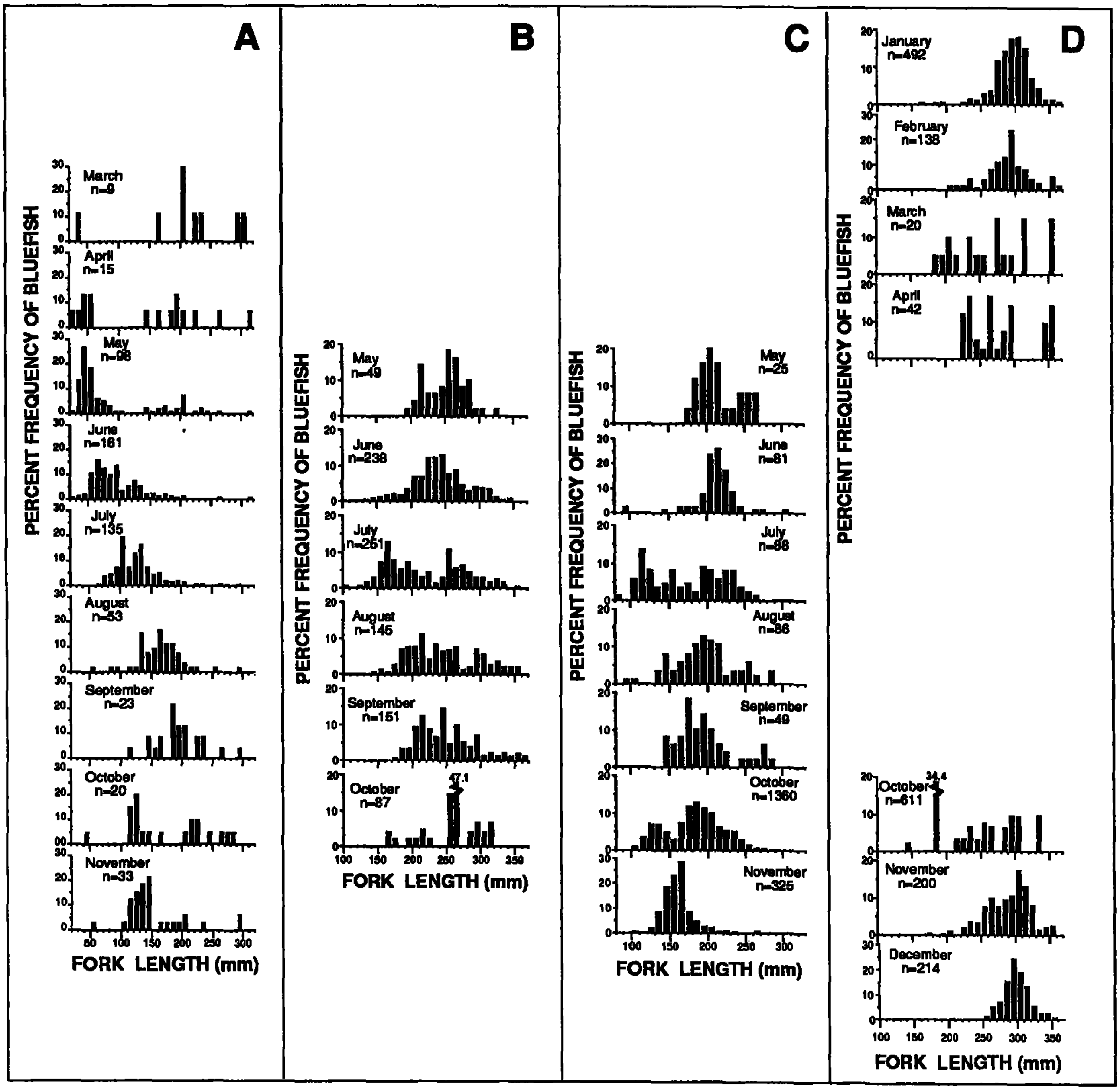

Figure 1

Length-frequency histograms of bluefish *Pomatomus saltatrix* <360mmFL for (A) monthly data pooled over the years 1979–90 from a N.C. Dep. Mar. Fish. trawl survey; (B) 1984 monthly data from the N.C. summer estuarine pound-net fishery; (C) 1988 monthly data from the SEAMAP nearshore trawl survey between N.C. and Florida; and (D) 1984–85 monthly data from the N.C. winter oceanic trawl fishery. Years plotted for the last three data sets are representative of data from other years. Ordinates are either 20 or 30%.

Fig. 2). These summer-spawned fish appeared to reach a size similar to that of spring-spawned fish at a common age (Fig. 3), but because they were spawned 2mo later (on average), they were smaller on common sampling dates (Fig. 1A,B,C).

Evidence of fall-spawned juveniles Winter trawl collections did not contain small juveniles between October and January, despite the expectation of an additional length-mode representing fall-spawned fish (Fig. 1D). There was very little evidence of fall-spawned fish in any of the length-frequency data, except possibly two fish (~40–60mmFL) collected in October and November in North Carolina estuaries (Fig. 1A). Based on otolith ageing, a single specimen collected in August was determined to be 206d old (i.e., with a corresponding birthdate of 9 January) which was unique in relation to all other estimated birthdates in this study

Table 2
Descriptive statistics for 43 aged specimens of juvenile bluefish *Pomatomus saltatrix* collected in North and South Carolina (NC and SC). Fork length (mmFL), age (d), and growth rate (GR; mm/d) are given as means. One standard deviation (SD) is provided where more than one specimen was measured.

Collection date	Location	Mean FL	SD	Mean Age	SD	Mean GR	SD	n
			1987					
15 Jun	Pamlico Sound NC	75		74.0		0.986		1
29 Jul	Pamlico River NC	119.6	14.5	101.3	13.1	1.169	0.134	5
13 Aug	Pamlico Sound NC	208		142.0		1.456		1
17 Aug	Pamlico Sound NC	192		125.3		1.516		1
			1988					
29 Apr	Breech Inlet SC	50.7	3.05	62.4	1.21	0.779	1.147	3
17 May	Breech Inlet SC	40		51.3		0.740		1
16 Jun	Breech Inlet SC	57.8	11.9	51.4	7.53	1.079	0.128	5
26 Jul	North Inlet SC	112.7	6.74	91.8	12.0	1.216	0.102	10
2 Aug	Pamlico Sound NC	159.5	37.0	143.6	8.94	1.088	0.206	4
2 Aug	Pamlico Sound NC	220		206		1.058		1
25 Oct	Bogue Inlet NC	118.2	31.3	103.2	12.3	1.128	0.064	10
2 Nov	Stono Inlet SC	101		110.0		0.900		1

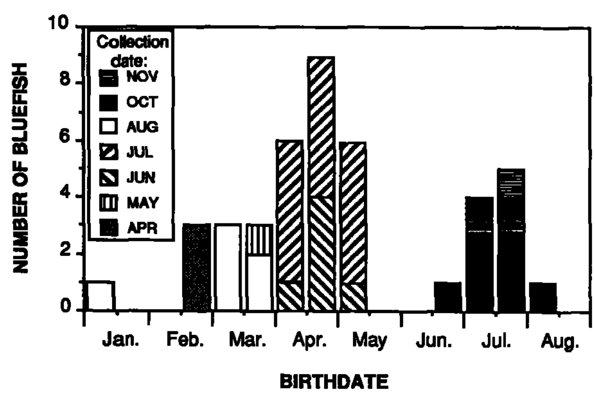

Figure 2
Back-calculated birthdate for 43 YOY bluefish *Pomatomus saltatrix* examined in this study. Date of collection is also shown by month.

(Table 2, Fig. 2) and may have been produced at the tail end of the "fall-spawning" period.

Discussion

Spring-spawned YOY bluefish This cohort recruited to the estuaries of North and South Carolina as early as April and as young as 40d old, and continued to ingress as late as mid-June. Spring-spawned bluefish grew rapidly and appeared in the North Carolina pound-net fishery and in trawls over the nearshore continental shelf in July. Spring-spawned bluefish arrived in SAB estuaries at about the same age (i.e., 40–60d old) but at an earlier first date of estuarine recruitment than in northern estuaries such as New York and New Jersey. Spring-spawned bluefish arrive to the New York Bight no earlier than late May and approximately 60d after hatching (Nyman & Conover 1988, McBride & Conover 1991).

Our findings support Collins & Stender's (1987) hypothesis that at least some spring-spawned YOY bluefish are transported directly inshore and enter estuaries south of Cape Fear. Combined with previous evidence of dispersal north of Cape Hatteras (Nyman & Conover 1988, McBride & Conover 1991), spring-spawned bluefish appear to recruit to estuaries within a broad geographic region encompassing both the SAB and the MAB.

Summer-spawned YOY bluefish This cohort also appeared in estuaries and in nearshore habitats within the SAB. Summer-spawned fish arrived in October at ~100–150mmFL and were generally older than 100d. The presence of these summer-spawned fish in the SAB demonstrates that this cohort migrates from their MAB spawning/nursery grounds into the SAB in the fall. Lund and Maltezos (1970) demonstrated that YOY bluefish tagged in New York migrated to the SAB, but these tagged fish were the larger spring-spawned fish.

Fall-spawned YOY bluefish This cohort was not clearly observed in length-frequency data and, at most,

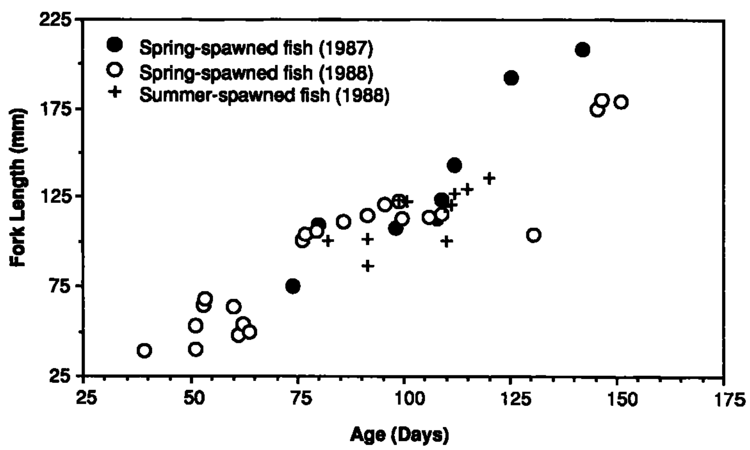

Figure 3
Fork length (FL) as related to daily age of bluefish *Pomatomus saltatrix*, based on samples collected near inlets and within estuaries. Linear regression equations for spring-spawned YOY bluefish were FL= -62.8+1.86(Age) [r^2=0.85] for 1987, and FL= -6.67+1.20(Age) [r^2=0.87] for 1988.

one specimen appeared in our otolith analysis. The winter data used in our study may be inappropriate for sampling fall-spawned bluefish because the trawl fishery uses a large mesh size and fishes in deep water (Table 1). Presumptive fall-spawned YOY fish were uncommon in previous surveys between North Carolina and Florida (Table 3). Wenner & Sedberry (1989) speculated that they had collected fall-spawned fish during January and May trawl collections in nearshore habitat of the SAB, but their interpretation may have been confounded by use of age-length relationships from Wilk (1977). Wilk's growth estimates do not account for inter-cohort differences in size-at-first-annulus or in growth rates (Lassiter 1962, McBride & Conover 1991). Future analysis of age structure of young bluefish in the SAB should focus on this cohort.

Implications for relative contribution of each cohort We observed polymodal length distributions that represented the size difference between spring- and summer-spawned YOY bluefish cohorts during the fall. Barger (1990) reported that bluefish collected in the SAB had a backcalculated mean FL at Annulus-I of 290mm. This size matches the mean FL at Annulus-I reported for spring-spawned fish from North Carolina in the late 1950s (Lassiter 1962). This observation supports the conclusion that the spring-spawned cohort is of dominant abundance relative to the other cohorts, as interpreted by Chiarella & Conover (1990).

Table 3
Total number of young-of-the-year bluefish *Pomatomus saltatrix* collected in various seining studies from North Carolina to Florida. Number of bluefish is given by month, "Years" refers to the duration of each study, and size range is given in parentheses as mmFL (either as reported or as converted using regressions from McBride 1989). Asterisk indicates that length-frequencies were given as 5mm class-intervals. nd = no data. Sampling frequency ranged from biweekly to bimonthly; seine sizes 12.2–21.3m in length. References: (1) Tagatz & Dudley 1961, (2) Anderson et al. 1977, (3) Cupka 1972, (4) Miller & Jorgenson 1969, (5) Futch & Dwinell 1977.

Location (Ref.)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Years
Beaufort NC (1) Ocean Beach	0	0	0	0	1 (46)	0	1 (100)	0	0	7 (65–79)	12 (40–55)	0	1957–60
Beaufort NC (1) Salt Marsh	0	0	0	0	0	0	1 (136)	0	0	0	0	0	1957–60
Beaufort NC (1) River	0	0	1 (120)	0	4 (66–77)	1 (86)	1 (123)	0	0	0	0	0	1957–60
Folly Beach SC (2) Ocean Beach	0	0	0	0	0	1 (104)	1 (137)	0	0	0	0	0	1969–71
Murrells Inlet—Edisto beaches SC (3)	0	0	0	0	0	44 (69–124)	0	0	0	0	0	0	1971
St. Simons I. GA Ocean Beach (4)*	0	3 (66–85)	2 (96–125)	1 (46–50)	7 (36–90)	9 (36–95)	6 (46–70)	3 (96–125)	0	2 (51–60)	0	0	1953–61
Hutchinson I. FL Ocean Beach (5)	2 (325–366)	nd	0	nd	4 (273–317)	nd	3 (42–51)	nd	0	nd	2 (70–367)	nd	1971–73

Fall-spawned fish are the least represented cohort among juveniles and are known mostly from larval surveys (e.g., Kendall & Walford 1979, Collins & Stender 1987). Collins & Stender (1987) reported bluefish larvae <4mm in the SAB to be more abundant in the spring compared with the fall. Other estuarine surveys have collected small bluefish (<100mm) from October–March in the SAB (Table 3) which strongly suggests that at least some fall-spawned fish do recruit to estuaries.

We suggest that the fall-spawned cohort contributes the least, the summer-spawned cohort contributes somewhat more, and the spring-spawned cohort contributes the most to the Atlantic coast bluefish population, at least in recent years. It is not clear why such differences in abundance among cohorts occur nor for how long such differences persist. The spring-spawned cohort may be more abundant because it is spawned at a place and time enabling invasion of estuaries within the SAB, as well as to estuaries as far north as Maine (Targett & McCleave 1974). The fall-spawned cohort may be less abundant, on average, as it is likely to experience colder temperatures and lower food supplies relative to the other cohorts.

Estuaries of the MAB may be more important as nursery grounds for bluefish than are those of the SAB. Summer abundances of spring- and summer-spawned YOY bluefish in New York Bight estuaries are apparently much higher (0.2–6.3 fish/30m seine haul; McBride & Conover 1991) than in the SAB, based on small numbers of bluefish collected during year-long studies in the south (Table 3). Rountree & Able (1992) also found YOY bluefish to be very common (sixth most abundant fish of 63 spp.) in New Jersey marsh creeks, in contrast to much lower relative abundances in similar polyhaline creeks in the SAB (e.g., Cain & Dean 1976). The wide latitudinal distribution and movements of young bluefish, within and between the Middle and South Atlantic Bights, demonstrate the need to monitor and manage bluefish on a large geographic scale (i.e., nearly the entire U.S. Atlantic coast).

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