Abstract.—The bluefish, *Pomatomus saltatrix* (Linnaeus), is abundant in the South and Middle Atlantic Bights, where more than 75% of the shore-based catches are juveniles (age 0). No information is available on the distribution, food, and age of juvenile bluefish north of the Middle Atlantic Bight. The objectives of the present study were to review and summarize unpublished records of catch locations, to characterize the diet of juvenile bluefish, and to derive parent spawning dates (and possible spawning locations) for juvenile bluefish in Maine. Most observations of juvenile bluefish were from southwestern Maine. The most northeasterly site was Little Kennebec Bay (near Machiasport, Maine). During this study, juvenile bluefish were collected from three locations: Marsh River (1990–1991), Sagadahoc Bay (1990), and Merepoint Bay (1991). The diet of juvenile bluefish varied with size. Fish from Sagadahoc Bay, measuring 37–64 mm fork length (FL), fed predominantly on mysids and copepods. Fish from the Marsh River, measuring 81–200 mm FL, fed on fish and large crustaceans. Daily growth rings were counted on the sagitta of juvenile bluefish. Spawning dates, backcalculated from these counts, suggest that fish captured in the Marsh River (1990–1991) originated from a spring spawning (March–May), and fish captured in Sagadahoc Bay (1990) originated from a summer spawning (predominantly June). We do not believe that these spring and summer spawned fish originated from the known major spring and summer spawning grounds in the South and Mid-Atlantic Bights, respectively. The time required to swim from even the northern portion of these major spawning grounds to the site of capture exceeds the known age of the fish derived from counting daily growth rings. The results suggest that both major spawning areas have been extended to the northeast, or unknown spawning areas exist closer to Maine.

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The distribution, food, and age of juvenile bluefish, *Pomatomus saltatrix*, in Maine

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Bluefish, *Pomatomus saltatrix*, are widely and irregularly distributed along the continental shelf in temperate and warm water regions (Briggs, 1960; Wilk, 1977). On the Atlantic coast of North America the species is particularly abundant in southern Florida, North Carolina, Virginia, and from New Jersey to southern Massachusetts, where it is highly sought by salt water recreational anglers for its superior fighting qualities. Stray adult bluefish have been reported during the summer in New Brunswick waters (Bay of Fundy, Passamaquoddy Bay, St. Johns River) and the south shore of Nova Scotia (Scott and Scott, 1988). In the Gulf of Maine, the abundance of bluefish has fluctuated widely over time (Bigelow and Schroeder, 1953). During the mid-1970's, an increase in abundance resulted in the development of a major recreational fishery for adult fish in Maine. This increase is reflected in the incidental bluefish catch recorded since 1986 from gillnet fishing activity for more desirable commercial species (cod, etc.): 46.9 metric tons (t) (1986); 8.8 t (1987); 3.9 t (1988); 34.6 t (1989); 24.4 t (1990); 51.9 t (1991): 37.0 t (1992).[1]

Both shore and boat-based recreational fisheries exploit young bluefish (age 0 and 1) in the South Atlantic. More than 75% of the shore-based recreational catch along the south and mid-Atlantic coasts are juvenile fish (age 0).[2] Although isolated reports of juvenile bluefish have been reported in Maine waters (Bigelow and Schroeder, 1953; Lund, 1961; Targett and McCleave, 1974), no information is available on the distribution, food, and age of these fish. The objectives of this study were 1) to review and summarize unpublished locations where juvenile bluefish have been captured between the Piscataqua River (Maine-New Hampshire border) and Passamaquoddy Bay (Maine-New Brunswick border), 2) to characterize the diet of juvenile bluefish in Maine, and 3) to derive parent spawning dates and possible spawning locations from counts of daily growth rings on juvenile bluefish otoliths obtained in Maine.

Materials and methods

Records of juvenile bluefish in Maine

Unpublished records of juvenile bluefish along coastal Maine were reviewed. Sightings were considered reliable if we actually observed the specimens of juvenile bluefish reported or if the observers could

[1] Morrill, R. NMFS Port Agent, Portland, Maine. Personal commun., 1993.

[2] Crecco, V., M. Terceiro, and C. Moore. 1987. A stock assessment of Atlantic coast bluefish, *Pomatomus saltatrix*. Special report prepared for the Atlantic States Marine Fisheries Commission, Washington, D.C., 86 p.

correctly identify preserved juvenile bluefish from the laboratory fish collection.

Study locations

The primary sampling sites were in the Marsh River (a tributary of the Sheepscot River in Newcastle, Maine) near the confluence of Sherman Lake Outlet and Deer Meadow Brook (Fig. 1A). These sites were selected because juvenile bluefish were consistently captured there in preliminary netting experiments conducted during the summers of 1986–89. The sites are approximately 6.5 km from the confluence of the Marsh River and the Sheepscot River and 34.3 km from the mouth of the Sheepscot River. Marsh banks abut the meandering river and mud flats slope from the base of these banks to the edge of the riverbed. The riverbed is about 46–49 m wide at low tide. The mean tidal range is 1.60 m (U.S. Dep. Commer., 1990–91).

Juvenile bluefish were also obtained from sampling sites at Kennebec Point (Fig. 1B) and Merepoint Bay (Fig. 1C). The Kennebec Point site is used routinely by the Division of Benthic and Demersal Fisheries (State of Maine, Dep. of Marine Resources, W. Boothbay Harbor, Maine 04575) to monitor biweekly variation in species diversity and abundance; occasionally, juvenile bluefish were captured there. The site consists of a sandy beach and a small cove, 1.8 km from open ocean. The mean tidal range is 1.37 m (U.S. Dep. Commer., 1990–91).

Abundant schools of juvenile bluefish and clupeids inhabit the Merepoint Bay site, located in shallow water between the floats at Paul's Marina (Fig. 1C). This site is 16.7 km from open ocean and the tidal range is 1.46 m (U.S. Dep. Commer., 1990–91).

Sampling gear

Gill nets were employed to capture juvenile bluefish in the Marsh River for the following reasons. First, the fish were dispersed and sporadic in occurrence and other methods of capture would probably have produced few fish. Swift tidal currents prevented the use of seines at other than low slack water, and a seine requires two operators and frequently only one was available.

Two sinking gill nets (Sterling Marine Products, Jonesport, Maine 04649), measuring 2.4 m in depth and 48.8 m in length, were suspended between stakes driven into the banks of the Marsh River. Ropes suspending these nets bifurcated 4.6 m from the end of each net; one length was attached to the float line and the other to the lead line. Poles measuring 2.1 m were positioned between the float and lead lines at each end of each net to prevent the nets from collapsing and twisting during rapid tidal flows at mid-ebb and mid-flood. A window weight (2.4 kg) was attached to the lower end of each pole to maintain the net vertically. One net was a variable mesh type constructed from two 6.1-m panels of each of the following square mesh sizes: 1.27 cm, 1.90 cm, 2.54 cm, and 3.18 cm. Individual panels were randomly positioned. Additional floats were attached to the float line of these sinking nets so they fished approximately 15–30 cm below the surface. This enabled floating debris to pass over the net. The second net was constructed entirely of 1.27-cm square mesh.

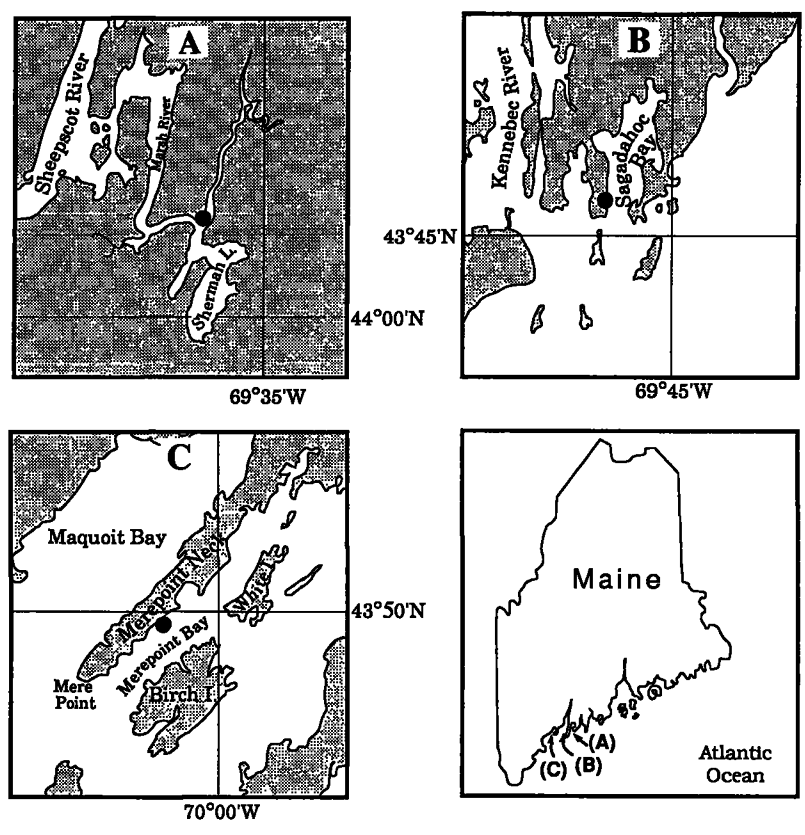

Figure 1
Sampling locations for juvenile bluefish, *Pomatomas saltatrix*, in (**A**) Marsh River, (**B**) Sagadahoc Bay, and (**C**) Merepoint Bay, Maine.

Beginning in June, gill nets were fished for approximately four hours, once a week, until catches revealed that bluefish were present in the river. The nets were then fished two or three times a week. Fishing was again reduced to one set per week in September when no further catches of bluefish were made. When two weeks of fishing produced no juvenile bluefish, fishing was discontinued. Gill nets were set in the Marsh River on 20, 27 June; 4, 11, 18, 25 July; 1, 6, 14, 16, 21, 22, 23, 27, 28, 30 August; 5, 6, 11, 12, 18, 20, 26 September; 3, 12 October 1990 and 20, 26 June; 9, 17, 22, 25, 29 July; 1, 6, 12, 15, 22, 29 August; 4, 5, 10, 12, 17 September; and 1, 8 October 1991. When bluefish were present, the net was inspected every 30 minutes without pulling and resetting it. All fish were removed from the net, identified to species, and measured to the nearest mm.

Juvenile bluefish were captured by beach seine on 10 August 1990 and 27 September 1991 at Kennebec Point. The seine was constructed of 6.35-mm square mesh and measured 1.2 m × 15.2 m. It was hauled a horizontal distance of 152.4 m on each sampling date. Fish were also collected at Kennebec Point on 22 August 1990 in a fyke net constructed of 6.35-mm square mesh with two 15.2-m wings. The fyke net was set in a dry channel at low tide, and a 3-hour set was initiated when the incoming tide first reached the hoops. Juvenile bluefish were captured at Merepoint on 9 September 1991 by using the variable mesh gill net described previously.

Field and laboratory data recorded

Fishing time was recorded during each sampling trip to the Marsh River. The set was initiated when the net was set, attached to stakes, and spread. Termination of the set occurred when the net was detached from one stake. Temperature and salinity were recorded at the surface and bottom with a YSI Model 33 SCT Meter immediately following the beginning of a set and just prior to the end of a set. Tide condition, time of slack water (if it occurred), and maximum depth noted from graduations on the SCT cable were also recorded.

Both individuals and schools (two or more gilled in close proximity) of juvenile bluefish were captured in the gill nets. The fish were stored in plastic bags containing information on time of capture (to the nearest 30 minutes), date of capture, and mesh size of the capture panel. Fish were stored in an ice cooler until returned to the laboratory.

Within nine hours of capture, fish were wiped with paper towels and weighed to the nearest 0.1 gram. Both total length (TL) and fork length (FL) (Hubbs and Lagler, 1958) were recorded to the nearest millimeter. Stomachs were removed and frozen in small scintillation vials. Heads were refrigerated until the sagitta were removed.

Daily growth rate was derived from the total increase in length divided by the number of daily growth increments counted. Total growth in length is equivalent to size (FL) at capture minus the approximate size at hatching (2 mm, Deuel et al., 1966).

Treatment and analysis of stomach contents

Stomachs were thawed and submerged in 3% sea water formalin for approximately 19 hours to harden stomach contents. Stomachs were then rinsed several times with sea water and their contents were identified to the lowest taxon, counted, blotted on a paper towel, and weighed to 0.0001 grams. Stomach contents were then refrozen and freeze-dried (Labconco Freeze Dryer 8) for 48 hours at –40°C under a vacuum of approximately 25 microns mercury (Hg). Dry weights were recorded to the nearest 0.0001 gm.

Three prey item indices were computed to reduce potential bias associated with a single index (Hynes, 1950; Windell, 1971; Friedland et al., 1988). We employed the methodology of Friedland et al. (1988) in computing 1) the number of stomachs in which a species occurred expressed as a) a percentage of the total number of stomachs containing food (F=percent frequency of occurrence) and b) a percentage of the total number of stomachs examined (F1=percent frequency of occurrence); 2) the number of individuals of each prey species expressed as a percentage of the total number of food items (N=percent numerical abundance); and 3) the wet weight of a species expressed as a percentage of the total wet weight of food items (W=percent wet weight) and the dry weight of a species expressed as a percentage of the total dry weight of food items (W1=percent dry weight).

Preparation and analysis of otoliths

Saggita were removed from each fish within 24 hours of capture. Excess tissue was removed with forceps. Pairs of sagitta were stored in 7-mL scintillation vials for 1–3 months prior to mounting and ageing. Each sagitta was mounted concave side down on a microscope slide with Epo-Kwick (Buehler Ltd., Lake Bluff, Illinois). Commercial grade wet-dry sandpaper (600 grit or 24 μ) was used for initial coarse sanding. Final sanding and polishing was performed with 9-μ and 0.3-μ wet-dry sandpaper respectively (Buehler, Ltd). The addition of a small drop of glycerine to the surface of the polished otolith assisted in the resolution of daily growth rings. Three replicate counts were performed during one day by one reader using a compound microscope with transmitted polarized light at 100–200×. Counts were rarely accomplished in a straight line; it was usually necessary to traverse the otolith in either a general dorsal or ventral direction to complete a count because daily growth rings in many portions of the otolith are obscure. Each counting pathway was usually different. The criterion of Nyman and Conover (1988) was used: if one of three counts differed by >10%, an additional count was performed and the value that differed by >10% was discarded. The mean of the three remaining counts was recorded. Dates of first ring deposition for juvenile bluefish collected from all sources were backcalculated from the number of growth increments counted.

Estimates of swimming speed and swimming distance

The distance juvenile bluefish were capable of swimming per day was calculated from estimates of the average body length during migration and the relationship between swimming speed and average body length. Average body length was equal to one-half the mean size of fish collected during a 2-week period immediately following first appearance at a sampling site minus 2 mm, the size at hatching (Deuel et al., 1966). The swimming speed for fish such as salmon, cod, and herring is about three times the body length/sec for fish measuring 10–100 mm (Harden Jones, 1968). Juvenile bluefish measuring 155–213 mm TL swam at speeds averaging 94 mm/sec at 20°C and 180–260 mm/sec when cooler water was added (Olla et al., 1985). We estimated swimming speed of juvenile bluefish at no more than 2 body length/sec.

The mean size of juvenile bluefish collected from the Marsh River during a 2-week period immediately following their first appearance in 1990 and 1991 was 108 mm FL (n=17) and 101 mm FL (n=19). Total growth between hatching and appearance at the collection site in 1990 was 106 mm (108 mm minus 2 mm [the size at hatching]) and in 1991, 99 mm. The average size of the fish during this migration would be one-half these values or 53 and 50 mm. Swimming distances per day during migrations in 1990 and 1991 were 53 mm × 2 (twice the body length) = 106 mm/sec (9.16 km/day) and 50 mm × 2 = 100 mm/sec (8.64 km/day). Similarly, the mean size of juvenile bluefish collected from Sagadahoc Bay during August 1990 was 48 mm FL (n=29). The swimming distance per day was therefore 23 mm × 2 = 46 mm/sec (3.97 km/day).

The shortest distances between the northern portions of the spawning grounds in the South Atlantic Bight to the collection site in the Marsh River and the Middle Atlantic Bight to the collection site in Sagadahoc Bay were estimated at 1350 km and 425 km respectively.

Statistical analysis

The relationship between fork length and the number of daily rings for juvenile bluefish captured in Maine during 1990–91 was described by linear regressions, where X is the $\log_{10}$ of fork length and Y is the number of daily rings. Slopes were then compared with ANCOVA. The curvilinear relationship of the same data from Maine (1990–91) and New York (1985–86) was described by quadratic equations, where X is fork length and Y is number of daily rings. The relationship of fork length to growth rate for combined data from Maine was described by a linear regression, where X is the fork length and Y is the rate of growth.

Results and discussion

Records of juvenile bluefish from the coast of Maine

Most records of juvenile bluefish were from southwestern Maine (York, Cumberland, Sagadahoc, and Lincoln counties) during the months of July, August, and September (Table 1). Fish varied in size from 37 to 197 mm FL (39–218 mm TL) from both oceanic and estuarine environments. Atlantic puffins (*Fratercula arctica arctica*), Arctic terns (*Sterna paradioaea*), and roseate terns (*Sterna dougallii dougalli*) were reported as feeding on young-of-year bluefish in July near Matinicus Rock and Seal Island (Knox County).[3] These observations indicated that juvenile bluefish occur in the offshore waters of Maine prior to their usual appearance inshore during August–September. Clark (1973) observed that juvenile bluefish remain where salinities are high when they first arrive, and later, as summer progresses, they penetrate into estuaries. Little Kennebec Bay (Table 1, No. 28) is the most northeast location where the capture of juvenile bluefish was confirmed. Three juvenile bluefish were among 1,000 age-1 Atlantic herring, *Clupea harengus*, tagged at this location on 25 August 1983 (Creaser and Libby, 1986).

Young-of-year (YOY) bluefish may be more abundant northeast of Boothbay Harbor than suggested by Table 1. The scarcity of information from this area

[3] Kress, S. Cornell Univ. Ornithology Lab, Ithaca, NY. Personal commun., January 1991.

Table 1
Unpublished records of juvenile bluefish, *Pomatomas saltatrix*, in Maine.

Location	N. Lat.	E. Long.	Date of capture	Oceanic (O) or estuarine (E)	No. captured	Size (mm)[1]		Method of capture[2]
						TL	FL	
Wells Harbor (York Co.)								
1 Wells Harbor	43°19"	70°34'	Aug 1991	E	1	68		FN
Old Orchard Beach (York Co.)								
2 1 Mile off Amusement Pier	43°31'	70°21'	Summer 1961–1964	O	—	Juvenile		HL
Scarborough Marsh (Cumberland Co.)								
3 Confl. of Dunston, Libby, Nonesuch R.	43°33'	70°20'	Summer 1987	E	—	Juvenile		HL
Portland Harbor (Cumberland Co.)								
4 Union Wharf	43°39'15"	70°15'	Sept 1984	O	6	150–200		HL
5 SMVTI Dock	43°39'	70°14'15"	Sept 1986	O	—	130–150		HL
Royal River (Cumberland Co.)								
6 Royal River	43°47'30"	70°10'	Summer 1988	E	—	Juvenile		—
Merepoint (Cumberland Co.)								
7 Merepoint Bay	43°50'	70°00'01"	26 Sept 1991	E	97	150–174		GN
Jenny Island, Casco Bay (Cumberland Co.)								
8 Jenny Island	43°46'	69°55	16 July 1991	E	1	40		CT
New Meadows River (Cumb.–Sagadahoc Co.)								
9 Howard Pt., Thomas Bay	43°53'15"	69°53'10"	Aug 1988	E	3	70–130		FK
Kennebec River (Sagadahoc Co.)								
10 Atkins Bay	43°45'	69°48'	Summer 1981	E	—	80–90		HS
11 Winnegance Bay	43°53'	69°49'	Summer 1988–1990	E	—	50–150		HL
12 Bath Bridge	43°55'	69°48'30"	Summer 1982	E	90	<100		OT
13 Mouth of Androscoggin R.	43°57'	69°53'	5 Aug 1983	E	2	82–86		HS
14 Mouth of Abagadasset R.	44°00'30"	69°51'	17 July 1986	E	5	70–77		HS
Mouth of Abagadasset R.			11 Sept 1987	E	2	142–150		HS
Mouth of Abagadasset R.			3 Aug 1989	E	8	52–76		HS
Mouth of Abagadasset R.			3 July 1991	E	6	112–115		HS
Mouth of Abagadasset R.			18 July 1991	E	2	84–94		HS
Sagadahoc Bay (Sagadahoc Co.)								
15 Kennebec Pt.	43°45'20"	69°45'45"	10–22 Aug 1990	O	29	39–70	37–64	HS
Montsweag Bay (Lincoln Co.)								
16 Berry Island	43°58'15"	69°40'55"	30 Aug 1972	E	1	112		HS
Berry Island			29 Aug 1973	E	2	132–141		HS
Berry Island			8 Sept 1974	E	4	125–140		HS
Sheepscot River (Lincoln Co.)								
17 Cross River	43°55'	69°37'	8 Aug 1991	E	1	115		HS
18 The Eddy	43°59'30"	69°39'	9 July 1991	E	3	80–85		HS
19 Marsh River	44°01'	69°35'45"	14 Aug 1986	E	28	93–121		GN
Marsh River			26 Aug 1987	E	6	129–163		GN
Marsh River			8–28 Aug 1989	E	102	92–194		GN
Marsh River			1 Aug–26 Sept 1990	E	149	89–218	81–197	GN
Marsh River			17 July–17 Sept 1991	E	60	101–217	193–196	GN
20 Sheepscot Falls	44°02'45"	69°37'	Aug 1967	E	—	150–200		HL
21 Sheepscot River (town of Sheepscot)	44°03'30"	69°36'30"	2 Aug 1989	E	1	140		HL
Boothbay Harbor (Lincoln Co.)								
22 Lobster Cove	43°51'	69°37'	30 Aug 1990	O	1	145	131	HL
Lobster Cove			11 Aug 1991	O	4	162–192		HL
23 Townsend Gut	43°50'	69°39"	5 Sept 1985	O	1	Juvenile		HL
24 DMR Dock	43°50'45"	69°38'30"	14 Sept 1971	O	5	95–105	89–97	—
DMR Dock			25 Aug 1978	O	1	86		DN
DMR Dock			4 July 1984	O	3	40–50		HL
25 Foot Bridge	43°51'	69°37'40"	Summer 1970–1974	O	—	Juveniles (2 sizes)		HS
Matinicus (Knox Co.)								
26 Matinicus Rock	43°47'	68°51'30"	18 July 1986	O	1	77		AP
Matinicus Rock			5 July 1989	O	2	85–90		AP
Matinicus Rock			Mid July 1990	O	2	30–40		AT
Matinicus Rock			9–17 July 1991	O	14	40–50		AT

Table 1 (Continued)

Location	N. Lat.	E. Long.	Date of capture	Oceanic (O) or estuarine (E)	No. captured	Size (mm)[1] TL	FL	Method of capture[2]
Matinicus Rock			24–30 July 1991	O	4	50–60		RT
Seal Island (Knox Co.)								
27 Seal Is.	43°53'	68°45'	July 1991	O	1	50		AT
Little Kennebec Bay (Washington Co.)								
28 Marston Pt.	44°39'	67°26'15"	25 Aug 1983	O	3	100–130		HW

[1] TL = total length; FL = fork length.
[2] OT = Otter trawl; FN = Fyke net ; HL = Hook and line; — = Unknown; HS = Haul seine ; AP = Atlantic puffin; GN = Gill net; AT = Artic tern; DN = Dip net; CT = Common tern ; HW = Herring weir; RT = Roseate tern.

may result from the lack of scientific fish sampling activity and lack of familiarity with the identification of juvenile bluefish by the sportfishing public and finfish processors. Clark (1973) attributed high densities of juvenile bluefish in areas such as South Carolina and the New York Bight to sampling activity and availability of records from those areas.

Some published information exists on the distribution of juvenile bluefish in southwestern Maine. They have been reported from Casco Bay (Bigelow and Schroeder, 1953; Wilk, 1977), Boothbay Harbor (Lund, 1961) and Montsweag Bay (Targett and McCleave, 1974).

Length-frequency distributions

Length-frequency distributions of juvenile bluefish captured in the Marsh River (1990–91), Sagadahoc Bay (1990), and Merepoint Bay (1991) varied between 8 and 20 cm, 3 and 6 cm, and between 14 and 17 cm respectively (Fig. 2, A–D). Length-frequency data from the Marsh River was combined in 1-cm groupings and presented as one figure per year because fish were collected for only two months. Although the size range recorded during both 1990 and 1991 was similar, larger juveniles were more prevalent during 1991 (Fig. 2, A and B). The length-frequency composition of fish captured by beach seine from Sagadahoc Bay on 10 and 22 August 1990 (Fig. 2C) confirms the presence of small juveniles of 3–6 cm FL in Maine waters.

Previous reports of juvenile bluefish less than 70 mm from Wells Harbor, Winnegance Bay, the mouth of the Abagadasset River, Boothbay Harbor, Matinicus Rock and Seal Island have been presented in Table 1. The overall length-frequency range (8–20 cm FL) reported for fish captured in the Marsh River during 1 August–26 September 1990 and 17 July–17 September 1991 was similar to the length-frequency range reported from Great South Bay, New York (8–22 cm FL) during 28 May–12 August 1985 and 10 June–20 August 1986 (Nyman and Conover, 1988). Length-frequency distributions generated from gillnet catches (Fig. 2, A, B, D) are biased because panels of individual mesh sizes in gill nets are selective for specific sizes of fish.

Temperature and salinity data collected during gillnet sets

Juvenile bluefish were captured on both incoming (I) and outgoing (O) tides between 1 August and 26 September 1990 and between 17 July and 17 September 1991. Specific water temperatures do not appear to be associated with the arrival and departure of juvenile bluefish. Bluefish were first captured at water temperatures of 24.6–27.0°C (1990) and 22.8–24.0°C (1991). None were captured when the temperature dropped below 16.0°C (1990) and 19.3°C (1991). Water temperatures varied between 16.0 and 27.0°C (1990) and between 19.3 and 27.4°C (1991) when bluefish were present.

Lund and Maltezos (1970) reported that juveniles and adults appear at temperatures of 12–15°C and depart at temperatures of 13–15°C. Oben (1957) reported that juveniles appear at temperatures of 18–24.5°C and depart at 13–15°C. Similarly, Nyman and Conover (1988) reported that juveniles appear at 20–24°C and depart at water temperatures in the "middle-teens." We believe that juvenile bluefish arrived at the mouth of the Sheepscot River when the water temperature was relatively low and they were attracted to the Marsh River, 34.3 km upstream, by the warmer water. These fish appeared to remain in the Marsh River until the water temperature dropped to a temperature range that was lower than the water temperature at the time of their arrival in the sampling area.

The salinity of the Marsh River varied between 9.5 and 23.3 ppt (1990) and between 9.6 and 26.5 ppt (1991) when juvenile bluefish were present.

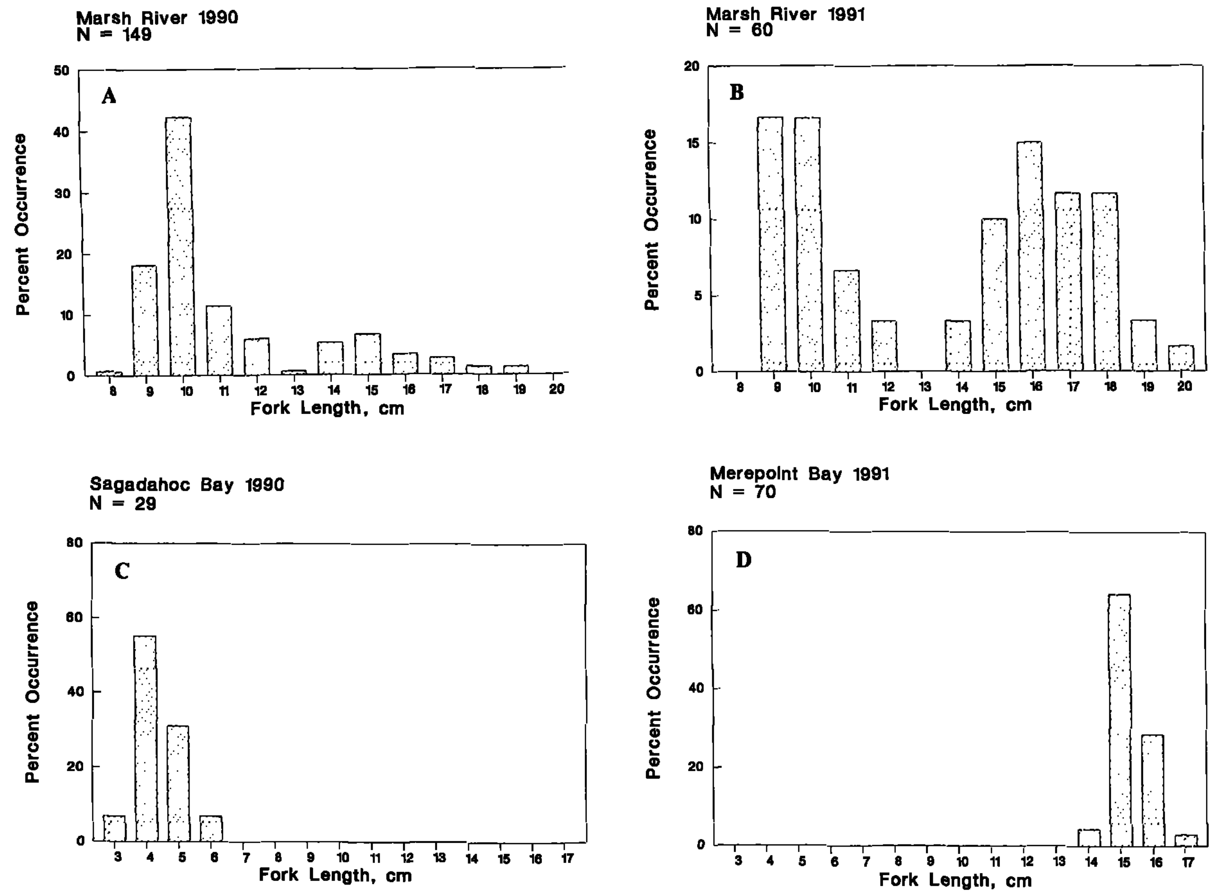

Figure 2

Length-frequency histograms for juvenile bluefish, *Pomatomas saltatrix*, collected in Maine: (**A**) Marsh River 1 Aug.–26 Sept. 1990; (**B**) Marsh River 17 July–17 Sept. 1991; (**C**) Sagadahoc Bay 10–22 Aug. 1990; and (**D**) Merepoint Bay 26 Sept. 1991.

Smale and Kok (1983) collected juveniles at 12–35 ppt, Clark (1973) occasionally found bluefish in very brackish water, and Baird (1873) captured juveniles from the freshwater portion of tidal rivers.

Stomach contents

Stomach contents of juvenile bluefish (81–200 mm FL) collected from the Marsh River in 1990 and 1991 are presented in Table 2. During 1990, fish were present in 81.4% of stomachs containing food (F), crustaceans in 39.5% (F), and plant material in 4.7% (F). During 1991, crustaceans were slightly more prevalent than fish. Crustaceans were present in 69.0% of stomachs containing food (F), fish in 62.1% (F), and plant material in 5.2% (F). The frequency of occurrence of polychaetes was 3.4% (F) and of insects, 1.7% (F).

During 1990 and 1991, crustaceans were the predominant prey items in terms of numbers of individuals observed (N) expressed as a percent of the total number of prey items recorded. Crustaceans composed 58.0% (1990) and 83.4% (1991) of the total prey items, fish composed 39.9% (1990) and 11.3% (1991), and plant material 2.0% (1990) and 4.5% (1991). During 1991, 0.5% and 0.3% of the total number of prey items were polychaetes and insects.

During 1990 and 1991, fish were the predominant prey in terms of wet or dry weight expressed as a percentage of the total wet weight (W) or dry weight (W1) of all prey species recorded. Fish composed 77.4% of total wet weight (W) and 79.9% of total dry weight (W1) during 1990 and 61.9% (W) and 67.5% (W1) during 1991. Crustaceans composed 22.5% (W) and 20.0% (W1) during 1990 and 37.3% (W) and

Table 2

The stomach contents of 149 juvenile bluefish, *Pomatomas saltatrix*, measuring 81–197 mm FL ($\bar{x}$=117 mm), and 60 juveniles measuring 93–200 mm FL ($\bar{x}$=142 mm), collected from the Marsh River, Maine, during 1 August–26 September 1990 and 17 July–17 September 1991, respectively.

	Marsh River 1990					Marsh River 1991				
Taxon	F (%)[1]	F1 (%)[2]	N (%)[3]	W (%)[4]	W1 (%)[5]	F (%)	F1 (%)	N (*) (%)	W (%)	W1 (%)
Class Crustacea										
Argulus sp.	1.550	1.342	1.024	0.021	0.027					
Corophium sp.						1.724	1.667	0.263 (0.606)	0.011	0.009
Crangon septemspinosa	34.884	30.201	55.631	22.351	19.888	63.793	61.667	26.579 (61.212)	37.294	31.830
Rhithropanopus harrisii	0.775	0.671	0.341	0.061	0.064					
Unidentified Crustacea	1.550	1.342	0.683	0.063	0.031					
Unidentified Isopoda	0.775	0.671	0.341	0.029	0.037					
Zoea of Majidae sp.						3.448	3.333	56.579	0.006	0.005
Total	39.535	34.228	58.020	22.525	20.046	68.966	66.667	83.421 (61.818)	37.310	31.844
Class Osteichthyes										
Alosa pseudoharengus	6.202	5.369	4.096	13.751	13.953					
Clupeidae spp.	5.426	4.698	2.730	7.392	8.045	15.517	15.000	3.158 (7.273)	27.131	29.792
Fundulus heteroclitus	0.775	0.671	0.683	7.309	9.239	1.724	1.667	0.526 (1.212)	6.720	7.366
Menidia menidia	9.302	3.054	5.119	13.229	13.798	8.621	8.333	1.579 (3.636)	2.471	2.228
Fish remains	59.690	51.678	27.304	37.739	34.861	36.207	35.000	6.053 (13.939)	25.589	28.146
Total	81.395	70.470	39.932	77.421	79.895	62.069	60.000	11.316 (26.061)	61.911	67.532
Class Polychaeta										
Polychaete remains					3.448	3.333	0.526	(1.212)	0.445	0.342
Total					3.448	3.333	0.526	(1.212)	0.445	0.342
Class Insecta										
Hymanoptera (unident.)					1.724	1.667	0.263	(0.606)	0.009	0.005
Total					1.724	1.667	0.263	(0.606)	0.009	0.005
Plant material										
Leafy	0.775	0.671	0.341	0.005	0.007					
Woody	3.986	3.356	1.706	0.049	0.052	5.172	5.000	4.474 (10.303)	0.325	0.278
Total	4.651	4.027	2.048	0.054	0.059	5.172	5.000	4.474 (10.303)	0.325	0.278

	Marsh River 1990	Marsh River 1991
Number of stomachs examined	149	60
Number of stomachs containing food (% containing food)	129 (86.58)	58 (96.67)
Number of empty stomachs (% empty)	20 (13.42)	2 (3.33)
Mean wet weight/stomach (all stomachs) gm	0.651	1.133
Mean dry weight/stomach (all stomachs) gm	0.116	0.183
Mean wet weight/stomach (stomachs with food) gm	0.752	1.172
Mean dry weight/stomach (stomachs with food) gm	0.134	0.189

[1] F = % frequency of occurrence — the number of stomachs in which a species (taxon) occurred expressed as a % of the total number of stomachs containing food.
[2] F1 = % frequency of occurrence — the number of stomachs in which a species (taxon) occurred expressed as a % of the total number of stomachs examined.
[3] N = % numerical abundance — the number of individuals of each species (taxon) expressed as a % of the total number of food items (individual prey in stomachs) (*) designates the % numerical abundance excluding 215 zoea of Majidae found in the stomachs of two fish.
[4] W = % weight — wet weight of a species (taxon, prey category) expressed as a % of the total wet weight of food items.
[5] W1 = % weight — dry weight of a species (taxon, prey category) expressed as a % of the total dry weight of food items.

31.8% (W1) during 1991. Plant material accounted for 0.1% (W) and 0.1% (W1) during 1990 and 0.3% (W) and 0.3% (W1) during 1991. Polychaetes made up 0.4% (W) and 0.3% (W1) during 1991; insects made up 0.01% (W) and 0.01% (W1).

Stomach contents of juvenile bluefish collected from other areas in Maine during 1990 and 1991 are presented in Table 3. Bluefish measuring 150–173 mm FL were captured from Merepoint Bay on 9 September 1991. Fish were the predominant prey item for all indices: 80.0% (F), 67.7% (N), 85.0% (W), and 88.6% (W1). Crustaceans composed 24.0% (F), 32.3% (N), 15.0% (W), and 11.4% (W1).

Bluefish measuring 37–64 mm FL were captured from Sagadahoc Bay on 10 and 22 August 1990. The predominant prey items recorded from these small juveniles were crustaceans (mysids and copepods). The frequency of occurrence of mysids and copepods in stomachs containing food (F) was 10.3% and 96.6%, respectively. Crustaceans were also the predominant prey items in terms of their wet or dry weight, expressed as a percentage of the total wet weight (W) or dry weight (W1). Crustaceans composed 82.2% of the total wet weight (W) and 80.0% of the total dry weight (W1). Fish remains were a minor constituent of the stomach contents of these small bluefish; they occurred in 6.9% of stomachs containing food (F). Fish also composed 17.7% of the total wet weight (W) and 21.0% of the total dry weight (W1). No information was available regarding the numbers of individuals observed (N) expressed as a percent of the total number of prey items recorded because copepod remains were so numerous that it was impractical to count them.

The diet of juvenile bluefish collected from the Marsh River in 1990 and 1991 and from Merepoint Bay in 1991 is consistent with observations by Breder (1922), Grant (1962), data for bluefish >10 cm reported by Smale and Kok (1983), and the 1981 results recorded in Friedland et al. (1988). All studies showed that the major portion of the diet (by weight or volume) of juvenile bluefish ≥8 cm in length consisted of fish. Although results presented by Lassiter (1962) and Naughton and Saloman (1984) are also consistent with this observation, Lassiter (1962) did not report bluefish lengths and some of the bluefish in Naughton and Saloman's (1984) data were older than age 1 (e.g. 39.9 cm).

Our findings regarding the diet of juvenile bluefish collected from Sagadahoc Bay (1990) were consistent with results presented by Kendall and Naplin (1981) and Smale and Kok (1983) for bluefish <100 mm. Smale and Kok (1983) reported that juvenile bluefish <100 mm feed predominantly on small crustaceans, and Kendall and Naplin (1981) stated that most of the diet of juvenile bluefish ($\bar{x}$=4.33 mm) consisted of copepods, copepodites, cladocera, and fish eggs. A transition to pisciverous feeding by juvenile bluefish at a size range between 60 and 100 mm has been reported (Nichols, 1913; Greeley, 1939; Oben, 1957; Clark, 1973; Smale and Kok, 1983). The transition to fish as prey had not yet occurred in bluefish measuring 37–64 mm from Sagadahoc Bay (Table 3).

On a per cent weight basis, the dominant prey species of juvenile bluefish (81–200 mm FL) collected from the Marsh River and Merepoint Bay included the mud shrimp *Crangon septemspinosa*, juvenile alewives, *Alosa pseudoharengus*, unidentified clupeids, Atlantic silversides, *Menidia menidia*, mum-

Table 3

The stomach contents of 34 juvenile bluefish, *Pomatomas saltatrix*, measuring 150–173 mm FL ($\bar{x}$=156 mm), collected from Merepoint Bay on 9 September 1991, and 29 small juveniles, measuring 37–64 mm FL ($\bar{x}$=48 mm), collected from Sagadahoc Bay, Maine, on 10 and 22 August 1990.

	Merepoint Bay 1991					Sagadahoc Bay 1990				
Taxon	F(%)	F1(%)	N(%)	W(%)	W1(%)	F(%)	F1(%)	N(%)	W(%)	W1(%)
Class Crustacea										
Crangon septemspinosa	24.000	17.647	32.258	14.973	11.400					
Mysidacea spp.						10.345	10.345	—	13.411	14.360
Copepod remains						96.552	96.552	—	68.746	64.621
Total	24.000	17.647	32.258	14.973	11.400	106.897	106.897		82.157	79.981
Class Osteichthyes										
Fish remains	68.000	50.000	58.065	40.057	42.353	6.897	6.897	—	17.742	21.019
Clupeidae spp.	12.000	8.824	9.677	44.970	46.247					
Total	80.000	58.824	67.742	85.027	88.600	6.897	6.897		17.742	21.019

	Merepoint Bay 1991	Sagadahoc Bay 1990
Number of stomachs examined	34	29
Number of stomachs containing food (% containing food)	25 (73.53)	29 (100)
Number of empty stomachs (% empty)	9 (26.47)	0 (0)
Mean wet weight/stomach (all stomachs) gms	0.48288	0.03057
Mean dry weight/stomach (all stomachs) gms	0.08890	0.00596
Mean wet weight/stomach (stomachs with food) gms	0.67367	0.03057
Mean dry weight/stomach (stomachs with food) gms	0.12091	0.00596

michogs, *Fundulus heteroclitus*, and unidentified fish remains (Tables 2 and 3). Other authors reported that a significant portion of the juvenile bluefish diet consists of shrimp (Linton, 1905; Wilk, 1977; Friedland et al., 1988), clupeids (Hildebrand and Schroeder, 1928; Greeley, 1939; Grant, 1962; Richards, 1976; Naughton and Saloman, 1984), Atlantic silversides (Hildebrand and Schroeder, 1928; Greeley, 1939; Grant, 1962; Lassiter, 1962; Wilk, 1977; Friedland et al., 1988), and cyprinodontids (Greeley, 1939; Grant, 1962; Wilk, 1977). Prey of minor importance included *Argulus* sp., *Corophium* sp., *Rhithropanopus harrisii*, unidentified crustacea and isopods, zoea of Majidae sp., polychaete remains, unidentified *Hymenoptera*, and both leafy and woody plant material (Table 2). Estuaries in Maine are probably seasonal nursery grounds where high prey densities and warm water temperatures result in rapid growth.

During 1990 and 1991, 13.42% and 3.33% of the fish collected in the Marsh River and 26.47% (1991) of the fish collected in Merepoint Bay possessed empty stomachs (Tables 2 and 3). With the exception of the 16% estimate reported by Grant (1962), who also used gill nets, the percent of empty stomachs reported by several investigators varied between 30 and 87%. Perhaps the low incidence of empty stomachs reported in our studies resulted from the use of gill nets, which constrict the gills and esophagus thus reducing the possibility of regurgitation.

An analysis of daily growth increments on otoliths

Growth increments on the otoliths of many species of juvenile fishes, including bluefish, are produced on a daily basis as long as growing conditions are adequate (Nyman and Conover, 1988). Bluefish collected from the Marsh River displayed 94–200 ($\bar{x}$=126) and 97–176 ($\bar{x}$=134) daily growth increments during 1990 and 1991, respectively. Fish collected from Sagadahoc Bay (1990) displayed 58–93 ($\bar{x}$=66) daily growth increments, and fish collected from Merepoint Bay (1991) displayed 125–146 ($\bar{x}$=134) daily growth increments. First ring deposition occurs approximately 2–4 days after spawning (Nyman and Conover, 1988) so these daily growth increments correspond to a total of approximately 129 days (Marsh River, 1990), 137 days (Marsh River, 1991), 69 days (Sagadahoc Bay, 1990), and 137 days (Merepoint Bay, 1991) of growth after spawning.

Spawning occurs somewhere along the Atlantic coast during practically every month of the year (Table 4). Several "seasonal" periods of significant spawning are evident. Major spawning periods occur during the "spring" (March–May) in the South Atlantic Bight and "summer" (May–September) in the Middle Atlantic Bight. A minor "fall-winter" (Kendall and Walford, 1979) and perhaps "summer-fall" (Collins and Stender, 1987) spawning period also occurs in the South Atlantic Bight.

It is unlikely that juvenile bluefish captured in the Marsh River during the spring and in Sagadahoc Bay during the summer originated from the major spring spawning in the South Atlantic Bight or the major summer spawning in the Middle Atlantic Bight. Most juvenile bluefish from the Marsh River originated from a spring spawning during March–May (Fig. 3, A and B). Conservative estimates of the time required to swim from the northern portion of the spawning ground in the South Atlantic Bight to the collection site in the Marsh River during 1990 and 1991 would equal 147 days (1350 km ÷ 9.16 km/day) and 156 days (1350 km ÷ 8.64 km/day), respectively. These estimates of swimming time exceed the known ages of juvenile bluefish derived from daily ring counts (129 days, 1990; 137 days, 1991) even before additional time from physical and biological factors are considered. These factors include 1) swimming into the current from Cape Hatteras to Southwestern Maine (Bumpus and Lauzier, 1965), 2) the possibility that swimming speed is less than twice the body length, 3) decreased swimming speed at night (Olla et al., 1985), and 4) feeding behavior which results in nonlinear movement.

Juvenile bluefish from Sagadahoc Bay originated from a summer spawning which occurred mainly during June (Fig. 3C). A conservative estimate of the time required to swim from the northern portion of the spawning ground in the Middle Atlantic Bight to the collection site in Sagadahoc Bay during 1990 would equal 107 days (425 km ÷ 3.97 km/day). This estimate greatly exceeds the known age of the fish (69 days). The estimate of swimming time is increased further when physical and biological factors that impede swimming are considered.

We believe that juvenile bluefish collected from the Marsh River and Sagadahoc Bay may be derived from unknown spawning areas closer to Maine. Lyman (1974) stated that "some of their spawning grounds are known but many remain to be discovered along much of the northeast coast." It is also possible that both major spawning areas known to exist in the South and Middle Atlantic Bights, have extended northward. Another possibility is that "larval transport mechanisms and spawning periodicities for bluefish are considerably more complex than previously believed" (Powles, 1981).

The relationship between the $\log_{10}$ of the fork length and the number of daily rings for 1990 and 1991 data is shown in Figure 4. The range of fish

Table 4
Seasonal spawning dates of bluefish, *Pomatomas saltatrix*, in the South and Middle Atlantic Bight.

	Location	M	A	M	J	J	A	S	O	N	D	J	F	Evidence of spawning	Size
South Atlantic Bight															
Collins and Stender (1987)	Cape Canaveral, FL–Cape Fear, NC		—	—										larvae present	≤4 mm SL
	Coast of Georgia and Florida						—	—		—				larvae present	≤4 mm SL
Kendall and Walford (1979)	Outer shelf S. Atlantic Bight		—	—										larvae present	≤10 mm SL
	Offshore South of Cape Hatteras, NC									fall and winter spawning					
Nyman and Conover (1988)	Long Island, NY	—	—	—										spawning date backcalculated	—
Pierce (1883)	Lake Worth and Juniper Inlet, FL											—		ripe adults	—
Powles (1981)	Cape Canaveral, FL–Cape Fear, NC		—	—										larvae present	no size given
Middle Atlantic Bight															
Baird (1873)	Fort Macon, NJ					—								ripe and running adults	—
Chiarella and Conover (1990)	Off New York				—	—	—							analysis of gonads	—
DeSylva et al. (1962)	Indian River Inlet, DE						—	—						larvae present	4 mm SL
Deuel et al. (1966)	3 miles east of Fire Island Inlet, Long Is., NY				—	—								ripe and running female	—
Herman (1963)	Narragansett Bay, RI					—								larvae present	3.12 mm SL
Kendall and Naplin (1981)	Ocean City, MD					—								larvae present	4.33 mm SL
Kendall and Walford (1979)	Midway over continental shelf of Mid-Atlantic Bight					—	—							larvae present	<10 mm SL
Morse et al. (1987)	Cape Hatteras, NC, to Long Is., NY				—	—	—	—						larvae present	no size given
Norcross et al. (1974)	Outer shelf off Virginia–N. Carolina				—	—	—							eggs present	—
	Outer shelf off Virginia–N. Carolina			—	—	—	—	—						larvae present	2.0–16.5 mm SL
Nyman and Conover (1988)	Hudson River, NY				—	—								spawning date backcalculated	—
Pearson (1941)	Mouth of Chesapeake Bay, VA					—								larvae present	4–7 mm SL
Perlmutter (1939)	Southern Long Island Shore, NY						—							ripe and running female	—
Sherman et al. (1984)	NE United States			—	—	—								larvae present	3.5–28 mm SL

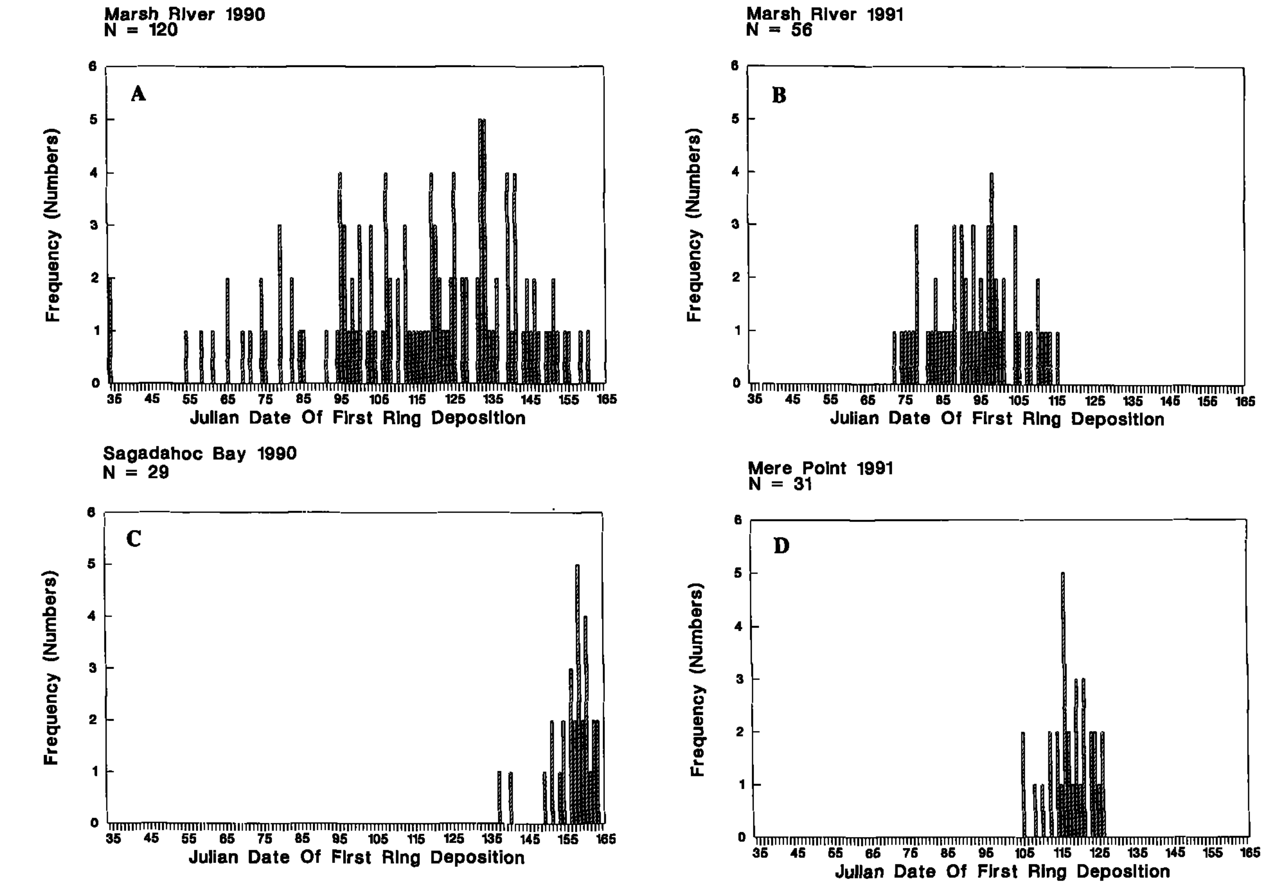

Figure 3

Estimated dates of ring deposition in otoliths of juvenile bluefish, *Pomatomas saltatrix*, collected in Maine: (**A**) Marsh River 1990; (**B**) Marsh River 1991; (**C**) Sagadahoc Bay 1990; and (**D**) Merepoint Bay 1991.

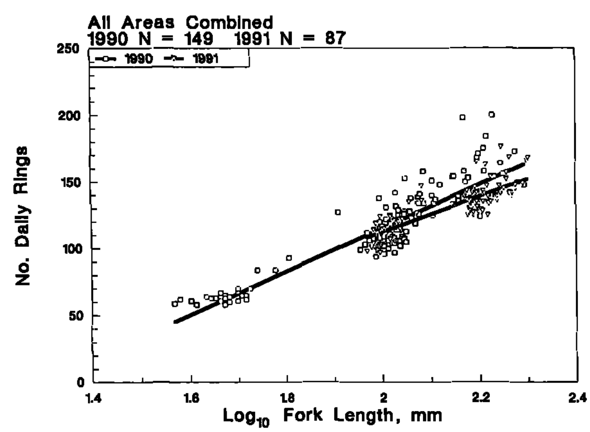

Figure 4

The relationship between $\log_{10}$ fork length (X) and the number of daily rings (Y) for juvenile bluefish, *Pomatomas saltatrix*, captured in Maine during 1990–91. The regression equations are $Y = -209.891 + 162.6751 \log_{10} X$, R^2=0.834, for 1990 and $Y= -151.461 + 132.0466 \log_{10} X$, R^2 = 0.629, for 1991.

lengths recorded during 1991 (93–200 mm) was small compared with 1990 (37–197 mm). The number of daily growth rings varied between 58 and 200 (1990) and between 97 and 176 (1991). Although an ANCOVA revealed that the slopes of the relationship of $\log_{10}$ fork length to number of daily rings differed significantly between years (P<0.05), the significance of this is questionable because the size range of fish also differed between years. Nyman and Conover (1988) analyzed similar regressions for juvenile bluefish captured in New York waters during 1985 and 1986 and found significant differences in slopes between years. Individual values for fork lengths and daily ring counts collected in New York waters during 1985–1986 obtained from Robert Nyman[4] were fit to quadratic equations and compared to similar values obtained in Maine during 1990–91 (Fig. 5). Fork lengths varied between 41 and 166 mm (1985) and between 31 and 167 mm (1986).

[4] Nyman, R. U.S. Environmental Protection Agency, 401 M St., SW, Washington, DC 20460. Personal commun., June 1991.

The number of daily growth rings varied between 44.3 and 160.0 (1985) and between 42.7 and 133.0 (1986). Fish captured in New York grew faster. This may have resulted from shorter migrations, longer exposure to warm water, or better food or feeding conditions. Raw data plots from which New York information (Fig. 5) were derived are presented in Nyman and Conover (1988, fig. 9).

The growth rate increased from about 0.7 mm/day to about 1.25 mm/day as fish length increased from 50 mm to 200 mm FL (Fig. 6). The mean growth rate was 0.96 mm/day. Nyman and Conover (1988) reported a growth rate of approximately 1.3 mm/day for fish obtained from field collections over a 61-day period.

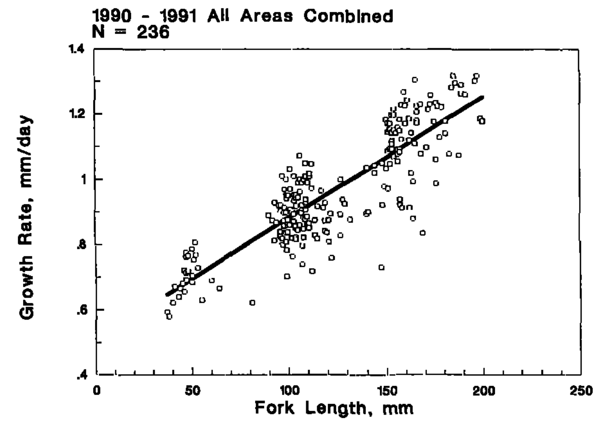

Figure 6

The relationship of fork length to growth rate for juvenile bluefish, *Pomatomas saltatrix*, collected in Maine during 1990–1991. The regression equation is $Y = 0.50990 + 0.00372X$, $R^2 = 0.750$.

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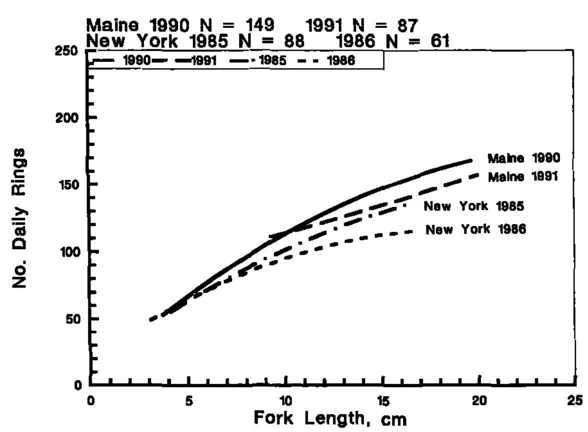

Figure 5

A comparison of the relationship of fork length to number of daily rings for juvenile bluefish, *Pomatomas saltatrix*, from Maine and New York. The regression equations are $Y = 8.53468 + 12.89328X - 0.24416X^2$, $R^2 = 0.847$, for Maine 1990; $Y = 79.49049 + 2.97353X + 0.4563X^2$, $R^2 = 0.635$, for Maine 1991; $Y = 15.19726 + 10.63463X - 0.20203X^2$, $R^2 = 0.840$, for New York 1985; and $Y = 20.22134 + 10.12947X - 0.26495X^2$, $R^2 = 0.835$, for New York 1986.

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