

**Abstract.**—Larval and tagging studies neither support nor refute the existence of two mid-Atlantic stocks of bluefish, *Pomatomus saltatrix*, one that spawns just south of Hatteras, North Carolina, in the spring, and the other off New England in the summer. Subsequent studies have suggested either a continuous spawning with two survival events, or two distinct spawning events, one in spring south of Hatteras, NC, and a second in mid-summer from Long Island to New England. Genetic studies have supported a single stock because they show the existence of a single gene pool. A stepwise linear discriminant function analysis (DFA) of morphometrics of “spring-spawned” yearling (200–400 mm) and older (>400 mm) bluefish did not classify fish by probable spawning cohort. It did, however separate the yearling fish (200–400 mm) by year class rather than geographic or seasonal spawning. Older fish (>400 mm) showed less separation because multiple (2–10) year classes were present. The DNA studies have revealed genetic homogeneity among these fish. This finding suggests that the morphological characteristics are phenotypically plastic and are influenced each year by the physical environment during spawning and the early juvenile stages.

## Morphometric separation of annual cohorts within mid-Atlantic bluefish, *Pomatomus saltatrix*, using discriminant function analysis\*

Herbert M. Austin

Daniel Scoles

Allison J. Abell

School of Marine Science  
Virginia Institute of Marine Science  
College of William and Mary  
Gloucester Point, Virginia 23062  
E-mail address (for H. M. Austin): [Haustin@vims.edu](mailto:Haustin@vims.edu)

The question of bluefish (*Pomatomus saltatrix*) stock composition along the east coast of the United States has been of considerable interest to fisheries scientists for 30 years and has recently (since 1986) become the focus of discussion by management agencies, primarily the Atlantic States Marine Fisheries Commission (ASMFC) and Mid-Atlantic Fisheries Management Council (MAFMC) (Anonymous, 1989). The problems of managing fisheries when the stock composition and boundaries are unclear have hampered effective management of weakfish, *Cynoscion regalis*, summer flounder, *Paralichthys dentatus*, surf clam, *Spisula solidissima*, and striped bass, *Morone saxatilis* by the ASMFC or MAFMC (or both) because current management practices manage by unit (genetic) stock. Interstate management is further hampered when a unit stock exhibits differential spatial reproduction and migration patterns (e.g. weakfish, Scoles, 1990).

The stock structure of the bluefish (*Pomatomus saltatrix*) in the western mid-Atlantic region is not well understood. Lund (1961) recorded meristic counts of gill rakers along the first branchial arch of young fish and suggested that six separate stocks of bluefish occur

along the western north Atlantic coast of the United States. He later suggested the occurrence of several races in this region on the basis of results of two mark-recapture studies (Beaumariage and Wittich, 1966; Lund and Maltezos, 1970). These results were not supportive of Lund's original six stock concept because they suggested that there might be a “Florida” or “South Atlantic Bight” and a “northern” or “mid-Atlantic Bight” stock. Subsequent analyses of temporal and spatial distributions of bluefish in the ichthyoplankton, and spawning times, suggested two north Atlantic stocks (Norcross et al, 1974; Kendall and Walford, 1979), in addition to a south Atlantic or Florida Stock (Collins and Stender, 1987).

Chiarella and Conover (1990), on the other hand, using back calculations of scales, demonstrated that most spawning in the north mid-Atlantic Bight (MAB) occurs during mid-summer (July) and is composed of spring-spawned fish, both of which suggest a single stock. They also found from back calculations that most yearling fish (260 mm) collected in waters along Long

Island during 1986–87 were spring-spawned. Later, McBride and Conover (1991), looking at young-of-the-year bluefish in the New York Bight during the summers of 1987 and 1988, found two discrete size groups by late summer (150 mm, 75 mm). Their otolith analyses confirmed that the fish represented both spring- and summer-spawned cohorts.

More recent larval studies (Smith et al., 1994; Hare and Cowen, 1993) suggest an alternate hypothesis, that of a continuous wave of spawning by a single stock from off Hatteras in April–May to off Cape Cod or Block Island in June–July with two survival events, one in spring and one later in the summer as a result of oceanographic conditions. These survival events may have led to the previous hypothesis of two distinct spawning events. At any rate, the genetic analyses of Graves et al. (1993), using mtDNA, have shown that progeny from both the spring and summer spawning were of the same stock, and that mid-Atlantic Bight bluefish compose a single genetic stock. The various hypotheses have been revisited by Juanes et al. (1996) in a review of global bluefish early life history.

A characterization of the seasonal movement and spawning of what was then (1977) considered the north Atlantic stocks was summarized by Wilk (1977). Before the advent of routine genetic testing, Wilk (1977) conducted a morphometric analysis of yearling fish from the North Carolina sounds and Middle Atlantic Bight to test the hypothesis that two stocks of bluefish occurred in the mid-Atlantic Bight. The preliminary data, results, and manuscript were lost in the 1984 NMFS/NOAA Sandy Hook Marine Laboratory fire. Wilk did find morphometric differences that were statistically significant (Wilk<sup>1</sup>). If these two geographically separate spawnings are by the same stock, as demonstrated by Graves et al. (1993), but exhibit morphological differences as suggested by Wilk, perhaps due to environmental phenotypic plasticity, then a potentially valuable tool for management exists, particularly if growth, and recruitment or harvest pressure (or both) are different. With this possibility in mind, we conducted a morphometric analysis of bluefish collected in the mid-Atlantic Bight of the U.S. east coast.

## Methods

A total of 1386 bluefish, ranging in size from 93 to 888 mm TL, were collected from April 1987 through

April 1990 from several locations between eastern Long Island, New York, and Beaufort, North Carolina. Samples were pooled on the basis of geography and date-year of collection (Tables 1 and 2). Most were collected from pound and gill nets, but several small fish were taken by 10.8-m (30-ft) otter trawl. The majority of fish over 600 mm TL were collected by hook and line tournament fishermen.

Twenty two morphometric measurements were recorded from the left side of the fish with a meter stick or dial calipers to the nearest millimeter. Names of morphometric variables and abbreviations are provided in Table 3. Scales were removed from under the pectoral fin of each fish, mounted on acetate sheets, and ages were determined with a microfilm reader according to the techniques of Hill and Loesch.<sup>2</sup>

Samples were classified by using stepwise linear discriminant function analysis (DFA) (Fisher, 1936) with SPSS software program (Norusis, 1985). An excellent introduction to the statistics of discriminant analysis is presented by Klecka (1989) in which all assumptions and shortcomings of the methods are discussed. Allometric growth can cause bias, and although it is recognized that it is impossible to remove all allometric bias, Riest (1985), in a review of transformation methods, has offered Thorpe's (1975) as among the best in this situation. Schaefer (1990) and Scoles (1990) also used this technique and found it satisfactory for removing size effects during morphometric analyses of tuna and weakfish.

Consequently, all measurements were transformed following equations taken from Thorpe (1975) where

$$\hat{Y}_i = 10^y$$

$$\hat{Y}_i = \log_{10} Y_i - b(\log_{10} X_i - \log_{10} \bar{X})$$

where  $\hat{Y}_i$  = the adjusted variable of the  $i$ th specimen;  
 $Y_i$  = the variable to be transformed of the  $i$ th specimen;  
 $b$  = the allometric coefficient;  
 $X_i$  = a standard measure of size of the  $i$ th specimen for which fork length was used;  
 and  
 $\bar{X}$  = the grand mean of standard lengths.

A third equation, combining the first two provides

$$\text{Log}_{10} \left[ Y_i / \hat{Y}_i \right] = b \text{Log}_{10} \left[ X_i / \bar{X} \right],$$

<sup>1</sup> Wilk, S. 1989. Sandy Hook Marine Laboratory, National Marine Fisheries Service, NOAA, Sandy Hook, NJ. Personal commun.

<sup>2</sup> Hill, B., and J. Loesch. 1989. Striped bass research in Virginia: characterization of Virginia commercial fisheries. Annual Report 88-89, 22 p. Virginia Institute of Marine Science, P.O. 1346, Gloucester Point, VA 23062.

**Table 1**

Bluefish collection data: date, location, number of fish collected, and gear used in collection. L.I.= Long Island; L.I.S. = Long Island Sound.

Date	Location	<i>n</i>	Gear
10 Mar 1987	Hatteras, NC	8	Gill net
30 Apr 1987	Aberdeen Creek, VA	10	Gill net
30 Apr 1987	Mobjack Bay, VA	21	Gill net
17 May 1987	Chesapeake Bay, VA	32	Hook and line
14 Jul 1987	Hatteras, NC	16	Seine
8 Jul 1987	Mobjack, VA	12	Gill net
2 Oct 1987	New Jersey	11	Trawl
6 Nov 1987	Chesapeake Bay, V	44	Hook and line
12 Apr 1988	Norfolk, VA	20	Gill Net
19 Apr 1988	Rappahannock R.	19	Pound net
1 May 1988	York River, VA	10	Pound net
12 May 1988	York River, VA	1	Pound net
16 Jun 1988	Ches. Bay, VA	58	Hook and line
18 Jul 1988	Pt. Lookout, L.I.	50	Gill net
19 Jul 1988	Peconic Bay, L.I.	24	Gill net
19 Jul 1988	Montauk, L.I.	71	Hook and line
25 Jul 1988	York River, VA	26	Pound net
28 Jul 1988	Hatteras, NC	85	Pound net
3 Aug 1988	York River, VA	8	Pound net
5 Aug 1988	York River, VA	76	Pound net
5 Aug 1988	L.I.S., CT	15	Trawl
9 Sep 1988	L.I.S., CT	171	Trawl
9 Sep. 1988	Potomac R.	69	Hook and line
4 Apr 1989	Pamlico Sound	81	Various
4 Apr 1989	Oregon Inlet, NC	169	Various
15 June 1989	Reedville, VA	86	Hook and line
25 July 1989	New York, NY	51	Various
15 Aug 1989	York River, VA	103	Pound net
9 Sep 1989	Hatteras, NC	42	Pound net

which more clearly shows  $Y_i$  is an estimate of the average  $Y_i$  for an individual of fork length  $X_i$ .

Following transformation, each variable was regressed against fork length (FL). The slope of each transformed variable on FL was zero or insignificant in all cases; therefore effects of allometry were disregarded. The results were plotted for visual inspection of outliers which were removed before subsequent analyses if they were outside the range of biological possibility, and thus suggested measurement error. Consequently, two subgroups of data were developed. The first included bluefish between 200 and 400 mm fork length (yearlings), to remove young-of-the-year from the data which are in the stage of growth most likely to show allometry and to dupli-

cate the size range used by Wilk and Walford in 1964 (Wilk, 1977). The second group included bluefish greater than 400 mm fork length.

The linear discriminant function used here is of the form

$$D = B_1 X_1 + B_2 X_2 + B_3 X_3 + \dots + B_n X_n + C$$

and is similar to a multiple linear regression

where  $D$  = the discriminant function that characterizes each reference group;  
 $X_n$ 's = the independent variables (individual measurements) selected at in a step-wise fashion; and

Table 2

Discriminant function analysis sample groupings by location, year, and size category. Ches Bay = Chesapeake Bay.

Group	Year	ID number	Sample size and length range (mm, in parentheses)	
			200–400 mm	>400 mm
Summer Hatteras	1987	1	14 (303–382)	2 (417–441)
Summer Ches Bay	1987	2	10 (258–316)	37 (448–884)
Spring Hatteras	1987	3	—	8 (684–765)
Spring Ches Bay	1987	4	15 (325–385)	30 (801–852)
Summer Ches Bay	1988	5	11 (225–382)	106 (570–830)
Summer Long Isl.	1988	6	7 (219–395)	174 (555–811)
Spring VA Coast	1988	7	—	13 (471–731)
Spring Ches Bay	1988	8	—	26 (471–757)
Summer Ches Bay	1988	9	104 (245–291)	—
Summer Hatteras	1988	10	85 (235–321)	—
Spring Hatteras	1989	11	42 (357–398)	101 (477–784)
Summer Ches Bay	1989	12	128 (215–352)	51 (405–525)
Summer Long Isl.	1989	13	—	44 (418–734)
Summer Hatteras	1989	14	—	29 (412–516)
Spring Pamlico	1989	15	71 (357–398)	7 (402–715)
Spring Ches Bay	1990	16	26 <sup>1</sup>	30 <sup>1</sup>
			524 (215–398)	658 (402–884)

<sup>1</sup> Length data lost.

Table 3

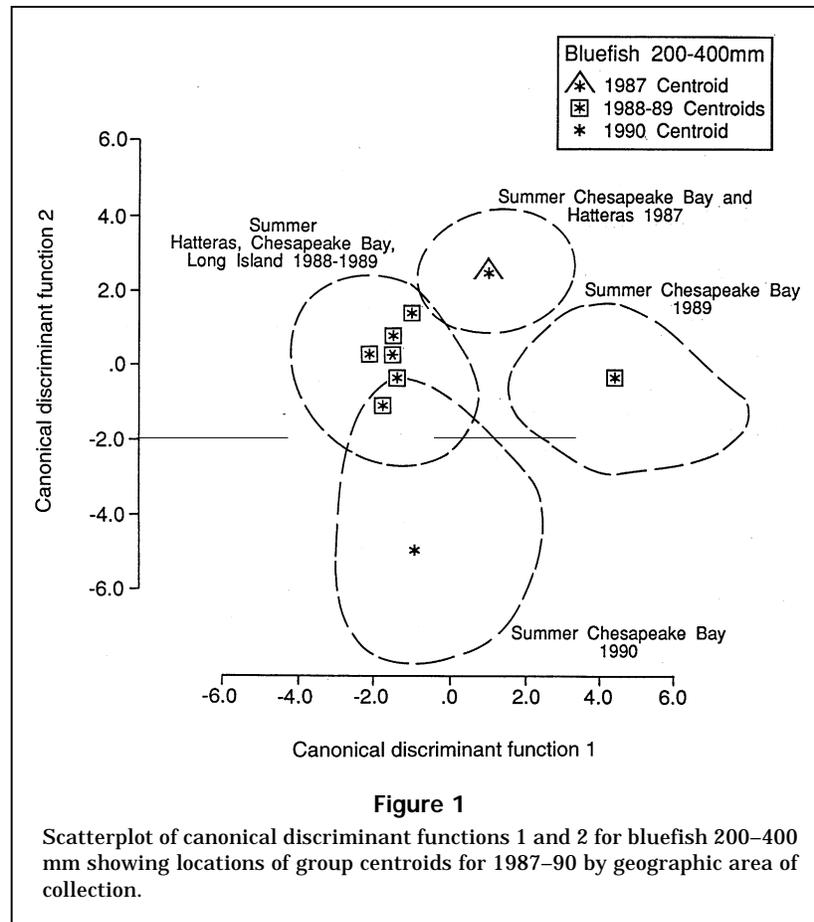
List of morphometric measurements on bluefish. Abbreviations and name of variable are those used in text.

Abbreviation	Description
PMX	Premaxilla
MAX	Maxilla
IOB	Interorbital
POB	Postorbital
POP	Preoperculum ("cheek")
OPC	Operculum
HDP	Head depth
PCO	Pectoral fin origin
PCI	Pectoral fin insertion
PLO	Pelvic fin origin
PLI	Pelvic fin insertion
VNT	Vent
AFO	Anal fin origin
AFI	Anal fin insertion
D1O	First dorsal fin origin
D1I	First dorsal fin insertion
D2O	Second dorsal fin origin
D2I	Second dorsal fin insertion
GTH	Girth
TOL	Total length
FKL	Fork length
STL	Standard length
DSP	First and second dorsal space

 $B_n$ 's = the coefficients or "unstandardized function coefficients"; and

 $C$  = a constant.

Initially we intended to follow the 1960s methods of Wilk (1977) by assigning a spring-southern and summer-northern *a priori* reference designation. We were unable however, to collect a reference group of spring- and summer-spawned yearling bluefish. From the length frequencies of the yearling fish (211–382 mm) that we collected, it appeared that all were "spring-spawned" (Chiarella and Conover, 1990). As a result we made no effort *a priori* to separate "spring-spawned" from "summer-spawned" yearling fish on the basis of scale back calculations as Chiarella and Conover (1990) had done but assumed all were spring-spawned. *A priori* assignment of reference or learning groups is often used to determine the discriminant function which is then used to classify the individuals of known origin to one or the other reference groups. If, however, more than two stocks are present, the individuals of the third stock will be "force fitted" into one of the reference groups. Rather than forcing *a priori* assignments of two groups, and to identify possible additional stocks (from the south [McBride et al. 1993]) or morphometrically distinct



groups as Wilk (1977) found, we conducted the DFA without *a priori* assignments.

Finally, an unweighted paired group method (UPGM) of clustering with arithmetic averages, a form of cluster analysis, was run to examine the relative distance between group centroids. Centroids that appear in a cluster are morphologically similar.

## Results

The first five canonical functions are listed because they carry the analysis through the 95% cumulative percentage for fish 200–400 mm (Tables 4 and 5); seven functions are included for the fish >400 mm; however, the eigenvalues (Tables 5 and 6) show that only the first two functions are important in each case. The discriminant scores and centroids from functions 1 and 2 were plotted against each other to develop a graphic representation of the relationship among groups (Figs. 1 and 2).

Wilk's 1960's (1977) analysis found that the inter-dorsal space was a discriminating character. To provide a comparison, we computed an "inter-dorsal

**Table 4**

Summary of stepwise discriminant function analysis for 16 groups and 16 morphometric characters. Fish were 200–400 mm FL. See Table 3 for definitions of variables.

Step no.	Variable entered	Wilk's lambda	Minimum		
			<i>P</i>	<i>D</i>	<i>P</i>
1	PLI	0.44335	<0.0001	0.00764	0.8081
2	HDP	0.34477	<0.0001	0.23817	0.2317
3	MAX	0.25160	<0.0001	0.65660	<0.0001
4	DSP	0.16585	<0.0001	0.87455	0.0001
5	IOB	0.13113	<0.0001	1.20062	<0.0001
6	OPC	0.12388	<0.0001	1.29810	<0.0001
7	PCO	0.10184	<0.0001	1.44335	<0.0001
8	AFO	0.09450	<0.0001	1.47319	<0.0001
9	D2I	0.08292	<0.0001	1.55493	<0.0001
10	D1O	0.07776	<0.0001	1.62040	<0.0001
11	AFI	0.07325	<0.0001	1.67691	<0.0001
12	POB	0.06806	<0.0001	1.69120	<0.0001
13	POP	0.06544	<0.0001	1.70979	<0.0001
14	PMX	0.05928	<0.0001	1.72065	<0.0001
15	PLO	0.05329	<0.0001	1.72103	0.0001
16	D1I	0.04386	<0.0001	1.72130	0.0001

**Table 5**  
Summary of first five canonical discriminant functions. Fish were 200–400 mm FL.

Function	Eigenvalue	Cumulative percent	Canonical correlation	Wilk's lambda	Chi squared	df	<i>P</i>
1	2.29051	48.91	0.834324	0.15912	935.6	150	<0.0001
2	1.16710	73.84	0.733863	0.34483	541.6	126	<0.0001
3	0.54375	85.45	0.593486	0.53234	320.9	104	<0.0001
4	0.28451	91.53	0.470633	0.68379	193.5	84	<0.0001
5	0.14586	94.64	0.356785	0.78354	124.2	66	<0.0001

**Table 6**  
Summary of the first seven canonical discriminant functions. Fish were >400 mm FL.

Function	Eigenvalue	Cumulative percent	Canonical correlation	Wilk's lambda	Chi squared	df	<i>P</i>
1	1.4858	42.4	0.77312	0.1880	1072.9	180	<0.0001
2	0.8153	65.6	0.67016	0.3413	690.1	154	<0.0001
3	0.4462	78.4	0.55546	0.4936	453.2	130	<0.0001
4	0.2595	85.8	0.45387	0.6217	305.1	108	<0.0001
5	0.1682	90.6	0.37945	0.7263	205.3	88	<0.0001
6	0.0900	93.1	0.27740	0.7917	149.9	70	<0.0001
7	0.0769	95.4	0.26722	0.8526	102.4	54	<0.0001

**Table 7**

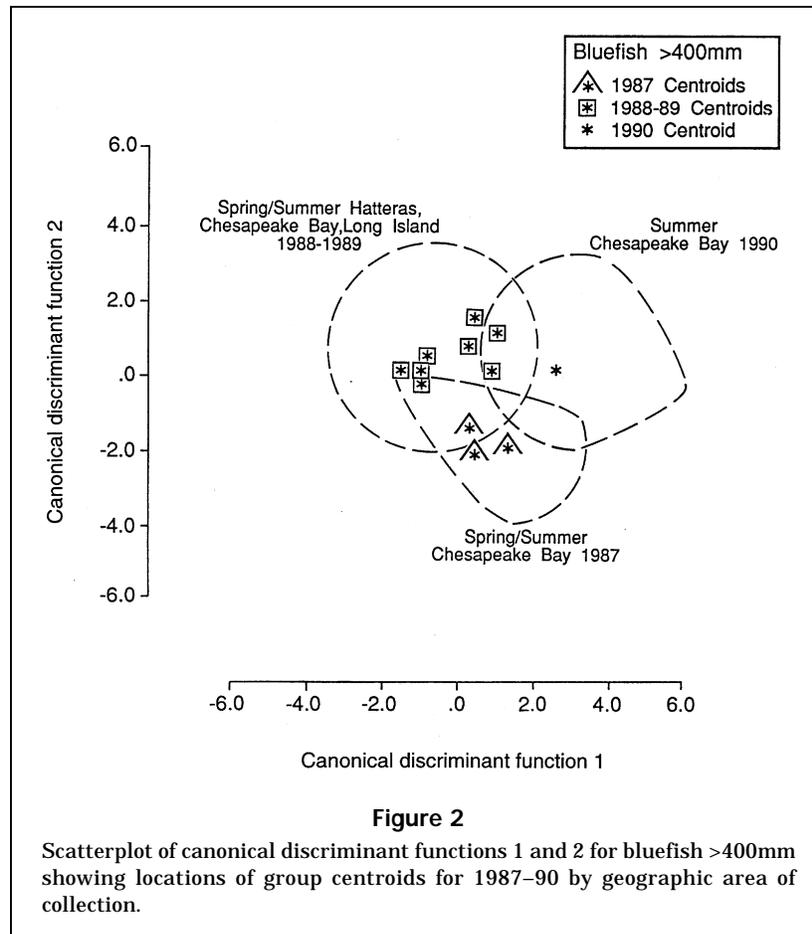
Summary of stepwise discriminant function analysis for 16 groups and 16 morphometric characters. Fish were >400 mm FL. See Table 3 for definitions of variables.

Step no.	Variable entered	Wilk's lambda	Minimum		
			<i>P</i>	<i>D</i>	<i>P</i>
1	D1I	0.7177	<0.0001	0.0007	0.9364
2	POP	0.6367	<0.0001	0.0288	0.8088
3	PLO	0.4628	<0.0001	0.2543	0.0520
4	DSP	0.4326	<0.0001	0.4455	0.1638
5	HDP	0.2946	<0.0001	0.6365	0.0008
6	AFO	0.2645	<0.0001	0.7851	0.0237
7	PCO	0.2483	<0.0001	0.8786	0.0225
8	PLI	0.1813	<0.0001	1.0243	<0.0001
9	D1O	0.1653	<0.0001	1.2288	<0.0001
10	POB	0.1323	<0.0001	1.2774	<0.0001
11	IOB	0.1090	<0.0001	1.3481	<0.0001
12	D2I	0.1025	<0.0001	1.4211	<0.0001
13	OPC	0.0994	<0.0001	1.4769	<0.0001
14	MAX	0.0996	<0.0001	1.5093	<0.0001
15	PMX	0.0776	<0.0001	1.5274	<0.0001
16	AFI	0.0756	<0.0001	1.5402	<0.0001

space" term (DSP), as the difference between the first dorsal insertion (D1I) less the second dorsal origin (D2O). When the analysis was run with this new variable (DSP), it was selected as an important term in the functions (Tables 4 and 9).

The centroids for yearling fish do not fall into two classes, which would have suggested either a geographic north-south or temporal spring-summer spawned classification (Fig. 1); rather they fall into three clusters of cohorts by year class, regardless of geography of collection site (Table 10). For example, collections during 1987 at Hatteras, North Carolina, and Chesapeake Bay, Virginia (the 1986 year class), are separate and distinct from both the 1988 and 1989 collections (1987 and 1988 year classes) and also from the Hatteras and Chesapeake Bay collections. Further, the 1989 collections (1988 year class) were classified into two groups, one of which was the same as the 1988 collection. The 1990 collection (1989 year class) fell in between 1988 and 1989, overlapping both.

The centroids of the large fish (>400 mm), a mixture of up to 10 year classes in a sample, showed little geographic, temporal, or year-class classification (Fig. 2).



## Discussion

Several authors (Nyman and Conover, 1988; McBride, 1989; Simpson et al., 1990) working in the Long Island region and analyzing length-frequency data, reported exclusively spring-spawned young-of-the-year during 1985-86. Both spring-spawned and some late arriving summer-spawned young-of-the-year were collected there in 1987, and then a shift occurred to predominantly summer-spawned fish during the summer-fall of 1988.

Because ratios continued to be similar for the yearling fish in our collections and because length frequencies were also similar, our 1987 samples from Hatteras and the Chesapeake Bay were apparently from the predominantly spring-spawned 1986 year class. Our 1988 samples, the 1987 year class, were also predominantly spring spawned but were classified morphologically separate from the 1986 year class.

Our 1989 samples (the 1988 year class) from Hatteras, Chesapeake Bay, and Long Island showed a split classification, some the same as our 1988

samples (the 1987 year class) and the rest, separate from both 1987 and 1988 year classes. The 1990 samples, from a dominant 1989 year class, collected in the Chesapeake Bay, overlapped slightly between the 1987 and 1988 year classes (Fig. 1).

If the shift from spring-spawned to summer-spawned young-of-the-year noted by the above authors for Long Island holds for Chesapeake-Hatteras yearling fish, then the morphologically distinct 1986 year class from our 1987 collections was composed of spring-spawned fish. The 1988-90 collections of the 1987-89 year classes, may be a mix of spring- and summer-spawned fish but show no separation. As stated earlier, however, our length frequencies of yearling fish in all years (1987-90) suggest that our samples were all spring-spawned fish (Table 2). An alternate explanation is that the morphologically distinct yearling fish, representing separate year classes or annual cohorts, and spawned in differing environments each year are demonstrating environmental or phenotypic plasticity. That is, that their morphological characters are environmentally determined and are different each year.

Table 8

Canonical discriminant function coefficients linear discriminant equation (Norusis, 1985):  $D = B_0 + B_1X_1 + B_2X_2 + B_3X_3 \dots B_nX_n$ . See Table 3 for definitions of variables.

Variable	Unstandardized function coefficients			
	200-400 mm FL function		>400 mm FL function	
	1	2	1	2
PMX	-11.3805	-7.5218	-5.8925	-27.9831
MAX	1.2972	4.1059	8.0311	30.1133
IOB	11.3277	-0.4940	2.0227	24.8566
POB	-6.1778	-18.1707	-5.7929	-45.9063
POP	6.1848	4.7921	-5.1122	25.7729
OPC	-26.3362	6.4774	-2.5250	-29.3489
HDP	-0.6669	29.7938	26.4669	17.4505
PCO	36.7537	-2.9036	1.8195	-20.8899
PLO	10.1294	-13.7243	20.1050	-4.4471
PLI	26.8615	31.4590	-57.1219	26.6134
AFO	-31.2089	8.5720	42.9709	-2.0460
AFI	31.6723	35.3519	-24.5871	12.8353
D10	4.0019	-3.4074	-35.3567	-8.2396
D11	12.8394	-22.4628	48.7193	-14.1872
DSP	0.2674	3.7165	1.3185	1.3386
D2I	32.9298	-6.5686	3.9964	39.1365
CONSTANT	-212.7263	-118.6822	-45.9465	-78.7146

The larger fish in this study are a composite of at least ten year classes (2–11 years); therefore separation or classification would be expected to be less precise. Indeed there was considerable overlap in classification of the larger fish (Table 10).

From results of the DFA, and in light of the back calculations of Chiarella and Conover (1990) and the genetic data of Graves et al. (1993), it would appear that there is only one stock of bluefish in the mid-Atlantic Bight and that the morphometric differences among bluefish cohorts are a result of phenotypic plasticity. Because the environment at the time of spawning and juvenile development varies geographically and interannually, so too will morphometric features. As the fish grow, their plastic morphological characters, expressed as an index of character length versus fish length, become less and less reliable; when year classes mix, as in our >400 mm sample, they provide no discriminant characterization unless separated by individual year class.

Although a single genetic stock, the two MAB cohorts (spring- and summer-spawned), may exhibit interannual differential recruitment success and survival to yearlings. In addition, the reported differ-

Table 9

Canonical discriminant function group centroid means. \* = no collections from this size group

Group	200–400 mm		>400 mm	
	Function 1	Function 2	Function 1	Function 2
1	-1.1747	-2.4628	2.2954	-4.1523
2	-1.8353	-4.8299	-0.7644	-2.2536
3		*	-0.9446	0.5734
4	-1.4581	-2.4707	-0.4563	-2.1051
5	0.2588	1.6696	0.9954	0.6740
6	-0.4975	0.3665	1.3013	-0.0488
7		*	0.8351	-0.6780
8		*	1.4361	-0.1726
9	-1.4280	-0.0648		*
10	-1.0596	0.8962		*
11	-0.7187	1.0913	-0.0650	0.3479
12	2.2186	-0.3778	-1.1776	0.1391
13		*	-1.5116	0.4816
14	2.7864	1.0578	-1.3068	1.6483
15	-0.2675	0.3093	-0.7993	0.5799
16	1.1706	-0.0615	-1.9122	0.4894

ences in growth, seasons and location of spawning, migration routes, and variations in fishing mortality along the MAB can complicate management efforts if the two cohorts are managed as a single stock. Even for a single mid-Atlantic genetic stock, recruitment variations between spring and summer cohorts may be significant, year to year, and consideration should be given to monitoring the annual contribution of the spring-spawned and summer-spawned cohorts as the stock may be healthier when the spring-spawned predominate for several years running (Chiarella and Conover, 1990). The morphometric separation by year class provides evidence that the environment likely affects bluefish size and shape; this may prove to be a useful tool in separating yearling bluefish by the geographic area in which they spent their first year of development.

## Conclusions

Previous larval and tagging studies neither support nor refute the existence of one or more MAB bluefish stocks, one that spawns just south of Hatteras, North Carolina, in the spring and the other off New England in the summer. The mtDNA analysis by Graves et al. (1993) suggests that there is one mid-Atlantic stock which from our results produces several environmentally induced morphotypes.

Table 10

Classification results by geographic area and year for fish 200–400 mm FL and fish >400 mm FL. SU = Summer; SP = Spring; HA = Hatteras; CB = Chesapeake Bay; LI = Long Island; PS = Pamlico Sound, NC.

Group	Group number	n	Predicted group membership (%)															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
200–400 mm FL																		
SU/HA/87	1	14	64	7						7			7			14		
SU/CB/87	2	10		100														
SP/CB/87	4	15	7		47						27	13				7		
SU/CB/88	5	11				46						27				9	18	
SU/LI/88	6	7			29	14				29			14				14	
SU/CB/88	9	104	1			1				76	14	3				3	2	
SU/HA/88	10	85			1					19	61	7	1				11	
SP/HA/89	11	42								2	36	55	2				5	
SU/CB/89	12	128			1					5	2	2	79		2	3	6	
SU/HA/89	14	11											64		27		9	
SP/PS/89	15	71								13	16	1	1				69	
SU/CB/90	16	26	4							4	4	15					4	69
>400 mm FL																		
SU/HA/87	1	2	100															
SU/CB/87	2	37		73		14		8						3				3
SP/HA/87	3	8			88								12					
SP/CB/87	4	30		13		70	7	7		3								
SU/CB/88	5	106				1	53	26		2			9	4		1	1	3
SU/LI/88	6	174		1			8	76	1	1			12	1	1	1		
SU/VC/88	7	13						54	39					7				
SP/CB/88	8	26		4		4	8	27	8	35			15					
SP/HA/89	11	101		2			2	5	1	3			66	7	6	5		4
SP/CB/89	12	51		2		4	4	6	2				33	35	6	6	2	
SU/LI/89	13	44		2	2	2							41	5	41	5		2
SU/HA/89	14	29					10						10		4	69		7
SU/PS/89	15	7												14				86
SU/CB/90	16	30		7					3				11	12	7	7		47

## Acknowledgments

We wish to acknowledge the field assistance of Ana Beardsley and Jan McDowell, as well as the officials of the various Virginia bluefish tournaments that made samples available to us. Critical review was provided by John Graves and Jack Musick of VIMS. The most helpful comments of an anonymous reviewer strengthened the manuscript and we are most grateful to this anonymous colleague. The work was supported by a grant to the Virginia Institute of Marine Science from the U. S. Fish and Wildlife Service, through the Virginia Marine Resources Commission, grant number F-60-R.

## Literature cited

### Anonymous.

1989. Bluefish Fisheries Management Plan, Atlantic States Marine Fisheries Commission, Wash., D.C., 54 p.

### Beaumariage, D., and A. Wittich.

1966. Returns from the 1964 Schlitz tagging program, Florida. Board Cons. Tech. Ser. 47, 50 p. Florida Dep. Natural Resources, St. Petersburg, FL.

### Chiarella, L. A., and D. O. Conover.

1990. Spawning season and first-year growth of adult bluefish from the New York Bight. Trans. Am. Fish. Soc. 119:455–462.

### Collins, M. R. and B. W. Stender.

1988. Larval king mackerel (*Scomberomorus cavalla*), Spanish mackerel (*S. maculatus*), and bluefish (*Pomatomus*

*saltatrix*) off the southeast coast of the United States, 1973–1980. *Bull. Mar. Sci.*, 41:822–834.

**Fisher, R.**

1936. The use of multiple measurements in taxonomic problems. *Ann.-Eugenics* 7:179–188.

**Graves, J. E., J. R. McDowell, A. M. Beardsley, and D. R. Scoles.**

1993. Population genetic structure of the bluefish, *Pomatomus saltatrix*, in Atlantic coastal waters. *Fish. Bull.* 90:469–475.

**Hare, J. A., and R. K. Cowen.**

1993. Ecological and evolutionary implications of the larval transport and reproductive strategy of bluefish, *Pomatomus saltatrix*. *Mar. Ecol. Prog. Ser.* 98:1–16.

**Juanes, F., J. A. Hare, and A. G. Miskiewicz.**

1996. Comparing early life history strategies of *Pomatomus saltatrix*: a global approach. *Mar. Freshwater Res.* 47:365–379.

**Kendall, A., and L. Walford.**

1979. Sources and distribution of bluefish, *Pomatomus saltatrix*, larvae and juveniles off the east coast of the United States. *Fish. Bull.* 77(1):213–227.

**Klecka, W. R.**

1989. Discriminant analysis. Series: Quantitative applications in the social sciences. Sage Publ., Inc., Thousand Oaks, CA, 70 p.

**Lund, W.**

1961. A racial investigation of bluefish, *Pomatomus saltatrix* of the Atlantic Coast of North America. *Bol. del Inst'o. Oceanog. Venezuela* 1(1):73–129.

**Lund, W., and G. Maltezos.**

1970. Movements and migrations of the bluefish, *Pomatomus saltatrix* tagged in waters of New York and southern New England. *Trans. Am. Fish. Soc.*, 99(4):719–725.

**McBride, R. S.**

1989. Comparative growth and abundance of spring- versus summer- spawned young-of-the-year bluefish, *Pomatomus saltatrix*, recruiting to the New York Bight. M.S. thesis submitted to the State Univ. of New York at Stony Brook, NY, 56 p.

**McBride, R. S., and D. O. Conover.**

1990. Recruitment of young-of-the-year bluefish *Pomatomus saltatrix* to the New York Bight: variation in abundance and growth of spring- and summer-spawned cohorts. *Mar. Ecol. Prog. Ser.* 78:205–216.

**McBride, R. S., J. L. Ross, and D. O. Conover.**

1993. Recruitment of bluefish *Pomatomus saltatrix* to es-

tuaries of the U.S. South Atlantic Bight. *Fish. Bull.* 91:389–395.

**Norcross, J. J., S. L. Richardson, W. Massman, and E. Joseph.**

1974. Development of young bluefish, *Pomatomus saltatrix* and distribution of eggs and young in Virginia waters. *Trans. Am. Fish. Soc.* 103(3):477–497.

**Norusis, M.**

1985. SPSS advanced users guide. SPSS Inc., Chicago, IL, 474 p.

**Nyman, R. M., and D. O. Conover.**

1988. The relation between spawning season and the recruitment of young-of-the-year bluefish, *Pomatomus saltatrix*, to New York. *Fish. Bull.* 86(2):237–250.

**Riest, J. D.**

1985. An empirical evaluation of several univariate methods that adjust for size variation in morphometric data. *Can. J. Zool.* 63:1429–1439.

**Schaefer, K. M.**

1990. Geographic variation in morphometric characters and gill-raker counts of yellowfin tuna, *Thunnus albacares*, from the Pacific Ocean. *Fish. Bull.* 89:289–297.

**Scoles, D. R.**

1990. Stock identification of weakfish, *Cynoscion regalis*, by discriminant function analysis of morphometric characteristics. M.S. thesis submitted to the College of William and Mary, School of Marine Science, Virginia Institute of Marine Science, Gloucester Point, VA 23062, 51 p.

**Simpson, D. G., P. T. Howell, and M. W. Johnson.**

1990. Assessment of bluefish in Long Island Sound with reference to the coastwide stock. Section 2, job 6 in A study of marine recreational fisheries in Connecticut., p 83–104. Connecticut Dep. Environ. Cons., Hartford, CT.

**Smith, W., P. Berrien, and T. Pottoff.**

1994. Spawning patterns of bluefish, *Pomatomus saltatrix*, in the northeast continental shelf ecosystem. *Bull. Mar. Sci.* 54(1):8–16.

**Thorpe, R. S.**

1975. Quantitative handling of characters useful in snake systematics with particular reference to intraspecific variation in the ringed snake, *Natrix natrix*. *Biol. J. Linn. Soc.* 7:27–43.

**Wilk, S.**

1977. Biological and fisheries data on bluefish, *Pomatomus saltatrix*. U.S. Dep. Commer., NMFS/NOAA, Tech. Ser. Rep. 11, 55 p.