Abstract—Bluefish (*Pomatomus saltatrix*) were tagged and released in Atlantic coastal areas between Massachusetts and Florida from 1963 through 2003 as part of a National Marine Fisheries Service (NMFS) project and a volunteer program sponsored by the American Littoral Society (ALS). A total of 15,699 bluefish were tagged by NMFS and 20,398 by ALS volunteers and 4.3% (1075 NMFS tags and 464 ALS tags) were recaptured and reported. Time-at-large was limited; 65.8% of the recaptured tags were returned within two months of tagging, although nineteen of the returned tags remained at large for two years or more. Tag returns indicated seasonal migrations of fish between the Middle Atlantic Bight and Florida. Three groups of bluefish are proposed for Atlantic coastal waters on the basis of tag return data and are defined by the seasonal occurrence of fish between 30 and 45 cm fork length. The northern group occupied the area from Massachusetts to Delaware between late spring and late fall. Bluefish in the central region between Maryland and North Carolina represented a combination of seasonal transient and resident fish, as did the southern group in Florida. Mixing occurs among all three groups; and larger fish (>45 cm) spend winters in offshore areas. Estimates of von Bertalanffy growth parameters from tagging data were comparable to scale-based estimates. Swimming speeds between point of release and recapture averaged 2.6 km per day, and seasonal spikes greater than 5 km per day corresponded with periods of migration in spring and autumn.

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The migration patterns of bluefish (*Pomatomus saltatrix*) along the Atlantic coast determined from tag recoveries

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Bluefish (*Pomatomus saltatrix*) is a pelagic species with a worldwide distribution in temperate and subtropical oceans. In the United States, bluefish are found along the Atlantic coast from southern Florida to Cape Cod, Massachusetts, and occasionally as far north as Nova Scotia (Collette and Klein-MacPhee, 2002). The broad-scale seasonal movements of bluefish are known within the commercial and recreational fishing communities (Hersey, 1987), but details of the migratory pattern remain poorly documented in the scientific literature. Tagging studies provide the most direct evidence of seasonal movements, but the only published account for the Atlantic coast stock is a study in Long Island Sound by Lund and Maltezos (1970). Wilk (1977) provided a description of bluefish migration that remains the accepted standard and which was based on seasonal distribution of commercial and recreational catches, as well as on unpublished results of a tagging project conducted during the 1960s by David Deuel and colleagues at the NMFS James. J. Howard Marine Sciences Laboratory (formerly known as the Sandy Hook Marine Laboratory). The proposed migration involved a north–south coastal movement between New York–New Jersey offshore waters and southeastern Florida offshore waters during the fall and a return spring migration along the same route. Larger fish (i.e. greater than three pounds) were believed to follow a more offshore pathway.

The identification of distinct bluefish stocks contributing to this migratory group has been the subject of multiple investigations. The racial composition of bluefish on the Atlantic coast was investigated by Lund (1961) who concluded, primarily from differences in the number of gill rakers of small bluefish, that six races existed along the coast. Lassiter (1962) found differences in first year growth on scales, which indicated that two groups of fish inhabited North Carolina waters. Returned tags from bluefish tagged in the Long Island area

(Lund and Maltezos, 1970) also indicated two distinct stocks, although not necessarily the same groups as defined by Lassiter (1962). More recently, some scientists have concluded that either two distinct spawning groups exist (Norcross et al., 1974; Kendall and Walford, 1979) or one stock with two distinct survival periods (Hare and Cowen, 1993; Smith et al., 1994). Others, probing mitochondrial DNA (mtDNA) (Graves et al., 1993), have concluded that Atlantic coast bluefish constitute a single population. A discriminant function analysis of morphometric data has corroborated the one stock hypothesis despite evidence of phenotypically plastic characteristics (Austin et al., 1999).

Mark-recapture experiments provide an empirical method for evaluating both migratory behavior and stock composition. In 1962, the National Marine Fisheries Service (NMFS) initiated a study of the migratory patterns of bluefish to obtain information on the population structure of the Atlantic coast stock; this coastwide tagging program continued until 1967. The American Littoral Society (ALS) also coordinates an annual tagging program by private citizens that has resulted in 20 years of tag releases for a variety of species, including bluefish. This combined tag-recapture information constitutes the largest known tagging database for this species. The goal of our study was to investigate the migratory behavior of bluefish along the Atlantic coast by using the results of these previously unpublished tagging studies and to examine the single stock hypothesis in context of tag recovery information.

Materials and methods

The NMFS bluefish tagging program used several types of tags (variously colored). Field tests in 1963 indicated that a dorsal loop spaghetti tag would be more suitable, owing to a longer retention rate, than dart tags or jaw tags. This loop tag, described by Watson (1963), was closed with a pressure-fitted V-shaped clip. In addition, two other types of dorsal loop tags (both closed by knotting the ends of the tubing, and one having a clear outer covering) and an internal anchor tag (5/16 by 1-1/4 inches, with a 3″ streamer as described by Topp [1963]) were used. For visibility of the tags to fishermen, orange was chosen as the color for most of the dorsal loop tags and yellow for the streamer of the internal anchor tags. The fork length of each fish tagged and released was measured to the nearest cm. Recapture information was mailed to NMFS in Sandy Hook, NJ, and included data on recapture location, recapture date, fish length (usually in inches), and weight (lbs and oz, when possible).

The ALS program uses yellow dorsal loop tags that are inserted with a hollow needle through the muscle below the dorsal fins and tied with a simple overhand knot or, as in some recent tags, fastened with a snap-lock mechanism (Carlsen, 2000). Details on the date, location of release, fork length (to the nearest inch), and weight (lbs and oz, when possible) were furnished by the fishermen at the time of release. Information regarding tag recapture (including location, recapture date, fish length [inch] and weight) was mailed to ALS headquarters by the fishermen and the distance of the recapture location from shore was coded as inland, inshore (≤3 miles), or offshore (>3 miles). Not all tags recaptured in the ALS program were reported with complete details. As a result, some of the sample sizes presented in the present study differ among analyses, depending on the available data of the recaptured tags. Also, in order to standardize data from both programs and to minimize precision error resulting from unit conversions, fish length data are presented in centimeters followed by the inch equivalent rounded to the nearest whole number.

Several types of fishing gear were used to capture bluefish in the NMFS tagging program. Fish were captured by using gill nets deployed from research vessels, hook and line, commercially operated pound nets, and beach seines; bluefish tagged in the ALS program were captured with hook and line.

Bluefish tagged in the NMFS program were released in areas of seasonal abundance from southeastern Florida to Massachusetts, and major tagging efforts were made in southern Florida, North Carolina, Virginia, New Jersey, and New York (Fig.1). ALS tag releases were concentrated in the New York–New Jersey area, although tagging occurred from Florida to New England (Fig.1). Each ALS recapture location was categorized into 1 of 59 geographic areas and was assigned a latitude and longitude based on the center point of the recapture area. NMFS recaptures were assigned latitude and longitude coordinates based directly on recapture location.

Distance (km) traveled was calculated as the great circle distance between the point of release and point of recapture (NMML[1]) and there was a suitable waypoint if the pathway traversed land. Swimming speed was calculated as the linear distance traveled divided by days at large. In order to allow for acclimation to the presence of the tag, fish recovered within the first three days of release were not included in analyses. Additionally, because speed calculations were influenced by the number of days at large, speed estimates per two-month increments were restricted to tags recovered within 30-day periods to minimize recoveries spanning several months and to avoid averaging speed over various migratory phases. Swimming speeds were compared among months by using an analysis of variance (ANOVA) (Zar, 1974). Comparison of movements by size was made for 5-cm length classes to reduce potential bias from measurement error of recaptured fish.

Bluefish growth was modeled by using the change in fork length during the time-at-large. Von Bertalanffy growth curve parameters L_∞ and K were calculated by using the Fabens model (Fabens, 1965):

[1] NMML (National Marine Mammal Laboratory). 2004. Excel geometry functions. Website: http://nmml.afsc.noaa.gov/Software/ExcelGeoFunctions/excelgeofunc.htm [accessed 4 October 2004].

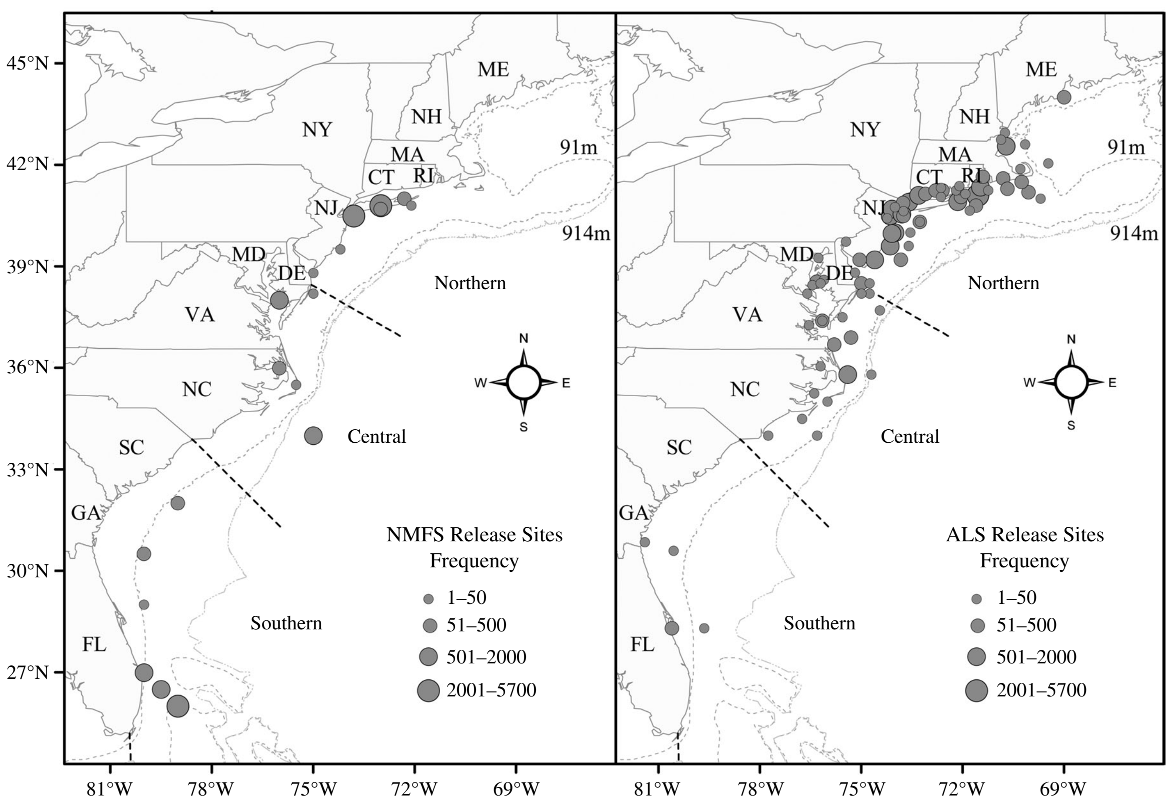

Figure 1

Distribution of release sites (by region) for bluefish (*Pomatomus saltatrix*) released during National Marine Fisheries Service (NMFS) (1963–1967) and American Littoral Society (ALS) (1983–2003) tagging programs.

$$L_{r,i} = L_{t,i} + (L_\infty - L_{t,i})(1 - e^{-K\Delta t_i}),$$

where $L_{r,i}$ = length at time of recapture;
$L_{t,i}$ = length at time of release; and
Δt_i = change in time (years) between release and recapture.

Parameter estimates were derived by using the SAS NONLIN procedure (SAS Inst., Inc., Cary NC). ALS and NMFS data were modeled separately because of a difference in the resolution of size measurements at release (centimeters for NMFS and inches for ALS). Bluefish at large less than 14 days, or fish with zero or negative growth, were excluded from the calculations.

Geographic distributions for tag recoveries were compared with commercial catch locations of bluefish reported from the Middle Atlantic Bight. NMFS vessel logbooks from commercial fishermen in the Northeast region contain information about landings, discards, and the spatial location of catch. Bluefish catch locations from 2001 to 2003 were summarized by month for all gear types. Length samples (measured to the nearest cm) collected by NMFS port agents from commercial landings were expanded to represent length distributions of total reported landings.

Results

During 1963 to 1967, the NMFS bluefish project tagged and released 15,699 bluefish; of these, 11,624 fish (74.0%) were captured with gill nets, 1393 (8.8%) with hook and line, 907 (5.8%) from beach seines, and 1775 (11.3%) from pound nets. Included in the hook-and-line total were 224 fish tagged by volunteer sportsmen in south Florida, New Jersey and New York (which resulted in 17 recaptures). The number of bluefish tagged and released are summarized by month and area in Table 1. From 1983 to 2003, recreational hook-and-line fishermen in the ALS tagging program caught and released 20,398 bluefish. Later recaptures totaled 1539 fish, of which 1075 were NMFS tagged and 464 were ALS tagged.

The NMFS rate of tag return varied by capture method, tag type, and tagging area. The highest return rates (9.6 %) were from pound net releases that could be attributed, in part, to a high recapture rate immediately after tagging. The second highest percentage (6.9 %) and largest number of recaptures (802) were fish captured with gillnets. Although only 4.7% of the fish released from hook-and-line gear were returned, over half of these released fish were from the first year of the tagging program (775 fish tagged, 16 returned, 2.1%),

Table 1

Number of bluefish (*Pomatomus saltatrix*) tags released by month and location of National Marine Fisheries Service (NMFS) and American Littoral Society (ALS) programs.

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
NMFS														
North	New England								4	26				30
	New York						196	31	1082	1859	150			3318
	north New Jersey						614	614	2651	1811				5690
	south New Jersey						3	1	4					
Central	Maryland						20							20
	Virginia					964	4							968
	North Carolina					127	274	40	57	43	569			1110
South	South Carolina				60	19								79
	north Florida				335	335								
	south Florida	510	572	1199	1008						100	425	331	4145
	Total	510	572	1199	1403	1110	1111	686	3794	3739	819	425	331	15,699
ALS														
North	New England	1	1		3	124	846	1233	1470	1845	1410	440	1	7374
	New York				3	368	803	568	568	661	1143	323	2	4439
	north New Jersey				76	1383	1181	814	956	961	837	411	22	6641
	south New Jersey					4	90	18	18	25	26	11		192
Central	Maryland					35	66	21	35	32	63	5	2	259
	Virginia				8	153	122	8	6	3	5	18	14	337
	North Carolina				11	21	6	4	14	10	421	124	26	637
South	South Carolina													
	Georgia				7	2		1	3	2	2	1		18
	Florida	122	43	59	93	24	1	5	2	9	23	20	100	501
	Total	123	44	59	201	2114	3115	2672	3072	3548	3930	1353	167	20,398

whereas the remainder of the hook-and-line releases (618 fish) resulted in 49 recaptured fish (7.9%). This difference may be attributable to less effective tags used during 1963, rather than the capture method. All ALS releases were fish caught with hook and line, but gear type was not recorded for the recaptured fish.

Tag types differed in rates of return and in time fish spent at large. Return rates for NMFS tags were similar between dorsal loop tags (760 of 10,752; 7.1%) and internal anchor tags (310 of 4441; 7.0%). All NMFS tagged fish recaptured after 17 months at liberty had been tagged with internal anchor tags. Abrasion of some dorsal tags occurred after two months and appeared more severe on tags returned from Florida releases. Some abrasion occurred on the external streamer of the internal anchor tags. ALS dorsal loop tags resulted in an overall return rate of 2.2%.

Return rates for the NMFS tags varied by area, from 4.5% in New York to 10.2% from Florida (Table 2). Eighty-three percent of recaptured tags that were at liberty one year (n=24) were from tagging in areas north of New Jersey, and all recaptured tags at liberty 2, 3, and 4 years (10, 4, and 4 fish recaptured, respectively) were also from tagging in these areas (Table 2). For all areas combined, 51.3% of the NMFS recaptured fish were at liberty less than one month and 88.1% were at liberty less than five months. Among ALS tags, 50.3% were at liberty for two months and 79.3% for five months or less. Only 4.5% of all returned fish were at liberty greater than one year and 1.2% greater than two years. The longest time-at-large for an ALS tagged bluefish was 1461 days and 1486 days for a NMFS-tagged fish.

The size at release of the 36,097 tagged bluefish differed between the two programs. Fork lengths (FL) ranged from 19 to 57 cm (7 to 22 inch) for NMFS and 15 to 114 cm (6 to 45 inch) for ALS (Fig. 2). The majority of fish released in the NMFS program (83.1%) were 30 to 45 cm (12 to 18 inch) and were 1-, 2-, or 3-year-olds according to estimates determined from scales from a subsample of similar size fish collected during the tagging operations. A greater size range of bluefish were tagged in the ALS program, and 88.2% measured 30 to 76 cm (12 to 30 inch).

Size frequencies of bluefish released, and of those subsequently recaptured, differed despite the relatively short times at large (Fig. 2). Changes in length can be attributed to growth, unit conversion, and associated measurement error. The NMFS recapture data set had 616 tag recoveries with appropriate fork length and time-at-large information, whereas the ALS set had 336 with these data (Fig. 3). The von Bertalanfy growth parameter estimates from these data were L_∞ of 100 cm and 118 cm (39 and 46 inch) for NMFS and

Table 2

Number of bluefish (*Pomatomus saltatrix*) tags returned from each release area by months at liberty. ALS = American Littoral Society; NMFS = National Marine Fisheries Service; NE = New England; NY = New York; NJ = New Jersey; MD = Maryland; VA = Virginia; NC = North Carolina; SC = South Carolina; FL = Florida.

	ALS							NMFS									
Month	NE	NY	NJ	MD	VA	NC	FL	NE	NY	NJ	VA	NC	SC	FL	ALS total	NMFS total	Combined total
0	20	48	40	3	3	2	9	1	36	178	34	37	2	265	125	552	677
1	32	30	38		1	2	3		30	68	9	17	2	102	106	229	335
2	20	27	24		4		3		5	32	7	6	1	43	78	94	172
3	7	15	14				3		7	10	4	4		22	39	47	86
4	5	5	6						3	4	6	2		10	16	25	41
5	3	3	1							4	3	3		4	7	14	21
6	2	1	1						4	1		1		3	4	9	13
7	3	7	1		1					1	2				12	3	15
8	4	12	2						3	3		1		1	18	8	26
9	1	6							8	3				1	7	12	19
10	4	5	4						13	4		1			13	18	31
11	1	5	2						12	6	1			2	8	21	29
12	1	5	3		1				6			1		1	10	8	18
13	2	3							6	3				1	5	10	15
14	1		1						1	2					2	3	5
15		1													1	0	1
16		1									1				1	1	2
17											1				0	1	1
18															0	0	0
19														1	0	1	1
20									1						0	1	1
21															0	0	0
22	2								1						2	1	3
23	1								3						0	3	3
24									3						1	3	4
25+	3	1						1	7	3					4	11	15
No. recaptured	112	175	137	3	10	4	18	2	149	322	68	73	5	456	459	1075	1534
No. released	7374	4439	6833	259	337	637	519	30	3318	5694	968	1110	79	4480	20,398	15,699	36,097
Return rate	2%	4%	2%	1%	3%	1%	3%	7%	4%	6%	7%	7%	6%	10%	2%	7%	4%

ALS, respectively, and K values of 0.230 and 0.206, respectively. The 95% confidence interval around L_∞ for the NMFS data ranged from 79 to 121 cm (31 to 48 inch) and ALS estimates ranged from 95 to 141 cm (37 to 56 inch). Confidence intervals for the K parameter ranged from 0.135 to 0.324 for the NMFS data and 0.109 to 0.303 for the ALS data.

A single vector drawn between tag release and recapture locations represents the shortest possible water route traveled between the two points. The actual route of travel likely diverts from this path; however it remains the basis for determining distance traveled. Movement of bluefish between western Long Island Sound and lower New York Bay through the East River was not indicated by the tag return data, and therefore passage of bluefish through the East River was not considered in the distance calculations. Seventy-five percent of the NMFS tags were recaptured within 100 km of the tagging location; whereas 9.7% were caught 350 km or farther from the tagging area. The maximum distance traveled was 2227 km (Chesapeake Bay to west Florida) for a fish at liberty 341 days (6.5 km per day). For the ALS recaptured fish, 59.7% were recaptured within 100 km of the point of release and 40.3% (187) traveled beyond 100 km averaging 295 km, and 45 bluefish traveled more than 400 km. The maximum distance was 1096 km for a fish at liberty for 76 days (14.4 km/day).

The number of days at liberty represents the maximum time possible for a fish to travel the straight-line distance between the tagging and recapture locations. Movement was generally less than 5 km per day (84.3% of recaptures) and the overall average speed of fish recaptured in both programs was 2.6 km per day. Seventeen bluefish traveled more than 20 km per day and had a maximum swimming speed of 48.3 km per day for three days.

The average swimming speeds for combined NMFS and ALS recaptured fish were significantly different among months (P=0.02). Speeds were highest during the autumn, peaking during October–November at 5.3 km per day, and there was another spike during April–May at 4.9 km per day (Fig. 4). These seasonal peaks were in contrast to the overall average of 2.6 km per day. Seasonal variations in swimming speed were considered indicative of periods of active migratory behavior. This annual cycle of movement was divided into four periods based on the average rate of travel for each month: winter residency (December to February), spring migration (March to May), summer residency (June to August), and autumn migration (September to November).

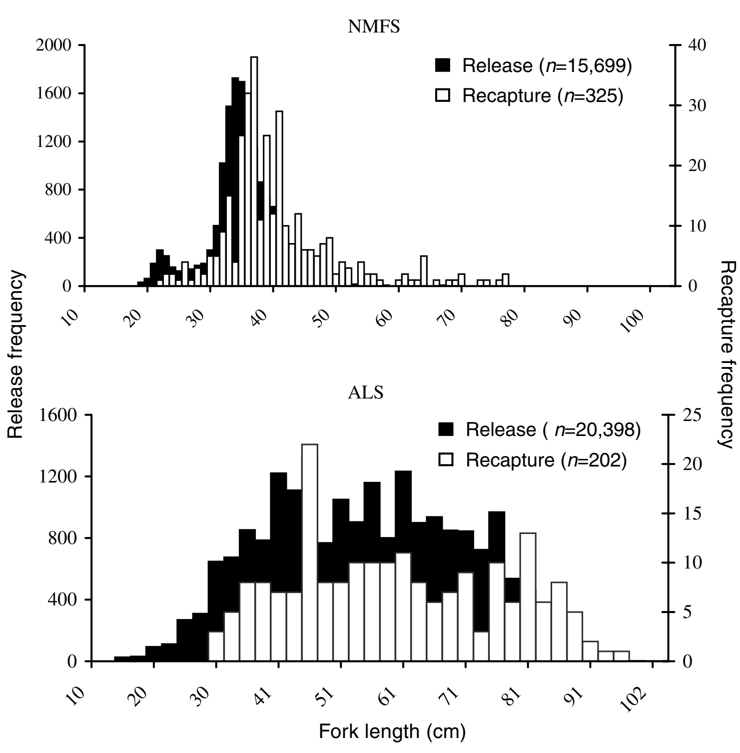

Figure 2

Frequency distributions for release and recapture fork lengths of bluefish (*Pomatomus saltatrix*) sampled in National Marine Fisheries Service (NMFS) and American Littoral Society (ALS) tagging programs.

The swimming speed and distance traveled during seasonal movements were different for all bluefish size groups. Swimming speed of fish 30–45 cm (12–18 inch) was greater than speed of fish 45–65 cm (18–26 inch) and this pattern was consistent across regions (Fig. 5). The speed disparity by size was influenced by the distance traveled, not by differences in time-at-large because the data were limited to recoveries within 90 days. Smaller bluefish, particularly those released in the northern region, traveled farther distances on average than fish in the larger size classes (Fig. 5).

Movement of tagged fish among areas is a function of both the behavior of the animal and adequate time-at-large to exercise that behavior. Half (229 of 459 fish with location information) of bluefish tagged with ALS tags were recaptured beyond the state of release; the remaining recaptured fish were caught in the area of release (Table 3). NMFS releases had a higher proportion recaptured bluefish within the state of release (77.1%; Table 3). Most long distance returns occurred during the first year after tagging; recoveries in years 1 through 4 after tagging were generally from the area of release (62 of 100) or in the release area and adjacent areas (91 of 100). Fish recaptured from New Jersey northward accounted for 89 of the 100 recaptured fish after one year at liberty, and all but two of these were from releases in this area. The higher percentage of recaptured fish from Florida may reflect greater annual fishing effort in contrast to northern areas.

Seasonal recaptures of tagged bluefish along the coast (Fig. 6) were a function of both fishing effort and the abundance of tagged fish in the area. Over ninety-one percent of all recaptured NMFS fish (978 of 1,075) were caught in inshore areas (including Chesapeake Bay, Delaware Bay, and Long Island Sound) or within one mile of the coast. Of the remaining 99 recaptures: one fish was caught 75 miles offshore and the rest within 30 miles of the coast; 47 between 1 and 6 miles, 40 between 6 and 20 miles, and 9 between 20 and 30 miles. Tagged fish released in New York and New Jersey accounted for 45 of the 50 returns over 6 miles offshore; 4 of those remaining fish were both released and recaptured off Florida, and the last fish had been released in Florida and recaptured off New Jersey. All of these 45 returns released from New York and New Jersey were recovered north of Delaware—most off New Jersey and New York. The offshore returns occurred from May through November, although most of the fall recaptured fish had been released during the same season (21 of the 23 recaptures in September, October, and November), whereas most spring and summer recaptured fish had been at liberty for at least one year (19 of the 22 recaptures from May though July).

Seasonal patterns of bluefish migration, determined from information within recovered tags, generally followed one of three patterns: north–south between the northern Middle-Atlantic and Florida; a north–south pattern within the Middle-Atlantic; and year round movements between inshore and offshore Florida. To simplify examination of migration patterns, recapture locations were divided into three regions. The area from Delaware to New England was designated the northern region, Maryland through North Carolina as the central region, and the area between South Carolina and southern Florida as the southern region. The single fish recovered in western Florida was ignored for our analysis. A recovery matrix by region showed that greater than 90% of the bluefish recaptured within the northern or southern region had originated within the same region (Table 4). However, within the central region, the percentage of recaptured fish originating in that region was only 80.3%. The remaining tags were either recaptured to the north (12.7%) or the south (7.0%). Distribution maps

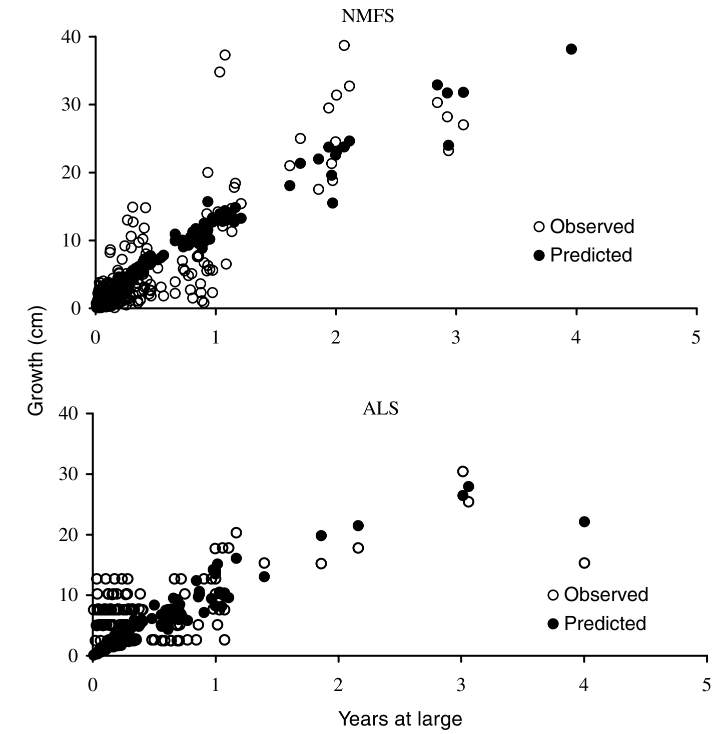

Figure 3

Changes (observed and predicted) in fork length during time at large (years) for bluefish (*Pomatomus saltatrix*) sampled in National Marine Fisheries Service (NMFS) and American Littoral Society (ALS) tagging programs.

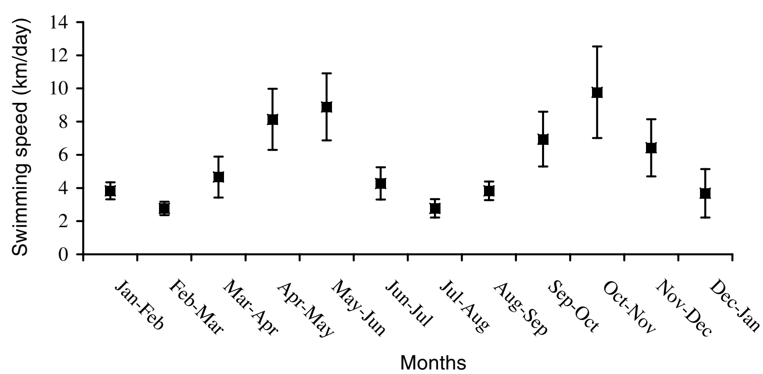

Figure 4

Mean monthly swimming speeds (km/day) of bluefish (*Pomatomus saltatrix*) ±95% confidence intervals from two combined program tag recoveries: National Marine Fisheries Service (1963–1967) and American Littoral Society (1983–2003).

of seasonal recaptured fish (Fig. 6) further highlighted the pattern of a northerly migration that began in May and was followed by southerly migration beginning in December. However, the entire coastal stock did not make the seasonal shift. Bluefish released in southern Florida were recaptured locally during the summer residency period and other fish tagged in southern Florida appeared in coastal New Jersey (Table 3).

Seasonal distribution data from bluefish tag returns indicated a southward movement of fish during the fall, culminating in an over-wintering aggregation near Cape Hatteras, North Carolina, and to the south. Commercial catch records from the Middle Atlantic for 2001 to 2003 indicated a greater seasonal inshore-offshore movement than that implied from tag recoveries. Vessel logbook data indicated that bluefish are present in the northern and central areas throughout the winter and have an increasingly offshore and southern distribution as water temperatures decrease. By March, the commercial catches increase off the coasts of Virginia and North Carolina (Fig. 7). The sizes of fish in these commercial catches were generally larger than those of tagged fish; lengths were between 25 and 70 cm and mean size was 45 cm. The commercial catch distribution expanded northward beginning in April, in a direction similar to the bluefish migratory route indicated by spring tag returns.

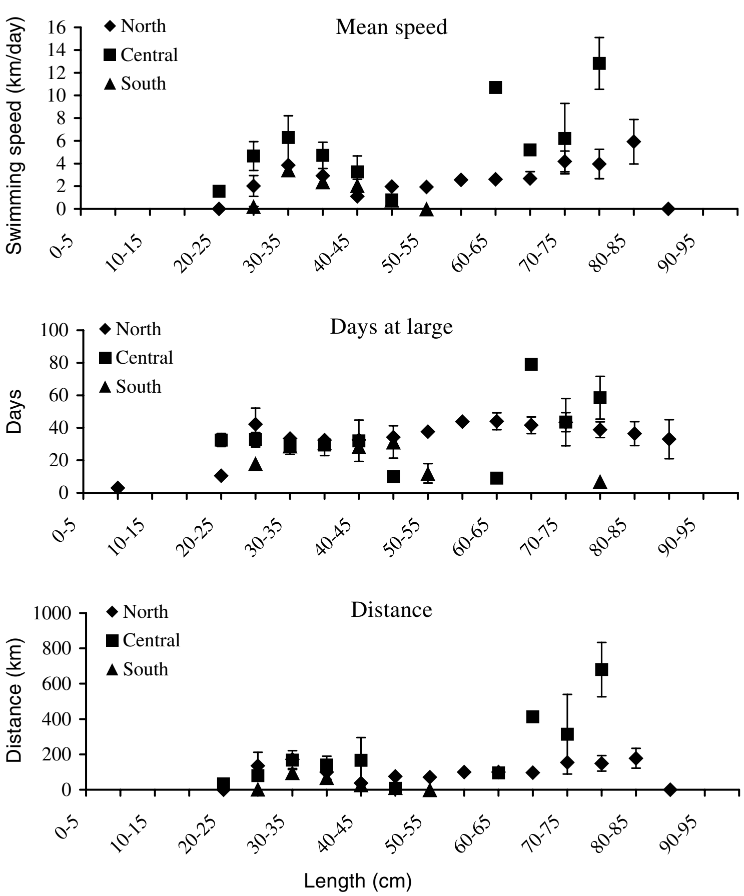

Figure 5

Mean swimming speed, days at large, and distance traveled (±95% confidence interval) by length for bluefish (*Pomatomus saltatrix*) sampled in National Marine Fisheries Service and American Littoral Society tagging programs.

Discussion

A generally established hypothesis for bluefish migration is that fish undergo a seasonal coastal migration, leaving the Mid-Atlantic Bight in autumn as water temperatures decrease and moving as far south as Florida. In spring, bluefish return north where they spend the warmer months in habitat suitable for larger, mature fish—possibly in habitat extending across the continental shelf (Wilk, 1977; Fahay et al., 1999). Our hypothesis expands that migration pattern to suggest there are three bodies of fish with different migration behaviors. One group has an extensive north–south migration between New England and Florida, a second group has a migration route within the Mid-Atlantic Bight bounded to the south by North Carolina, and a third group has an inshore-offshore migration within Florida waters. The geographic ranges of these three groups overlap during at least part of the year and the seasonal areas of distributions change with fish size.

Bluefish from Massachusetts to Delaware (northern region) leave the coastal areas in autumn, and fish less than approximately 45 cm (18 inch) migrate south along the coast and are found in the south Florida winter fishery. However, tag return data indicate that part of this size group, as well as all fish over 45 cm (18 inch), move offshore in autumn and are distributed during winter in offshore areas south of Virginia. Both size groups return to the northern area in spring and summer a year after tagging, as well as in successive years.

The Mid-Atlantic area from Maryland to North Carolina (central region) appears to be a transitional area in the migratory route. A group of fish tagged in the northern region migrated in fall to the central region and remained throughout the winter, whereas other fish continued south to Florida. In the spring, a portion of the Florida fish moved back to the central region, while others continued through to the northern region. The distribution of commercial catches reported in logbooks confirmed the movement of bluefish into offshore waters during autumn, and movement increasingly south as winter progresses. The reported landings of large

Table 3

Recapture matrix by state of release for National Marine Fisheries Service (NMFS) and American Littoral Society (ALS) bluefish (*Pomatomus saltatrix*) tag recoveries. NE = New England; NY = New York; NJ = New Jersey; DE/ME = Maine; MD = Maryland; VA = Virginia; NC = North Carolina; SC = South Carolina; FL = Florida.

NMFS	Recapture area										
Release area	NE	NY	north NJ	south NJ	DE/MD	VA	NC	SC	north FL	south FL	west FL
New England		2									
NY	2	96	33	4	1		3		3	7	
north NJ	2	25	210	31	8	2	32		6	6	
south NJ											
DE/MD											
VA			4	1	1	53	5	1		2	1
NC		2	3	1	4	56			5	2	
SC		1	4								
north FL									37		
south FL			3	2	1				36	377	

ALS	Recapture area										
Release area	ME	MA	RI	CT	NY	NJ	DE	MD	VA	NC	FL
AL											
ME		1									
MA		12	3	5		9	1	2	1	3	
RI		8	20	22	16	5		1		4	
CT		5	2	20	18	1	1			1	
NY		7	2	16	82	17	3			3	
NJ		3	3	13	25	65	10	4	2	5	
DE					1		4		1	1	
MD								3			
VA	1	1	1	2	1	2		1		1	
NC										4	
FL											19

bluefish fish during the Virginia–North Carolina winter fishery and the paucity of bluefish over 45 cm (18 inch) in the Florida fishery indicate that the larger fish do not continue the southern migration beyond North Carolina.

Bluefish are found throughout the summer in southern Florida (southern region) as evidenced by tag returns and fishery landings, although at a low level of abundance compared with fall through spring landings. The one fall recaptured tag in New Jersey from a fish released in Florida in the spring (at liberty 17 months) indicates that fish from the southern group are found in northern areas in subsequent years. Bluefish found off Georgia and South Carolina appear to be transitory, and are present primarily in spring and fall. The relative lack of tag recoveries in coastal South Carolina and Georgia implies a migratory pathway farther offshore, possibly closer to the shelf edge and Gulf Stream.

Change in fish size leads to a change in the seasonal migration route. The migratory groups are best defined

Table 4

Tag recovery matrix by region for combined National Marine Fisheries Service and American Littoral Society tags; data correspond to tag release and recaptures shown in Figure 6.

	Recapture region			
Release region	North	Central	South	Recaptures
North	812 (90%)	67 (7%)	22 (2%)	901
Central	20 (12%)	127 (80%)	11 (6%)	158
South	7 (1%)	4 (1%)	469 (98%)	480
Recaptures	839	198	502	1539

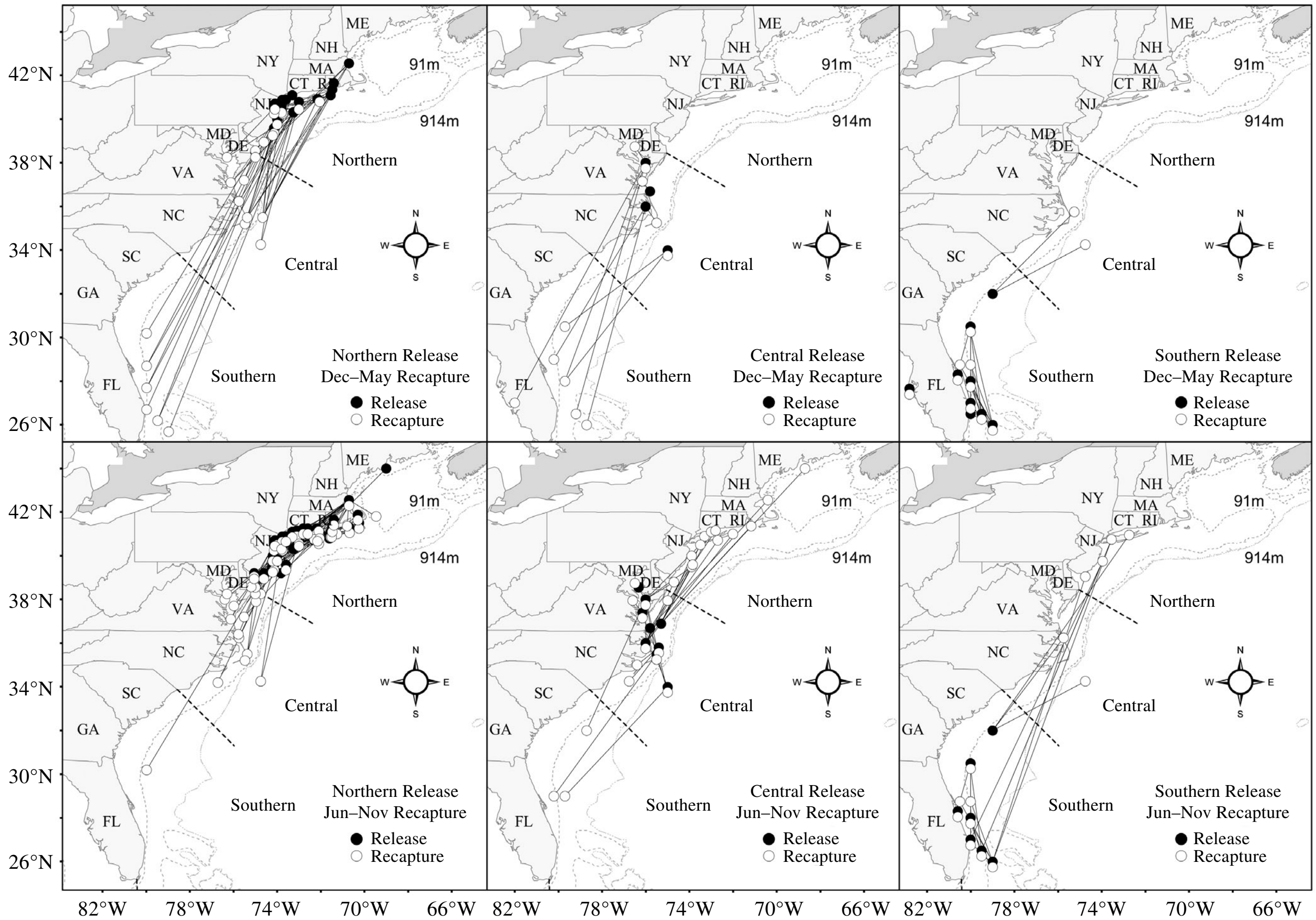

Figure 6

Geographic distribution of tag recoveries, by region of release and season of recapture, for bluefish (*Pomatomus saltatrix*) sampled in National Marine Fisheries Service (NMFS) and American Littoral Society (ALS) tagging programs combined.

by the seasonal aggregations of smaller fish (less than approximately 45 cm, 18 inch FL). Juvenile bluefish use a coastal migratory route that extends farther south and offshore with increasing size. Some fish past the juvenile stage may remain in Florida for a season while others return to northern areas in the first or second spring. As growth continues, north–south migration routes become truncated—replaced by a route that keeps fish within the Mid-Atlantic Bight circuit.

Because migration patterns appear to be size related, growth rate will determine how long individuals maintain a particular migration behavior. Tag-based growth rate estimates (K=0.23 and 0.21) are similar to values reported from scale-based age studies, but the tag model resulted in larger theoretical maximum sizes of 100 and 118 cm (39 to 46 inch). Salerno et al. (2001) reported an average L_∞ value of 87 cm and K equal to 0.26, whereas previously published estimates range from 67 to 128 cm (Lassiter, 1962; Wilk, 1977) and have K values ranging from 0.10 to 0.34 (Lassiter, 1962; Wilk 1977). The tag-based estimates of maximum size are similar in size to that of the largest fish reported in recreational landings (Salerno et al., 2001) and size of this largest fish caught in recreational landings could be considered an empirical estimate of L_∞. Otoliths have been shown to be preferable to scales for aging bluefish (Sipe and Chittenden, 2002). Growth parameters of bluefish from the South Atlantic, aged from otoliths (L_∞=101.9 cm, K=0.10 [Barger, 1990]), compare well with our tag-based estimates of L_∞, but produce very different growth-rate estimates.

The migration route bluefish follow from coastal New England to southern Florida, a distance of potentially >2000 km, is completed over the course of several months. Bluefish held in aquaria have been shown to travel at speeds from 40 to 60 cm/s and to have burst speeds up to 80–110 cm/s (Olla et al., 1970). An approximate average speed for bluefish similar in size to those tagged in the present study would be between 39 km per day (40 cm/s) and 59 km/day (60 cm/s). The majority of tagged fish moved between 0 and 5 km per day (84%), and most (97%) bluefish swam less than 20 km/day. However, several individuals averaged between 55 and 111 km per day. An average swimming speed

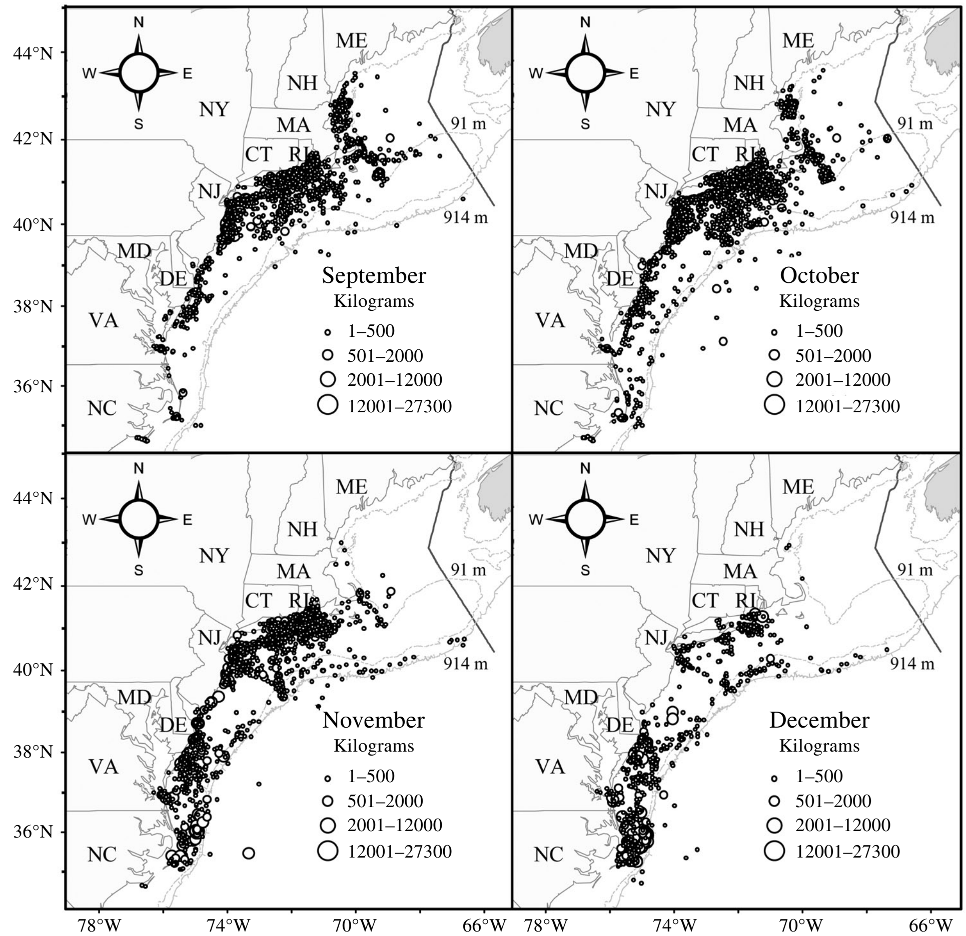

Figure 7

Distribution of bluefish (*Pomatomus saltatrix*) in the Middle Atlantic Bight based on commercial logbook catch records (2001–2003) for all gear types.

greater than 50 km per day would imply that some type of passive transport supplemented active swimming movement. The offshore distribution of bluefish in the South Atlantic Bight during winter, as inferred from tags, may provide an opportunity for bluefish to use the Gulf Stream during the northern migration.

Several recent studies have evaluated the stock structure of bluefish along the Atlantic coast by using genetic material (Chiarella and Conover, 1990; Graves et al., 1993; Davidson, 2002) and morphometric characteristics (Austin et al., 1999). These studies have concluded that bluefish along the U.S. Atlantic coast comprise a single stock. The tag recovery information for bluefish illustrates differences in movement patterns among areas, but these groupings do not imply unique stock characteristics. Consequently, there is no evidence from the tag recovery information that refutes the single stock hypothesis.

Implementation of a well-designed tag and release program is critical for analytical evaluation of migration (Schwarz et al., 1993). Limitations associated with tag recovery must be accounted for in the design of an effective tagging program. Recovery of most tags is a function of fishing effort; therefore recaptured tags must be considered in the context of the fisheries that will provide the recoveries. Unknown variations in fisheries over the past four decades may have influenced the patterns of bluefish tag recoveries in the NMFS and ALS programs, ultimately influencing interpretation of the results. In addition, time-at-large for fish in both programs was generally less than one year which may be due to tag-induced mortality and tag loss (Henderson-Arzapalo et al., 1999). Bluefish tagged in Western Australia were generally at large for less than a year and experienced tag losses between 25% and 38% (Young et al., 1999). The NMFS and ALS programs demonstrate that tagging is a viable tool in analyses of bluefish populations, but it has limitations. Using the knowledge gained from these tagging programs, scientist may find that a renewed tagging effort incorporating recent technological advances will provide further insight into the migratory behavior of bluefish and, in particular, the behavior linked to environmental cues.

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