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Predation by Age-0 Bluefish on Age-0 Anadromous Fishes in the Hudson River Estuary

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Abstract.—We examined the diets of 374 age-0 bluefish *Pomatomus saltatrix* collected in the Hudson River estuary from July to October 1989. Fish were the primary prey, accounting for 96–99% of the diet by weight. Anadromous fishes, including striped bass *Morone saxatilis*, blueback herring *Alosa aestivalis*, American shad *Alosa sapidissima*, and Atlantic tomcod *Microgadus tomcod*, constituted a large portion of the diet of bluefish of all sizes. There was a positive linear relationship between prey size and predator size. Small and medium-sized bluefish consumed mostly bay anchovies *Anchoa mitchilli*, striped bass, and white perch *Morone americana*, whereas the largest bluefish primarily preyed on Atlantic tomcod. Bluefish fed opportunistically on the most abundant prey (bay anchovies, striped bass, and white perch) but larger bluefish exhibited a preference for Atlantic tomcod. We also detected an ontogenetic shift in prey type that may have been determined by changes in the size and relative abundance of prey that occurred as the season progressed. Predation by age-0 bluefish may represent a substantial source of mortality for age-0 anadromous fishes in the Hudson River estuary.

The bluefish *Pomatomus saltatrix* is an important piscivorous predator during much of its life (Lassiter 1962; van der Elst 1976; Smale and Kok 1983; Naughton and Saloman 1984; Friedland et al. 1988; Bennett 1989). This species generally spawns offshore and the age-0 fish enter estuaries at 40–60 mm total length (van der Elst 1976; Nyman and Conover 1988; McBride and Conover 1991). Along the east coast of North America, age-0 bluefish enter estuaries as two distinct cohorts: the first arrives in early June (spring-spawned fish) and the second in late August (summer-spawned fish; Kendall and Walford 1979; McBride and Conover 1991). This offshore-to-inshore habitat shift coincides with an ontogenetic change in diet from small crustaceans to fish (Smale 1984; Bennett 1989; Marks 1991).

Mid-Atlantic estuaries are major nursery grounds for a variety of recreationally and commercially important anadromous fishes such as striped bass *Morone saxatilis*, American shad *Alosa sapidissima*, and blueback herring *Alosa aestivalis* (Miller and Dunn 1980; Day et al. 1989; Wootton 1990). Predation by age-0 bluefish may be an important source of mortality for the young of riverine and estuarine spawners, but this has not been documented because previous food habit studies of bluefish have been conducted primarily in marine waters (Grant 1962; Lassiter 1962; Richards 1976; Marais 1984; Friedland et al. 1988; Juanes 1992). Here we examine the diet and predator–prey-size relationships of age-0 bluefish in the Hudson River estuary and consider their potential effects on juvenile anadromous fish species.

Methods

The study area extended over a 24-km section of the lower Hudson River (Figure 1) that represented the primary nursery area for several anadromous fishes including striped bass, Atlantic tomcod *Microgadus tomcod*, and American shad (Moran and Limburg 1986; Beebe and Savidge 1988; Gladden et al. 1988). Fish sampling was

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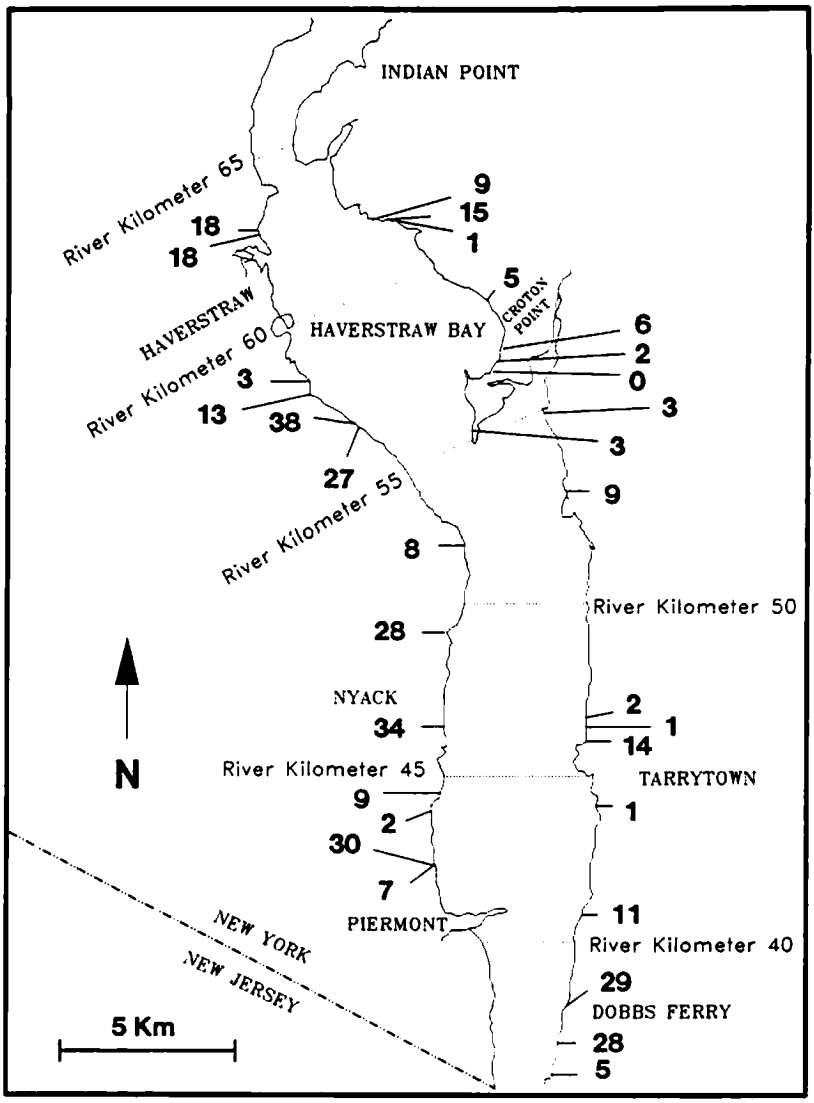

FIGURE 1.—Number of bluefish collected at each sampling site in the lower Hudson River, 1989.

conducted biweekly from mid-July to early November in 1989 at 31 stations. Collections were made with a 61-m × 3-m beach seine with 13-mm-mesh (stretched measure) wings and a 6-mm-mesh (stretched measure) bag; the seine was set from a boat. All fish were sorted by species, counted, and returned to the river with the exception of bluefish, which were immediately preserved in 10% formalin for later stomach analysis. Altogether, 374 bluefish were collected in salinities ranging from 2 to 10.4‰ and water temperatures ranging from 16 to 32°C. All bluefish were weighed wet (±0.01 g) and measured (total length, ±1 mm). Age-0 bluefish in our samples were 47–278 mm long and weighed 0.96–220.3 g.

Bluefish were grouped by cohort and length-class to assess potential ontogenetic diet shifts (Table 1). The mean length of the spring-spawned bluefish in each size category in Table 1 was similar to the mean length of bluefish collected during each sampling trip (July 12–13: 101.2 mm; July 25–26: 115.7 mm; August 9–10: 145.1 mm; September 5–October 6: 189.9 mm). The summer-spawned fish, which first appeared in the catch in early August, were easily distinguished by their smaller size from the spring-spawned fish (see

TABLE 1.—Stomach contents of age-0 bluefish by cohort (spring- or summer-spawned) and size category (total length in millimeters) collected in the Hudson River in 1989. Percent frequency of occurrence = %F; percent wet weight = %W.

	Spring-spawned bluefish								Summer-spawned bluefish			
	78–100 mm		101–120 mm		121–150 mm		150–278 mm		47–138 mm		All bluefish	
Prey item or statistic	%F	%W	%F	%W	%F	%W	%F	%W	%F	%W	%F	%W
Fish prey												
Blueback herring			1.5	1.7	7.0	13.6					1.6	1.1
American shad			4.5	4.2	2.3	5.8	1.2	1.1			2.0	1.5
Atlantic tomcod							28.6	58.5			9.4	50.3
Bay anchovy[a]	31.7	41.1	31.8	37.7	18.6	15.4	7.1	2.8	40.0	23.1	22.0	5.8
Striped bass	2.4	16.6	4.5	14.5	7.0	16.5	9.5	7.9			5.9	8.8
White perch[b]			3.0	6.6	4.6	3.5	6.0	3.2			3.5	3.3
Morone spp.	2.4	2.5	3.0	4.7	7.0	8.7	4.8	3.2	15.0	44.7	5.1	4.4
Atlantic silverside[c]	2.4	1.9	3.0	1.7	2.3	8.0	1.2	1.4			2.0	1.9
Cynoscion spp.							1.2	0.9			0.4	0.8
Tessellated darter[d]			1.5	3.0							0.4	0.1
Spottail shiner[e]							1.2	0.3			0.4	0.2
Bluefish							1.2	7.0			0.4	6.0
Unidentified fish remains	46.4	35.3	43.9	23.1	60.5	25.3	40.5	10.0	55.0	32.1	46.9	12.3
Fish eggs			1.5	0.0							0.4	0.0
Total fish	82.3	97.4	90.0	97.2	97.7	96.8	97.6	96.3	100.0	99.9	94.5	96.6
Invertebrate prey												
Blue crab[f]					2.3	2.0	2.4	3.2			1.2	2.9
Crangon spp.							3.6	0.1			1.2	0.1
Zoeae	12.2	2.5	10.6	2.5	11.6	1.2					6.7	0.2
Other	4.9	0.1			2.3	0.2	2.4	0.0	5.0	0.1	2.0	0.0
Miscellaneous												
Plant matter and gravel	7.3	0.0	7.6	0.3	2.3	0.0	3.6	0.2			5.1	0.2
Bluefish samples by cohort and size category												
Total number of stomachs analyzed	58		104		71		108		33		374	
Number containing prey	41		66		43		84		20		254	
Mean length of bluefish (mm)	93.9		110.05		133.4		195.9		108.3		128.4	

[a] *Anchoa mitchilli.* [b] *Morone americana.* [c] *Menidia menidia.* [d] *Etheostoma olmstedi.* [e] *Notropis hudsonius.* [f] *Callinectes sapidus.*

Kendall and Walford 1979; Nyman and Conover 1988; McBride and Conover 1991).

Bluefish stomachs were removed by incisions just posterior to the pharynx and anterior to the intestine. Each stomach was opened and the contents were identified, counted, blotted dry, weighed (±0.01 g), and measured (±0.1 mm). Two prey-consumption indices were computed as described by Hyslop (1980):

- percent frequency of occurrence (%F), the number of stomachs in which a prey item occurred expressed as a percentage of the total number of stomachs containing food; and
- percent wet weight (%W), wet weight of a prey item in the stomach expressed as a percentage of the total wet weight of all food items in the stomach.

Bluefish predators were separated into length-classes for comparisons and the relationship between predator length and prey length was determined with regression analysis and analysis of variance. To assess feeding selectivity, we compared the relative abundance of each of the 10 most abundant prey fishes in the Hudson River in 1989 (calculated from our field surveys) to their relative abundance in bluefish guts (measured as the frequency of occurrence by number) using Strauss's (1979) linear index.

$$L = r_i - p_i;$$

r_i is the abundance of prey type i in the gut and p_i is the abundance of prey item i in the environment. The electivity values range from +1 to −1, corresponding to positive ("preference") and negative ("avoidance") selection. Values between −0.10 and +0.10 are generally assumed to indicate nonselective ("random") feeding. The index was tested statistically with a two-sided Wilcoxon's signed-rank test (Sokal and Rohlf 1981; Kohler and Ney 1982). We performed the selectivity

analyses only on fish prey because we did not estimate the relative abundance of nonfish items eaten by bluefish. For this analysis, *Morone* spp. (fish of the genus *Morone* that could not be identified to species) were designated as striped bass or white perch according to the relative abundance of the two species in the field.

Results

Diet Analysis

Fish were the most important prey by frequency of occurrence and by weight for bluefish in all length-classes and cohorts (Table 1). Fish occurred in 82–100% of the bluefish stomachs, making up 96 to nearly 100% of the diet by weight. Bay anchovies were the predominant food and were most abundant in stomachs of bluefish smaller than 150 mm (Table 1; Figure 2). Atlantic tomcod were eaten only by spring-spawned bluefish larger than 150 mm, but accounted for 59% of diet weight for these predators (29%F). Collectively, striped bass, white perch, and *Morone* spp. occurred in 5–20% of the stomachs of bluefish in all length-classes and were 14–45% of the diet by weight (Table 1; Figure 2). American shad and blueback herring were somewhat common prey of 101–150-mm bluefish. Fish eaten less frequently were *Cynoscion* spp., tessellated darters, spottail shiners, and Atlantic silversides. Two small bluefish (50.3 and 51.4 mm) found in the stomach of a 198-mm bluefish were the only evidence of cannibalism. Unidentifiable fish remains were a large proportion of the gut contents of bluefish in all size-classes.

Blue crabs were the most important invertebrates by weight eaten by bluefish; they accounted for 2% (2%F) of the diet by weight of 121–150-mm fish and 3% (2%F) of the diet of fish larger than 150 mm. Zoeae were eaten by bluefish smaller than 150 mm and accounted for a maximum of 2.5% of the diet by weight (12%F) in bluefish smaller than 121 mm. Miscellaneous items (plant material and gravel) were of no dietary significance and were probably ingested accidentally. Empty stomachs were 22–39% of the entire sample (Table 1).

Predator–Prey Relationships

There was a significant, positive relationship ($r^2 = 0.61$, $N = 113$, $P \leq 0.0001$) between bluefish length and prey length (Figure 3). The analysis of variance indicated that mean prey lengths varied significantly among bluefish length-classes ($F = 45.3$; df = 3, 128; $P \leq 0.0001$). The length range of fish consumed appeared to increase with bluefish length. The largest increase in the length range of prey occurred in fish longer than 150 mm. An ontogenetic shift in prey type was also evident. Small bluefish (<120 mm) fed predominantly on bay anchovies, intermediate sizes (121–150 mm) fed mainly on *Morone* spp. and other fish, and the largest bluefish (>150 mm) fed primarily on Atlantic tomcod (Figures 2, 3).

The electivity indices showed that most prey species were ingested in proportion to their relative abundance in the field ($L < |0.10|$; i.e., "random" feeding). Atlantic tomcod, which seemed to be ingested preferentially ($L = 0.173$), was the exception (Table 2). The Wilcoxon signed-rank test suggests that bluefish ingested fish in proportion to their relative abundance ($N = 9$, $T+ = 24$, $T- = 31$; $P > 0.05$ in both cases).

Discussion

Previous studies demonstrated that age-0 bluefish in estuarine and marine environments are highly piscivorous and feed primarily on atherinids and engraulids (de Sylva et al. 1962; Grant 1962; van der Elst 1976; Smale 1984; Friedland et al. 1988; Bennett 1989; Juanes 1992). The forage base in the Hudson River estuary includes marine, freshwater, estuarine, and anadromous species, many of which use the river as a nursery area (Beebe and Savidge 1988; Gladden et al. 1988; McKown 1991). Our results indicate that age-0 anadromous fishes are a major portion of the diet of age-0 bluefish in the lower Hudson River. Sissenwine (1984) inferred that high mortality rates during the juvenile stages of fishes may significantly affect recruitment. The high growth rate (1.2–1.8 mm/d; Nyman and Conover 1988; McBride and Conover 1991) of bluefish during their estuarine residency coupled with a relatively large food intake (17–25% body weight/d; Juanes 1992) suggest that the effect of bluefish predation on the abundance of their prey could be substantial. The intensity of predation and its effect on a particular species in any given year is likely to reflect the relative abundances of predator and prey as well as the food preferences of the predator.

In a diverse community like that in the Hudson River estuary, opportunistic predators are presented with a broad array of potentially suitable prey (Moran and Limburg 1986; Beebe and Savidge 1988; Gladden et al. 1988). Predators may respond by selecting prey species that are highest in abundance, by feeding preferentially on partic-

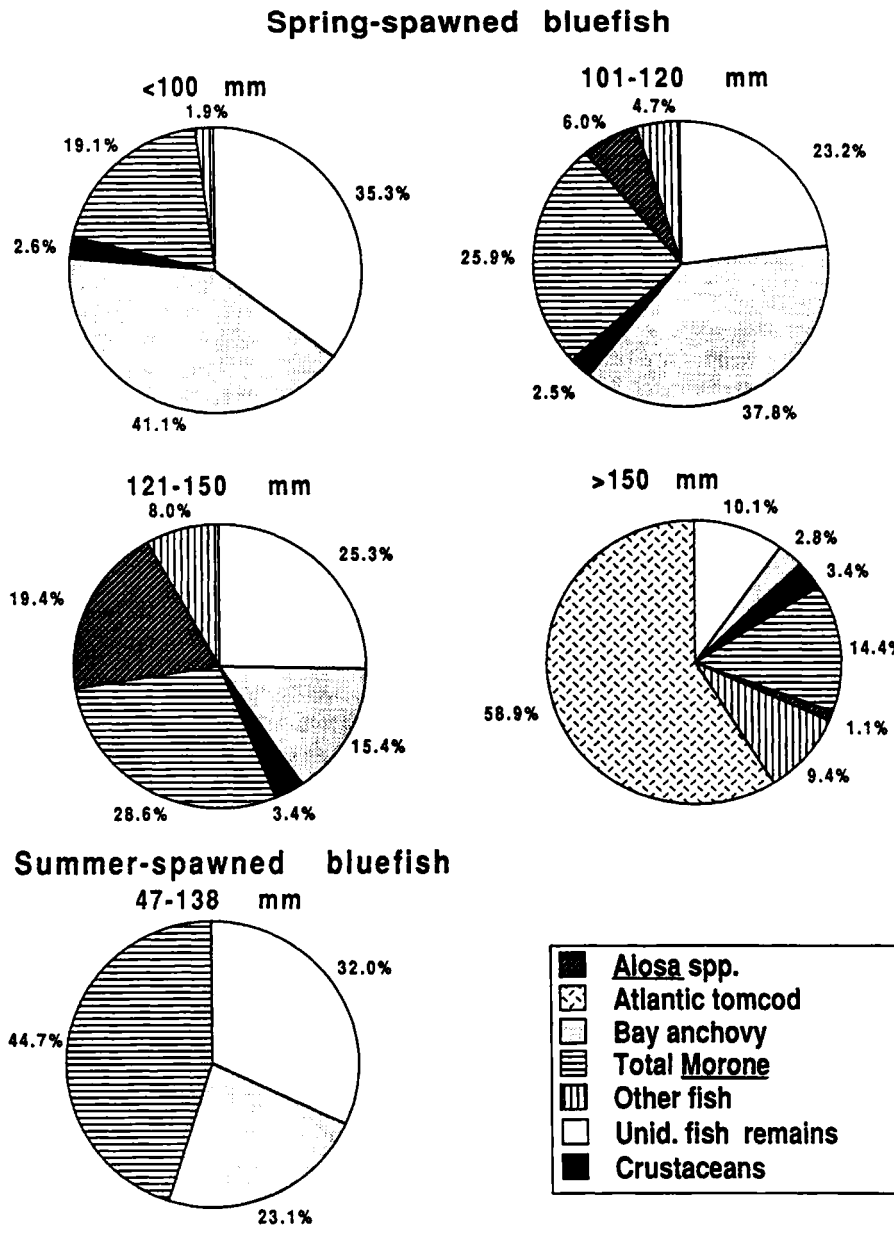

FIGURE 2.—Composition of the diet (by weight) of age-0 spring-spawned and summer-spawned bluefish in different length classes. *Alosa* spp. includes American shad and blueback herring. Total *Morone* includes striped bass, white perch, and unidentified *Morone* spp. Other fish include Atlantic silverside, *Cynoscion* spp., tesselated darter, spottail shiner, and bluefish. Crustaceans include blue crab, *Crangon* spp., zoeae, mysids, and gammarid amphipods, as well as insects.

ular species regardless of their abundance, or by feeding randomly (Ivlev 1961; Forney 1971). Our results suggest that age-0 bluefish generally feed randomly. Species that were relatively abundant but did not occur in the diet were the hogchoker and the banded killifish *Fundulus diaphanus*. Their absence from the diet may be attributed to the body form of the hogchoker or to the reduced availability of these demersal or nearshore species to pelagic predators. Atlantic tomcod was the only

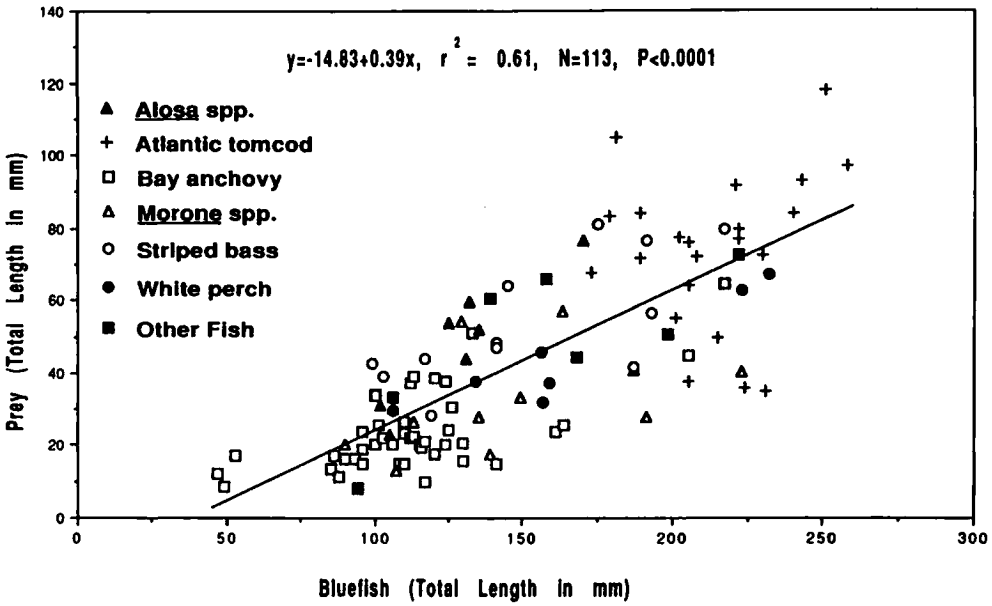

FIGURE 3.—Relationship between total length of prey fish (y) and total length of bluefish predators (x).

species that appeared to be ingested preferentially. The Atlantic tomcod is a coldwater, anadromous species that is most abundant in September and October (Klauda et al. 1988; McLaren et al. 1988; McKown 1991). Atlantic tomcod are probably the largest prey available to age-0 bluefish and they were consumed only by the largest bluefish. Texas Instruments (1976) also found that anadromous fishes were a large portion of the diet of age-0 bluefish in the lower Hudson River and that Atlantic tomcod was their most important fish prey in September.

When bluefish are abundant, they may be an important source of mortality for age-0 anadromous fishes. Little is known about the vulnerability of young striped bass to predation by other fishes (McGovern and Olney 1988; Monteleone and Houde 1992), but McFadden (1977) suggested that predation by bluefish was the greatest source of mortality for juvenile striped bass in the Hudson River. Texas Instruments (1976) found that striped bass were a larger proportion of the bluefish diet in 1973, when striped bass abundance was high, than in 1974, when striped bass abundance was low. In our study, the striped bass ranked at least third in dietary importance (8–17% by weight), and their actual importance may have been greater because a large proportion of the prey

TABLE 2.—Electivity values for the 10 most abundant teleost species in the Hudson River. Terms: n is the number of bluefish individuals containing that prey species, r is the percent occurrence in the gut, p is the percent occurrence in the environment, K is the rank of p, L is the Strauss index calculated as $r - p$, and W is the Wilcoxon signed rank of L ($T+$, the sum of the positive ranks = 24, and $T-$, the sum of the negative ranks = 31). The prey category *Morone* spp. (n = 13) was split proportionately between striped bass (15 + 8) and white perch (9 + 5).

Prey species	n	r	p	K	L	W
Bay anchovy	56	0.415	0.384	1	0.031	+7
Striped bass	23	0.170	0.185	2	−0.015	−5
White perch	14	0.104	0.184	3	−0.080	−8
Blueback herring	4	0.030	0.116	4	−0.086	−9
American shad	5	0.037	0.036	5	0.001	+1.5
Atlantic silverside	5	0.037	0.024	6	0.013	+4
Hogchoaker[a]	0	0.000	0.021	7	−0.021	−6
Striped mullet[b]	0	0.000	0.010	8	−0.010	−3
Bluefish	1	0.007	0.006	9	0.001	+1.5
Atlantic tomcod	24	0.178	0.005	10	0.173	+10

[a] *Trinectes maculatus.* [b] *Mugil cephalus.*

in the "unidentifiable fish remains" and "*Morone* spp." categories was probably striped bass.

Prey size and prey density may also be critical determinants of bluefish diet. We detected a relative shift in prey type with increasing bluefish size despite the homogeneous composition of the prey fish population throughout the sampling season (McKown 1991). The positive linear relationship between predator and prey sizes suggests that the shifts in prey types were partially size related. Thus, bay anchovies and *Morone* spp. were consumed mainly by small and medium-sized bluefish (<150 mm) whereas Atlantic tomcod were eaten exclusively by fish larger than 150 mm. The smallest bluefish containing an Atlantic tomcod was 173 mm (Figure 3). An ontogenetic increase in prey size is commonly seen in studies of fish food habits (Brooks and Dodson 1965; Ross 1978; Hunter and Kimbrell 1980; Peters 1983; Wetterer 1989; Persson 1990). However, the mean size of ingested prey may increase because the maximum prey size increases while the minimum prey size remains constant (Hunter 1980; Polis 1988). Although mean prey fish size increased with bluefish size in our study, even the largest bluefish ingested relatively small bay anchovies. A similar result was also observed in the diets of oceanic age-0 (17–74 mm) bluefish (Marks 1991) and in age-0 bluefish collected throughout the summer in the Great South Bay estuary in New York (Juanes 1992).

Our results indicate that age-0 anadromous fishes, when abundant, are likely to constitute a large portion of the diet of age-0 bluefish in estuaries. Seasonal and year-to-year variation in age-0 bluefish diets (Texas Instruments 1976; Friedland et al. 1988) and variation in abundance of spring- and summer-spawned bluefish (Nyman and Conover 1988; McBride and Conover 1991) may strongly affect mortality in prey fish populations in the Hudson River and other estuaries, but the dynamic relationships cannot be understood without additional study.

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