ONTOGENETIC SHIFTS IN FEEDING HABITS OF JUVENILE STRIPED BASS (*MORONE SAXATILIS*) IN THE MID-HUDSON RIVER ESTUARY

A Final Report of the Tibor T. Polgar Fellowship Program

Rebecca C. Jordan

Polgar Fellow

Program in Organismic and Evolutionary Biology
University of Massachusetts at Amherst
Amherst, MA 01003

Project Advisor:

Francis Juanes
Department of Forestry and Wildlife Management
University of Massachusetts at Amherst
Amherst, MA 01003

Jordan, R.C. and F. Juanes. 1999. Ontogenetic shifts in feeding habits of juvenile striped bass (*Morone saxatilis*) in the mid-Hudson River estuary. Section VI:21pp. In W.C. Nieder & J.R. Waldman (eds.), Final Reports of the Tibor T. Polgar Fellowship Program, 1998. Hudson River Foundation.

ABSTRACT

Striped bass (*Morone saxatilis)* are a commercially and recreationally valuable fish. In recent years, striped bass population numbers have increased dramatically. This population increase will most likely impact the trophic interactions occurring in the regions they inhabit. Little, however, is known about what juvenile striped bass feed on in estuarine systems, despite the fact that estuaries are an important habitat for juvenile striped bass. The objectives of this study were to investigate the trophic habits of the juvenile (age-0) striped bass in the Hudson River Estuary and more specifically to assess if ontogenetic shifts occur in prey type and size. The juveniles were collected using a beach seine on a bi-weekly basis from July to November over four years (1994-1997). Each fish was measured and weighed. The stomach contents were identified to the lowest taxa possible and quantified into size classes. We found that amphipods (mostly *Gammarus spp.)* constituted the most frequently occurring prey item and highest percentage of weight in juvenile striped bass diet. We saw little inter-annual differences in prey consumed. In addition, we found that an ontogenetic shift in prey type and prey size range occurred such that larger fish consumed a wider range of prey types and sizes. Our results are similar to those found in a previous Hudson River study (Gardinier and Hoff 1982) with the exception that no copepods or other planktonic prey were consumed. In contrast to our results, striped bass, in other estuaries (e.g., Potomac, Miramichi, etc.), fed on different prey items likely because of the availability of different prey and their generalist feeding strategy.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Striped bass (*Morone saxatilis*) have been a focus of recent studies for a number of reasons. First, striped bass are one of the most commercially and recreationally valuable anadromous fish found along the Atlantic coast of North America. In addition, the distribution of this species is widespread, ranging from the St. Lawrence River in Canada to the St. Johns River in Florida (Rulifson and Mckenna 1987). Finally, after a severe collapse (Houde and Rutherford 1993), dramatic increases in striped bass population sizes have been observed in recent years (Field 1997). This increase in population numbers will mostly likely impact ecological interactions along the range of habitats where striped bass exist.

Estuaries constitute an important habitat in the life history of striped bass (Setzler-Hamilton et al. 1981; Fay et al. 1983; Everly and Boreman 1996). The young are spawned in tidal rivers and migrate, as juveniles, into estuaries to feed and grow (Setzler-Hamilton et al. 1981; Rutherford and Houde 1994; Robichaud-LeBlanc et al. 1996; McGovern and Olney 1988 1996). The estuary continues to be an important feeding ground for adults as well (McLaren et al. 1981; Dunning et al. 1997). Given that striped bass use estuaries during all life stages, they are believed to influence the estuarine community as major components of the trophic web (Gardinier and Hoff 1982; McGovern and Olney 1988; Hartman and Brandt 1995a, b).

The Hudson River estuary is inhabited by a diverse assemblage of fishes (Beebe and Savage 1988) over a range of habitats. Striped bass are abundant in the Hudson and have been shown to play an integral role in the trophic interactions within the Hudson

River (Rathjen and Miller 1957; Gardinier and Hoffs 1982; Pace et al. 1993; Dunning et al. 1997; Buckel 1997). The lower estuarine portion, in particular, has been cited as an important nursery area for juvenile striped bass (Dey 1981; McKown and Young 1992; Dunning et al. 1997).

It has been suggested that year-class strength of striped bass is highly dependent upon juvenile feeding success (Stevens et al. 1985). Predation by larger fish is probably the major source of mortality within the juvenile stages (Juanes et al. 1993; Buckel and Conover 1997). This size-linked susceptibility is found in many fish (Werner and Gilliam 1984; Juanes 1994; Sogard 1997) and suggests that feeding success shown through enhanced growth rate can have a critical effect on survival and recruitment. The shift to piscivory, in particular, has been shown to greatly affect growth (Juanes and Conover 1995) and likely survival. Analysis of diet habits is necessary in assessing feeding success and as the first step in quantifying year class-strength and recruitment.

The dietary habits of Hudson River striped bass, including the juvenile stages, were briefly examined in the 1970s in response to the implementation of a number of power plants within the estuary (Gardinier and Hoff 1982; Barnthouse et al. 1988). Since then, little work has been done to investigate the feeding habits of juvenile striped bass within the river even though habitat quality and fish populations have changed. A number of recent studies, however, have focused on the diets of larval striped bass (Hjorth 1988, Pace et al. 1993; Limburg et al. 1997). Hjorth (1988) states that juveniles must be feeding on the same food items as the larvae, but provides no evidence for this statement. In other systems, it has been clearly shown that ontogenetic diet shifts in prey type occur frequently within the first year of life (Rulifson and McKenna 1987; Robichaud-LeBlanc et al. 1997). Furthermore, in the Hudson River, striped bass juveniles are generally located further downriver than larvae, in shallower and more saline habitats (Dey 1981; Boreman and Klauda 1988; Englert and Sugarman 1988). This shift in habitat, in combination with increasing size, is likely to lead to changes in the dietary habits (in either prey size or type) of juvenile striped bass.

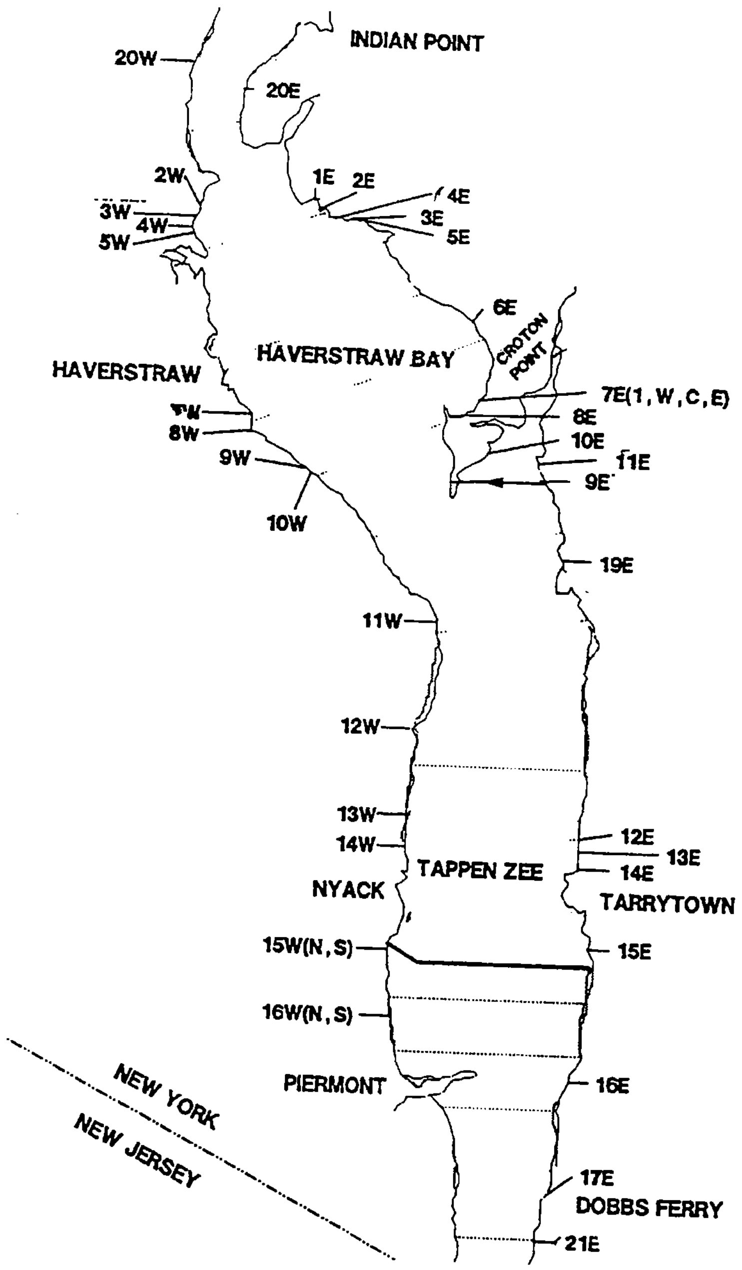
OBJECTIVES

The objectives of this study were to quantify juvenile striped bass diet, with regard to food type and size in the lower Hudson River estuary over a number of summer seasons. In addition, the relationship between predator size and prey size/type were investigated to discern any ontogenetic shifts in feeding habits. We restrict our analysis to age-0 juveniles.

METHODS

The study area is located around the Haverstraw Bay region within the lower Hudson River estuary (Figure 1). This area is a representative nursery area for juvenile striped bass (McKown, NYSDEC, pers. comm.). The fish were collected through a survey operated by the New York State Department of Environmental Conservation (NYSDEC). This survey is conducted annually on a bi-weekly basis from mid-July to early November. Samples were collected with a 61 m seine net at 25 fixed stations in the Haverstraw Bay. Approximately fifty juvenile striped bass were taken per month from late July to November (1994-1997) from this survey. The fish were immediately frozen for later analysis.

Figure 1. STUDY SITE. Below is the Haverstraw Bay (river kilometer 35 to 70) region of the Hudson River Estuary. Samples were taken at random over the twenty five fixed stations indicated by a solid line.



Total length, TL (± 0.01mm) and wet weight (± 0 .001 g) were measured from each fish. Occasionally individual tails were damaged and fork length (FL) or standard length (SL) were taken rather than total length. In these cases we converted to total length using the following regression relationship: TL= FL(1.10)-1.13 (R^2= 0.91, p<0.00, n=171), or TL= (total length- 4.23)/ 0.76 (R^2= 0.96, p<0.00, n=166). These equations were obtained through regression analysis on a sub-sample of the fish analyzed in this study where all three length measurements were taken.

We then removed and opened the stomachs from each fish. The contents were identified to the lowest taxa possible (using Weiss 1995), counted, weighed individually and as a whole (wet weight), and finally designated into three size classes based on the prey type: small (5-10mm TL), medium (11-20mm TL), and large (above 20mm TL).

The prey consumption patterns were described using two separate indices (Hyslop 1980). The first index was percent frequency occurrence, i.e., the number of stomachs in which a prey item occurred expressed as a percentage of the total number of stomachs containing food. The second index was percent wet weight, i.e., 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.

To assess ontogenetic shifts, juveniles were grouped into separate length classes by total length: <50mm, 50-75mm, 76-100mm, and >100mm. Using these groupings, I investigated the relationship between predator size and prey size. In particular, I used regression analysis to determine the predator and prey size relationship with regard to fish prey.

RESULTS

A total of 695 fish were analyzed. Of these, 576 (83%) had stomachs containing food items. The average number of prey types in an individual stomach was 1.33 (sd = ±0.75) and on average 0.9 % (sd = ± 1.22) of the total wet weight of the fish was attributed to the food items in the stomach. Additionally, several of the stomachs contained sediment and rocks.

Amphipods (mostly *Gammarus spp.*) were the most frequently occurring (50.0%) component of the juvenile diet (Table 1) both across the four years (Figure 2), and within each year (Figure 3). Decapod crustaceans (18.6%) and annelids (15.6%) also constituted a significant portion of the juvenile diet. As is usual in diet analysis studies, a large portion of the prey items were unable to be identified because the prey items were too digested.

Only slight inter-annual diet differences were noted over the four years (Figure 2). In 1994, brachyura (crabs) had a higher percent of occurrence than found in other years. Amphipods, when looking over all four years, occurred slightly less in 1995, and somewhat more in 1997. We found that the occurrence of unidentified prey decreased with year, presumably because of the age of the samples.

The percent wet weight analysis yielded slightly different results (Table 1). Amphipods (23.8%) still constituted the major portion of the diet, but decapods (28.2%) and fish (12.0%) constituted higher percent wet weight (Figure 3) versus their percent occurrence. Some caution should be used when considering the results of the percent wet weight analysis because a number of fish had been freezer burned to varying degrees.

Table 1. PERCENT FREQUENCY OF OCCURRENCE AND WET WEIGHT.
Below are the values for percent frequency of occurrence (%FO) and percent wet weight (%WW). *Gammarus spp.* constitute the highest values for both %FO and %WW. For the larger prey items, there is a slight increase of %WW when compared to %FO. Note that the weights of the fish scales were not taken.

Order Infraorder	Most specific taxa possible	%FO	%WW
Amphipoda			
	Gammarus spp.	46.7	23.7
	unidentified amphipods	3.3	0.1
Decapoda			
Brachyura	unidentified crabs	12.3	14.0
Caridea	*Crangon spp.*	3.5	10.1
	Palaemonetes pugio	<0	0.3
	Pandalidae	<0	0.8
	small unidentified shrimp (<5mm)	2.3	1.1
	large unidentified shrimp (>5mm)	0.5	2.0
Annelida			
	Nereis spp.	5.7	20.7
	unidentified polychaete	2.6	1.4
	unidentified annelid	7.3	1.6
Isopoda			
	Cyathura polita	3.6	1.8
	unidentified isopod	2.3	0.4
Fish			
	Anchoa mitchilli	1.9	6.1
	Morone spp.	0.4	4.9
	fish scales	3.3	n/a
	other (non *Anchoa/Morone)*	0.7	1.0
Unidentified			
	unidentified remains	39.4	18.5

Figure 2. PERCENT FREQUENCY OF OCCURRENCE
Below are the percent frequency of occurrence for the major prey types combined from all four years. Amphipods were the most frequently occurring.

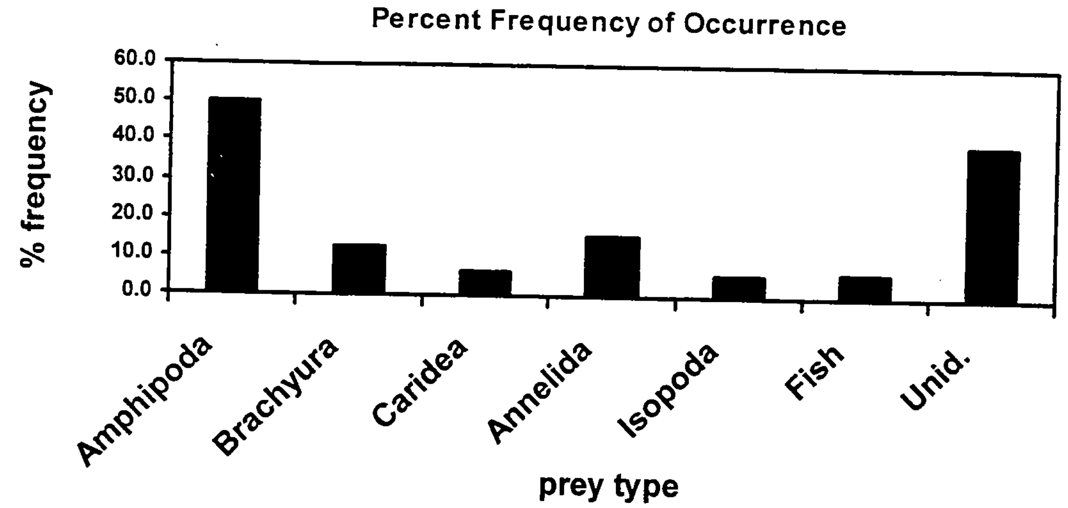


Figure 3. PERCENT WET WEIGHT
Below are the percent wet weights for the major prey types from all four years. Amphipods constitute the higest wet weight percentages.

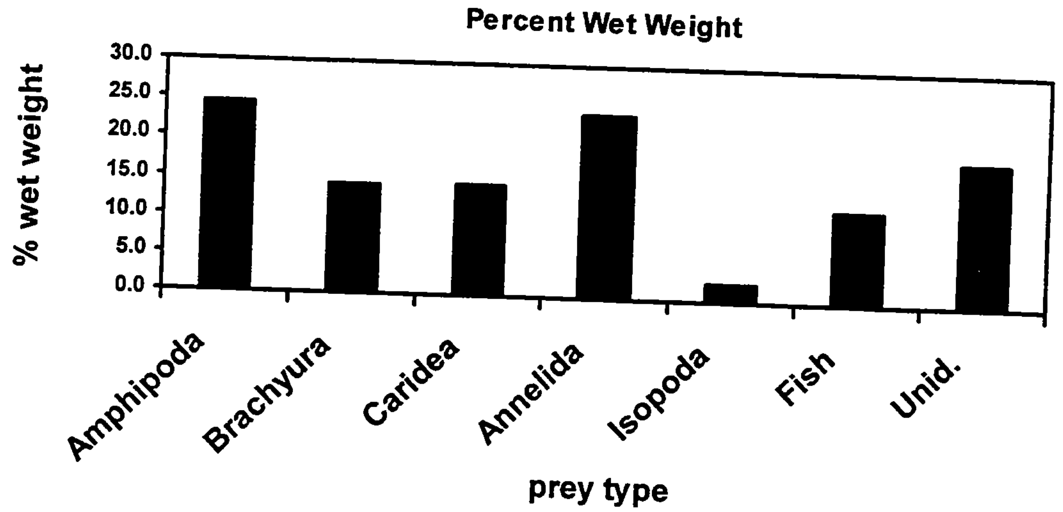
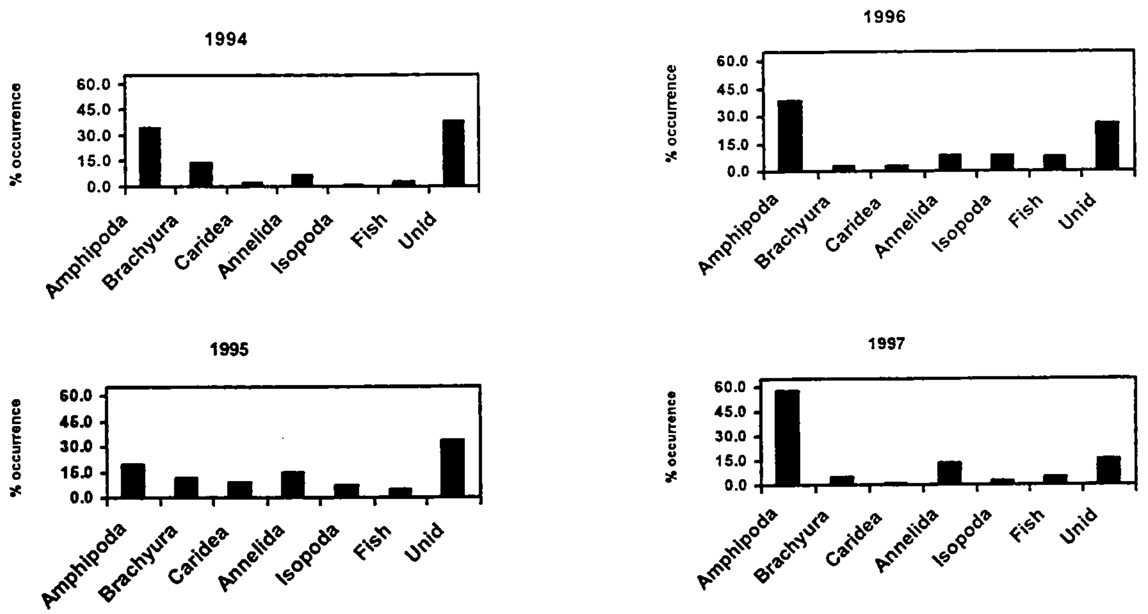


Figure 4. INTERANNUAL DIET DIFFERENCES
Below are the percent frequency of occurrence of each prey item separated over the four years of the study. Only slight differences were evident. In 1994, brachyura (crabs) had a higher percentage when compared to other years. Amphipods occurred slightly less in 1995 and more in 1997. The incidence of unidentified prey items decreased with year.



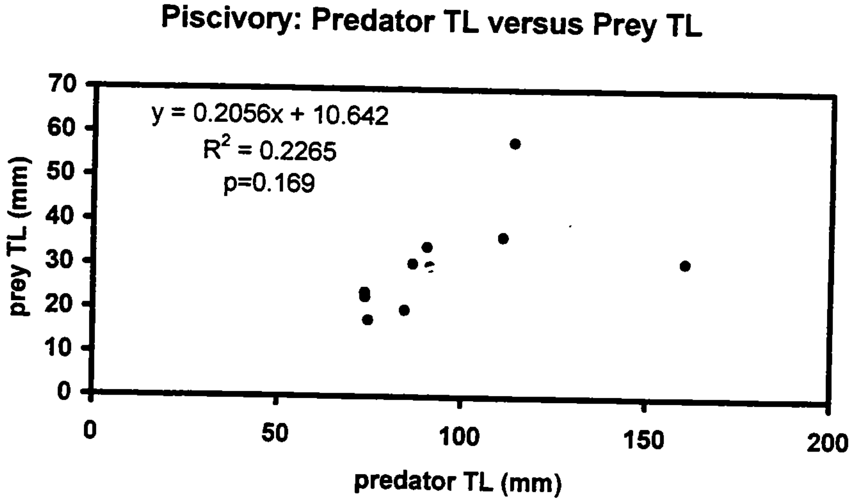
Because of this problem, inter-annual diet differences were not considered with this metric.

The results of the predator versus prey size analysis indicated that a slight ontogenetic shift did occur (Table 2). As the predator increased in length, the range of prey consumed and the eveness (i.e., similar numbers consumed from each prey size class) also increased. Finally, fish appeared in the diet at approximately 74 mm. Only a small number of fish were consumed. Seven of the ten total fish consumed were bay anchovy (*Anchoa mitchilli*), and the other three were white perch (*Morone americana*), striped bass (*Morone saxatilis*), and pipefish (*Syngnathus fuscus*). We did not find a significant relationship between predator versus prey total length (Figure 5). The relationship did become significant (R^2=0.28, p<0.00, n=9), however, when the pipefish was removed from the analysis.

Table 2. PREDATOR VERSUS PREY SIZE
Below are the percentages of small (5-10mm TL), medium (11-20mm TL), and large (>20mm TL) prey items consumed by each predator size class (also in mm TL). The range and eveness of prey sizes consumed increases with predator size.

	Prey size class (%)		
Predator size (mm)	Small	Medium	Large
<50	78.5	21.4	0.0
51-75	95.8	0.0	4.21
76-100	62.0	28.7	9.39
>100	31.1	35.6	33.4

Figure 5. PREDATOR VERSUS PREY LENGTH: PISCIVORY
Predator TL and prey (fish only) TL are plotted below. In addition, the results from the regression analysis are provided.



DISCUSSION

The results of our study show that *Gammarus spp.* constitute the most important prey item of juvenile (age-0) striped bass in the lower Hudson River estuary. A previous

the juvenile (age-0) diet (Gardinier and Hoff 1982). Studies done in other east coast estuaries, however, found mysids and shrimp to be the major components of juvenile diets (Markle and Grant 1970; Rulifson and McKenna 1987; Robichaud-LeBlanc et al. 1997). Boynton et al. (1981), however, report for the Potomac estuary that amphipods and insects constituted the most frequently occurring prey item in the juvenile diet. These authors also report that there were differences in diet with regard to the habitats (i.e., nearshore versus offshore and along gradients of salinity) where juveniles were collected. Habitat related differences can be noted in the Hudson River as well. For example, Schmidt (1993) found that in Manitou Marsh, a tidal marsh located on the east bank of the Hudson River, juveniles fed mostly on shrimp (*Palaemonetes pugio*) and copepods. Little data are available as to what portions of the Hudson River holds the highest abundances of juvenile striped bass, however, in other systems, it has been suggested that juveniles prefer shallower more saline portions of estuaries (Wainwright et al. 1996, Boynton et al. 1981) such as the portion of the Hudson where our study was conducted. No conclusions about prey selectivity, however, can be made without knowledge of prey availability.

Annelids and decapods were also constituents of juvenile diets and to a much lesser extent, fish and isopods. When analyzing the diet by wet weight, fish and shrimp had higher percentages than when considering percent occurrence. Presumably this shift in percentages is seen because of the larger size of both of these prey items. In addition, we found sediment and rocks in a large number of stomachs. This, in conjunction with a lack of planktonic prey suggests that the juveniles in this study were feeding mostly on the benthos. Finding mostly benthic prey is unusual when compared to the previous

Hudson River study where copepods were present in the juvenile striped bass stomachs (Gardinier and Hoff 1982).

We saw very little inter-annual variation in diet over the four years studied. In percent occurrence, crabs were slightly higher in 1994 than in other years. Amphipods, though highest in all years, fluctuated slightly by being lower in occurrence in 1995 and highest in 1997. Again, it is hard to say whether juveniles are selectively feeding on these prey items versus other prey because of a lack prey availability data. Other investigators, however, suggest that juvenile striped bass tend to feed on the prey items that are most available (Boynton et al. 1981, Robichaud-LeBlanc et al. 1997), although prey availability is rarely measured. Boynton et al. (1981) also suggest that it is this assumed generalist feeding strategy employed by juvenile striped bass that allow them to better adapt to varying food items. This feeding flexibility differs from the larval stages and could explain the broader habitat use and be a major contributor toward lower juvenile mortality.

In addition, our data suggest that ontogenetic shifts in both prey size and type in feeding habits do occur in juvenile striped bass. As a predator increases in length, it will ingest larger prey items while continuing to feed on smaller prey (i.e., the range of prey sizes consumed increases with predator length). In being able to consume a wider range of prey items, the juveniles will presumably increase their chances of feeding and increase the range of habitats they can feed in. It is unclear, however, what controls the limitation on prey size consumed (i.e., gape, foraging efficiency, etc.).

In our study, fish were first consumed by striped bass of approximately 74 mm TL. Most studies do not provide the exact length at when the onset of piscivory began in juvenile striped bass with the exception of Markle and Grant (1970), who reported that fish were first found in juvenile diets at 70 mm. Other studies, however, do mention that fish are not an important component of the diet until the juveniles reach 100-140 mm (Gardinier and Hoff 1982; Rulifson and McKenna 1987; Robichaud-LeBlanc et al. 1997). Most of the fish consumed in our study were bay anchovy. We did note one case of cannibalism, but are unsure as to whether this can be attributed to net feeding or as a natural event.

The data presented in this report are part of an on-going study of juvenile striped bass feeding habits in the Hudson River estuary. Future plans include collecting juveniles of larger size classes to futher investigate ontogenetic shifts and piscivory. In addition, data on habitat differences will be collected to see what effect habitat has on feeding habits. Given the importance of striped bass, especially in recent years, investigations on the impact of this species in estuarine systems should continue.

ACKNOWLEDGEMENTS

We would like to thank the Tibor T. Polgar Fellowship Program for supporting this work. Additionally, we would like to thank Kim McKown and the New York Department of Environmental Conservation, Tom Hurst, and David Howe for their contributions to this project. Finally, we thank the University of Massachusetts where this work was completed.

REFERENCES

Barnthouse, L. W., R. J. Klauda, D. S. Vaughan, and R. L. Kendall (editors). 1988. Science, law, and Hudson River power plants: a case study in environmental impact assessment. American Fisheries Society Monograph 4.

Beebe, C. A., and I. R. Savidge. 1988. Historical perspective on fish species composition and distribution in the Hudson River estuary. American Fisheries Society Monograph 4: 25-36.

Boreman, J., and R. J. Klauda. 1988. Distributions of early life stages of striped bass in the Hudson River estuary 1974-1979. American Fisheries Society Monograph 4: 53-58.

Boynton, W. R., T. T. Polgar, and H. H. Zion. 1981. Importance of juvenile striped bass food habits in the Potomac estuary. Trans. Am. Fish. Soc. 110: 56-63.

Buckel, J. A. 1997. Impact of bluefish predation on estuarine and continental shelf fishes. Doctoral dissertation. SUNY Stony Brook, Stony Brook, New York.

Buckel, J. A., and D. O. Conover. 1997. Movements, feeding periods and daily ration of piscivorous young-of-the-year bluefish (*Pomatomus saltatrix*) in the Hudson River estuary. Fish. Bull. 95: 665-679.

Dey, W. P. 1981. Mortality and growth of young-of-the-year striped bass in the Hudson River estuary. Tran. Am. Fish. Soc. 110: 151-157.

Dunning, D. J., J. R. Waldman, Q. E. Ross, and M. T. Mattson. 1997. Use of Atlantic tomcod and other prey by striped bass in the lower Hudson River estuary during winter. Trans. Am. Fish. Soc. 126: 857-861.

Englert, T. L., and D. Sugarman. 1988. Patterns of movement of striped bass and white perch larvae in the Hudson River estuary. Pages 148-168. *In* Fisheries research in the Hudson River. C. L. Smith, editor. State University of New York Press, Stony Brook.

Everly, A. W., and J. Boreman 1996. Habitat requirements of important fish species inhabiting the Hudson river estuary. NMFS, Office of Habitat Protection.

Fay, C. W., R. J. Neves, and G. B. Pardue 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid- Atlantic)--striped bass. U.S. Fish and Wildlife Service Biological Report. 82(11.8). U.S. Army Corps of Engineers TR EL-82-4, Vicksburg. 38 p.

Field, J.D. 1997. Atlantic striped bass management. Fisheries 22: 6-9.

Gardinier, M.N. and T.B. Hoff. 1982. Diet of striped bass in the Hudson River estuary. NY Fish & Game J. 29: 152-165.

Hartman, K. J., and S. B. Brandt. 1995a. Predatory demand and impact of striped bass, bluefish, and weakfish in the Chesapeake Bay: applications of bioenergetics models. Can. J. Fish. Aquat. Sci. 52: 1667-1687.

Hartman, K. J., and S. B. Brandt. 1995b. Trophic resource partitioning, diets, and growth of sympatric estuarine predators. Trans. Am. Fish. Soc. 124: 520-537.

Hjorth, D.A. 1988. Feeding selection of larval striped bass and white perch in the Peekskill region of the Hudson River. Pages 134-147 *In* Fisheries Research in the Hudson River. C.L. Smith, editor. State University of New York Press. Albany.

Houde, E. D., and E. S. Rutherford. 1993. Recent trends in estuarine fisheries: predictions of fish production and yield. Estuaries 16: 161-176.

Hyslop, E. J. 1980. Stomach contents analysis- a review of methods and their application. J. Fish. Biol. 17: 411-429.

Juanes, F., R. E. Marks, K. A. McKown, and D. O. Conover. 1993. Predation by age-0 bluefish on age-0 anadromous fishes in the Hudson River estuary. Trans. Am. Fish. Soc. 122: 348-356.

Juanes, F. 1994. What determines prey size selectivity in piscivorous fishes? Pages 79-100. *In* Theory and Application in Fish Feeding Ecology. D. J. Stouder, K. L. Fresh, and R. J. Feller, editors. Belle W. Baruch Library in Marine Sciences, no. 18, S. Carolina Univ. Press, Columbia.

Juanes, F. and D. O. Conover. 1995. Size-structured piscivory: advection and the linkage between predator and prey recruitment in young-of-the-year bluefish. Mar. Ecol. Prog. Ser. 128: 287-304.

Limburg, K. E., Pace, M.L., Fischer, D., and K. K. Arend. 1997. Consumption, selectivity, and use of zooplankton by larval striped bass and white perch in a seasonally pulsed estuary. Trans. Am. Fish. Soc. 126: 607-621.

Markle, D. F., and G. C. Grant. 1970. The summer food habits of young-of-the-year striped bass in three Virgina rivers. Chesapeake Science 11: 50-54.

McGovern, J.C., and J. E. Olney. 1988. Potential predation by fish and invertebrates on early life history stages of striped bass in the Pamunkey River, Virginia. Trans. Am. Fish. Soc. 117: 152-161.

McGovern, J. C., and J. E. Olney. 1996. Factors affecting survival of early life stages and subsequent recruitment of striped bass on the Pamunkey River, Virginia. Can. J. Fish. Aquat. Sci. 53: 1713-1726.

McKown, K. A., and B. H. Young. 1992. Effects of year class strength on size of young-of-the-year striped bass. p. 265-275. *In* C. L. Smith, editor. Estuarine research in the 1980's. State University of New York Press, Stony Brook.

McLaren, J. B., Cooper, J. C., Hoff, T.B., and V. Lander. 1981. Movements of Hudson River striped bass. Trans. Am. Fish. Soc. 110: 158-167.

Pace, M. L., S. B. Baines, H. Cyr, and J. A. Downing. 1993. Relationships among early life stages of *Morone americana* and *Morone saxatilis* from long-term monitoring of the Hudson River estuary. Can. J. Fish. Aquat. Sci. 50: 1976-1985.

Rathjen, W.F., and L.C. Miller. 1957. Aspects of the early life history of the striped bass (*Roccus saxatilis*) in the Hudson River. NY Fish & Game J. 4: 43-60.

Robichaud-LeBlanc, K. A., S. C. Courtenay, and A. Locke. 1996. Spawning and early life history of a northern population of striped bass (*Morone saxatilis*) in the Miramichi River estuary, Gulf of St. Lawrence. Can. J. Zool. 74: 1645-1655.

Robichaud-LeBlanc, K. A., Courtenay, S. C., and J. M. Hanson. 1997. Ontogenetic diet shifts in age-0 striped bass, (*Morone saxatilis*), from the Miramichi River estuary, Gulf of St. Lawrence. Can. J. Zool. 75: 1300-1307.

Rulifson, R.A., and S.A. McKenna. 1987. Food of striped bass in the upper Bay of Fundy, Canada. Trans. Am. Fish. Soc. 116: 199-122.

Rutherford, E. S., and E. D. Houde. 1994. The influence of temperature on cohort-specific growth, survival, and recruitment of striped bass, *Morone saxatilis*, larvae in Chesapeake Bay. Fish. Bull. 93: 315-332.

Schmidt, R.E. 1993. Fishes of Manitou Marsh with Comments on other Aquatic Organisms. Report prepared for the Museum of the Hudson Highlands. Annandale, New York.

Setzler-Hamilton, E. M., W. R. Boynton, J. A. Mihursky, T. T. Polgar, and K. V. Wood. 1981. Spatial and temporal distribution of striped bass eggs, larvae, and juveniles in the Potomac estuary. Trans. Am. Fish. Soc. 110: 121-136.

Sogard, S. M. 1997. Size-selective mortality in the juvenile stage of teleost fishes: a review. Bull. Mar. Sci. 60: 1129-1157.

Stevens, D. E., Kohlorst, D. W., and L. W. Miller. 1985. The decline of striped bass in the Sacramento - San Joaquin estuary, California. Trans. Am. Fish. Soc. 114: 12-30.

Wainwright, S.C., C. M. Fuller, R. H. Michener, and R. A. Richards. 1996. Spatial variation of trophic position and growth rate of juvenile striped bass (*Morone saxatilis*) in the Delaware river. Can. J. Fish. Aquat. Sci. 53: 685-692.

Weiss, H. M. 1995. Marine Animals of Southern New England and New York. DEP Bulletin 115, Hartford.

Werner, E. E., and J. F. Gilliam. 1984. The ontogenetic niche and species interactions in size-structured populations. Ann. Rev. Ecol. Syst. 15: 393-425.