

DIETS OF LARVAL WHITE PERCH AND STRIPED BASS IN THE KINGSTON
REGION OF THE HUDSON RIVER ESTUARY WITH COMMENTS ON THE
SIGNIFICANCE OF THE *BOSMINA* BLOOM

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ABSTRACT

White perch (*Morone americana*) and striped bass (*M. saxatilis*) larvae collected simultaneously in the Kingston region of the Hudson River estuary in 1992 were examined for food habits. White perch (N = 276) and striped bass (N = 203) had virtually identical food habits, primarily consisting of *Bosmina*, copepods, and *Leptodora*, in that order.

Both *Morone* species shifted from a *Bosmina* diet to a diet of copepods at about 8 mm SL. *Leptodora* increased in significance as the fish grew. Both *Morone* species fed almost exclusively on *Bosmina* during the peak bloom of this zooplankter, but switched to copepods as the *Bosmina* population declined. *Bosmina* is the first food that many *Morone* larvae consume.

Because their food habits are very similar and because they are syntopic in time and space, white perch and striped bass larvae could be competing for food. In the Kingston area, the food resources are large compared to the requirements of the fishes, but in the lower estuary food resources are lower in quality and competition is more likely there.

In Chesapeake Bay, *Bosmina* is very important for health and survival of *Morone* larvae. If this is true for the Hudson, the *Morone* larvae in the Kingston region should have low mortality rates. *Morone* larvae in the lower estuary, where *Bosmina* are scarce, should be less healthy and have higher mortality rates.

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INTRODUCTION

Both white perch (*Morone americana*) and striped bass (*M. saxatilis*) are considered significant fishes in the Hudson River ecosystem. In particular, the distribution and abundance of the larval stages has received a lot of attention (e.g., Englert and Sugarman 1988) because of impacts from power plants and the link between larval abundance and adult population size (Heimbuch et al. 1992).

One aspect of the biology of the larvae of these species that has not been adequately addressed is their feeding habits. The only published study on striped bass and white perch larval diet in the Hudson was done in the vicinity of Peekskill (Hjorth 1988). He sampled microzooplankton concomitantly and calculated electivity indices. Several comparative studies have been done on these two species in the Chesapeake Bay system (Takacs 1992, Setzler-Hamilton et al. 1981a).

Because striped bass and white perch are closely related and their larvae are both present in the plankton at the same times and places, competitive interactions between the two species could occur. Hjorth (1988), Takacs (1992), and Setzler-Hamilton et al. (1981a) suggested that competitive interactions for food resources are probable since diet overlap between the larvae of the two species was large.

Takacs (1992) presented data on the importance of *Bosmina*, a planktonic cladoceran, to the health of both *Morone* species. There is a substantial *Bosmina longirostris* bloom in the Hudson estuary (Pace et al. 1992) that corresponds with high densities of *Morone* larvae.

One purpose of this study was to document and compare food habits of the

larvae of white perch and striped bass in the Hudson estuary. A second purpose was to correlate fish food habits with the *Bosmina* bloom to describe the significance of the bloom to *Morone* larvae.

METHODS

Study Area- The tidal Hudson River is about 154 miles long extending from the Battery in Manhattan (River Mile, RM = 0) north to the dam at Troy (RM 154). We restricted this study to the tidal estuary in the vicinity of Kingston (RM 92) because the zooplankton community in this area has recently been characterized by M.L. Pace (Institute for Ecosystem Studies- IES). These zooplankton data are in sufficient detail to provide a good comparative base for larval fish food habits studies.

Procedures- White perch and striped bass larvae examined in this study were collected in the Long River Ichthyoplankton Survey sponsored by a group of Hudson River Utilities. Study design for this survey and collection methods are described in Klauda et al. (1988). Collections were chosen to correspond with zooplankton collections made by M.L. Pace (IES) in the Kingston area of the Hudson in the summer of 1992.

Ichthyoplankton was collected in 13 weekly sample runs ("river runs"- RR) in 1992 from river miles (RM) 90-95, vicinity of Kingston. Striped bass post yolk-sac larvae were not collected until May 27, 1992 (RR 7) and numbers of white perch post yolk-sac larvae were low prior to that date. We requested and received (from Normandeau Associates, Inc.-NAI) striped bass and white perch larvae from 4

collections (chosen to provide maximum numbers of specimens) from each of RR 7-13 between RM 90-95.

Upon receipt, larvae were sorted from their original vials (white perch and striped bass of all life stages were mixed). In each collection, all specimens >8 mm total length (TL) were removed and cleared and stained with Alcian Blue. Clearing and staining followed Potthoff (1984) except that we used reagent alcohol instead of 100% ethanol and did not attempt Alizarin staining. About half of the remaining larvae (<8 mm TL) were returned to their original vials and the other half were cleared and stained with Alcian Blue. We stained half of the smaller specimens because we did not want to alter taxonomic characters in all of the specimens at once. Clearing and Alcian Blue staining makes the food items readily visible in the larval guts (Schmidt 1993) as well as allowing examination of the skeletons.

Larvae >8 mm TL were identified (by RES) using pterygiophore interdigitation patterns following Fritzsche and Johnson (1980) and Olney et al. (1983). Larvae that had not developed pterygiophores (generally <8 mm TL) were identified using tooth characters; striped bass having numerous large teeth and white perch having few small teeth or none (Lippson and Moran 1974).

For each collection, up to 10 larvae of each species that had food in the gut were removed for further examination. When more than 10 specimens were available, larvae were not chosen at random, but selected to represent a range of sizes. In some of the collections, we could not find 10 striped bass.

Each larva was measured (standard length - SL) with an ocular micrometer;

caudal fins were often too damaged to measure TL. Lengths were converted to millimeters by comparing the ocular micrometer with a stage micrometer at the same power used to measure the specimens. A linear regression of SL on TL was determined for each species using cleared and Alcian Blue stained *Morone* larvae from the 1987 Long River Ichthyoplankton Survey (Schmidt 1993). A total of 153 white perch and 291 striped bass were used to derive the regression lines.

Stomach contents were teased from each larva with tiny insect pins (minuten nageIn), identified as far as practical, and counted. Presence of zooplankton fragments was noted but these data were not included in further analyses. After dissection, larvae and food items were stored (as specified by Potthoff 1984) in individual small vials. A small selection of copepods was identified by D. Strayer (IES).

Average number of zooplankton per stomach for striped bass was converted to number per 24 h by assuming that larvae fed at all times (McHugh and Heidinger 1977) at the same rate as in our samples. Evacuation rates of striped bass have been reported as 3.3 h at 18°C (Eldridge et al. 1982) and 2.5 h at 17°C (Meng 1993a), feeding on *Artemia* in both cases. The former rate implies 7.3 turnovers per 24 h and the latter, 9.6 turnovers per 24 h. Multiplying average number of food items by 7.3 and/or 9.6 gave us an estimate of total food items/day. We could find no data on white perch larval diurnal feeding behavior or evacuation times and we assumed that the striped bass data were applicable to this species.

The nutritional quality of copepods and cladocerans is closely equivalent (Griffiths 1975). We presumed that the nutritional quality of the major taxa

consumed was a function of the dry weight of the food item. Limburg and Strayer (1988) reported that *Bosmina* in the Hudson weighed 1.8 µg dry weight and Heinle et al. (1979 in Takacs 1992) reported 2.0 µg dry weight. We used the former value. Limburg and Strayer (1988) presented dry weights of calanoid copepods (primarily *Eurytemora affinis*) and cyclopoid copepods (primarily *Eurycyclops* and *Acanthocyclops*) as 10 and 8 µg dry weight per individual. Heinle et al. (1979 in Takacs 1992) reported 9.6-10.0 µg and Dumont et al. (1975) gave 10 µg for adult cyclopoids. We used 9 µg dry weight for copepods. Limburg and Strayer (1988) reported that an average Hudson River *Leptodora* weighed 8.3 µg dry weight. Average number of food items per 24 h were multiplied by dry weights as an estimate of nutritional quality of different food items.

Search volumes of the fish larvae (minimum amount of water necessary for the fish to search in order to ingest the number of organisms calculated for a 24 h period) were estimated from literature values for zooplankton densities for the Hudson in the Kingston area. *Bosmina* densities are from M.L. Pace (unpublished 1992 data); copepod densities are from Pace et al. (1992); *Leptodora* densities are from Lawler, Matusky, and Skelly (LMS 1975a and 1975b).

There is recent evidence that identification of the two *Morone* spp. is untrustworthy in the Hudson estuary (Schmidt 1993) and a similar problem was noted in the Chesapeake system (J. Olney, pers. comm.). We are not questioning identifications here, but we distrust any study that did not use pterygiophore interdigitation patterns to separate the two species.

RESULTS

We examined stomach contents of 203 striped bass larvae and 276 white perch larvae (Table 1). A total of 2523 food items was identified and counted. In descending order of abundance, they were: *Bosmina longirostris* (44.0% of the total food items), a small cladoceran; copepods (43.5%) consisting of several species of cyclopoids (i.e. *Diacyclops bicuspidatus*) and the calanoid *Eurytemora affinus*, all fairly large species; *Leptodora kindti* (8.6%), a very large predatory cladoceran; *Daphnia* sp. (3.3%), a large cladoceran; ostracods (0.4%); and chironomid midge larvae and pupae (0.2%). There was no obvious difference between striped bass and white perch when comparing percent composition of food habits (Fig. 1). White perch had a higher percentage of their diet as *Bosmina* than striped bass, whereas striped bass had marginally higher percentages in the other food categories (Fig. 1). Takacs (1992) also reported that white perch and striped bass larval foods were virtually identical within the same area as did all other studies cited in his thesis.

The relative percent composition of the three most abundant food items (Fig. 1) changed with size of the larvae (Figs. 2 and 3). All of our measurements of fish size are standard lengths in mm. The SL-TL regressions we derived from cleared and stained 1987 Hudson River *Morone* larvae were:

$$\text{for white perch; } SL(\text{mm}) = 2.18 + 0.662TL(\text{mm}),$$

$$\text{and for striped bass; } SL(\text{mm}) = 1.67 + 0.717TL(\text{mm}).$$

In white perch, individuals <8 mm SL fed almost exclusively on *Bosmina* with a much smaller incidence of copepods (Fig. 2). Between 8-9 mm SL, a dramatic shift

Table 1. Numbers of striped bass (SB) and white perch (WP) larvae examined from each tow taken in the Hudson River estuary in the vicinity of Kingston.

River Run	Tow #	Date 1992	River Mile	# WP	# SB
7	7836	5/27	93	8	5
7	7837	5/27	92	10	2
7	7841	5/27	91	9	6
7	7842	5/27	90	10	6
8	8049	6/3	93	10	7
8	8051	6/3	92	10	9
8	8052	6/3	92	10	7
8	8053	6/3	91	10	5
9	8307	6/10	92	10	7
9	8308	6/10	91	10	7
9	8309	6/10	91	10	1
9	8310	6/10	90	9	5
10	8507	6/17	93	10	10
10	8509	6/17	92	10	10
10	8510	6/17	92	10	10
10	8513	6/17	91	10	10
11	8735	6/24	92	10	8
11	8737	6/24	90	10	10
11	8738	6/24	90	10	10
11	8739	6/24	90	10	10
12	8972	7/1	95	10	4
12	8976	7/1	93	10	10
12	8979	7/1	92	10	9
12	8983	7/1	91	10	10
13	9198	7/8	91	10	9
13	9199	7/8	92	10	10
13	9202	7/8	93	10	3
13	9204	7/8	93	10	3

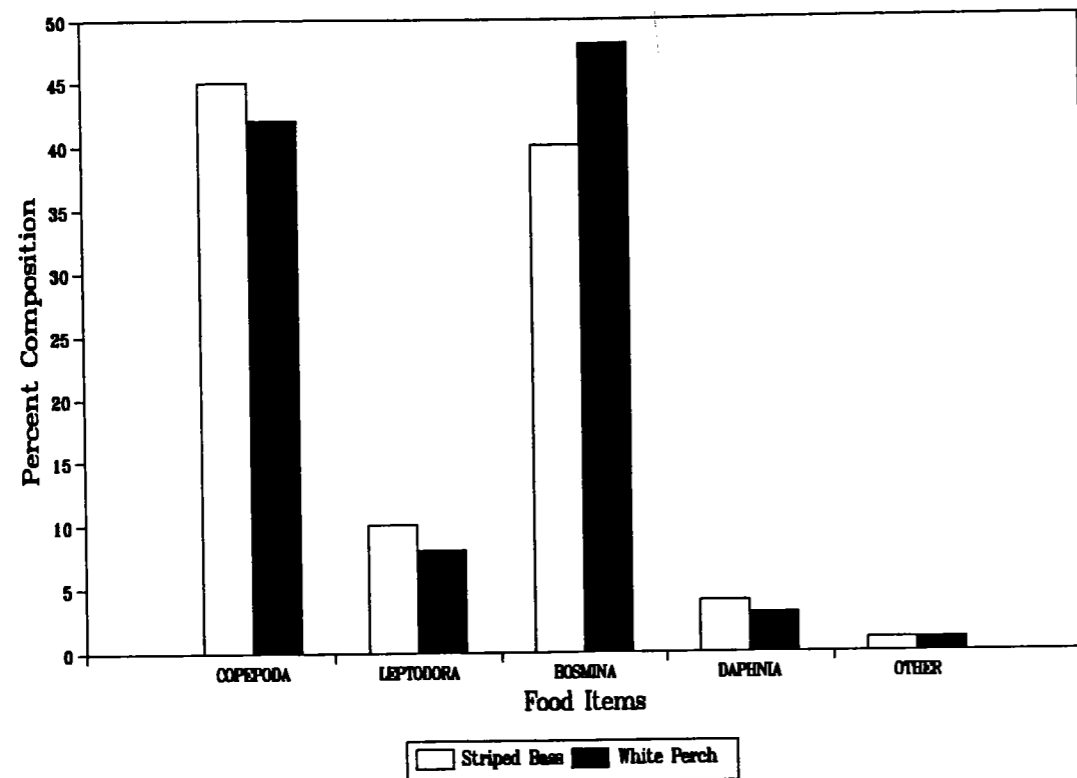


Figure 1. Food habits of striped bass and white perch larvae from the Hudson estuary near Kingston, 1992. Percent composition is based on the total number of food items in each species.

in dietary composition occurred with copepods becoming much more abundant in stomachs than *Bosmina*. Also, after 8 mm SL, *Leptodora* became increasingly more abundant in white perch stomachs, becoming the most common food item when the fish were >13 mm SL. *Bosmina* was a trivial component of the white perch diet when the fish were >11 mm SL.

Striped bass diet composition also changed as the fish grew (Fig. 3). The patterns seen were very similar to that of the white perch larvae (Fig. 2). As in the white perch, striped bass larvae fed primarily on *Bosmina* with a small component of

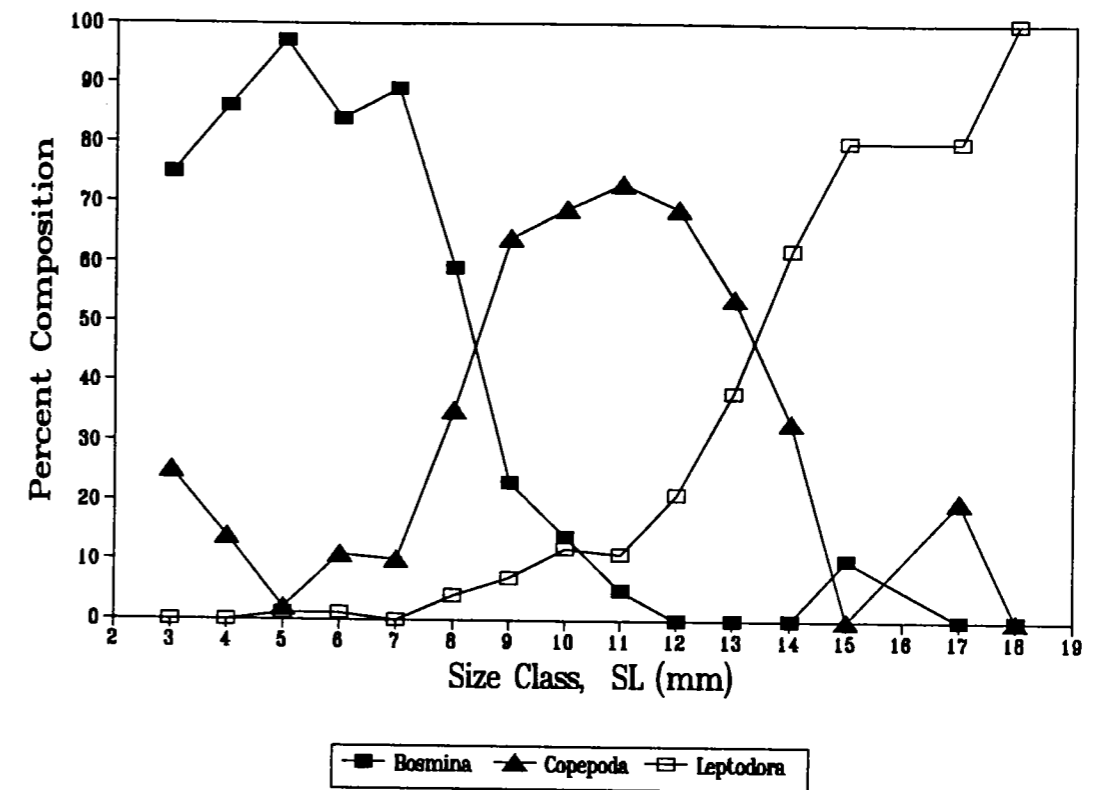


Figure 2. Food habits of larval white perch from the Hudson River estuary near Kingston, 1992. Percent composition is based on the total of all food items for each 1 cm size class of the larvae.

copepods until they exceeded 8 mm SL. Copepods then became the dominant food item with *Bosmina* contributing a trivial percentage when the fish were >11 mm SL. *Leptodora* was a relatively constant part of the diet (~20%) between 10-17 mm SL, as opposed to the increased abundance in white perch (Fig. 2). We had few striped bass specimens >18 mm SL and the data for large specimens are erratic.

In addition to changing the taxa that both white perch and striped bass are consuming as they grow, they are also shifting to larger food items. *Bosmina longirostris* has a body length of 0.4 mm, *Eurytemora affinis* is 1.0-1.5 mm long

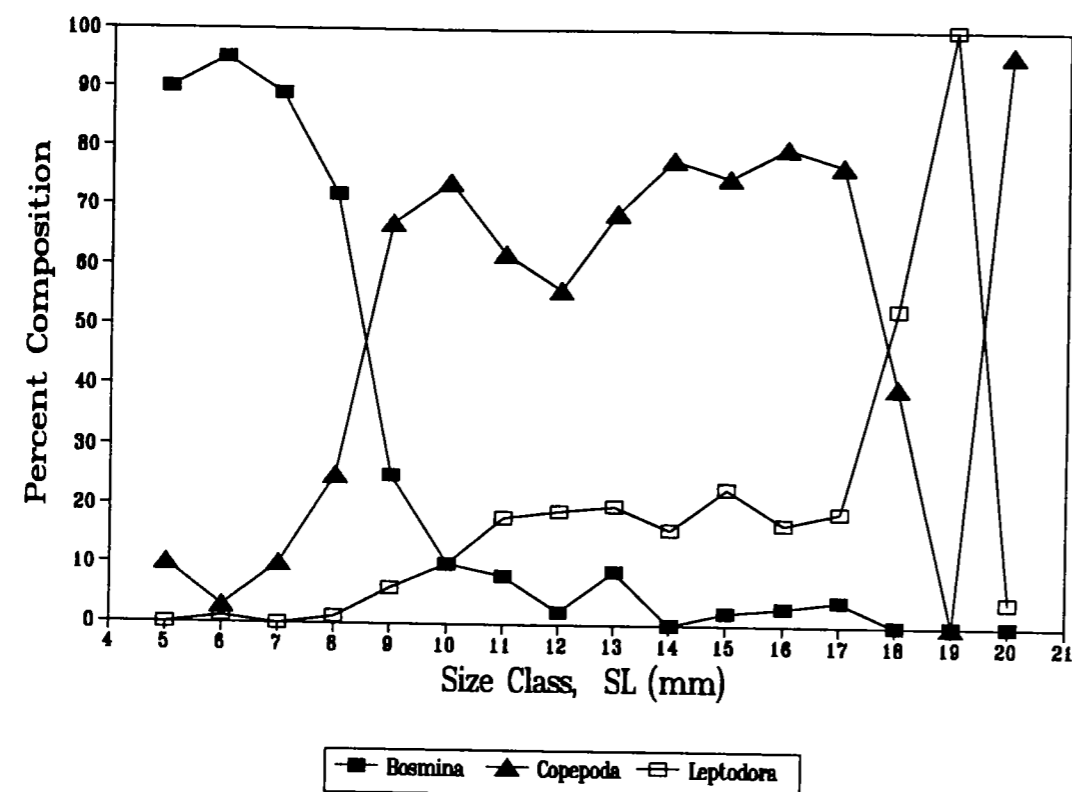


Figure 3. Food habits of larval striped bass from the Hudson River estuary near Kingston, 1992. Percent composition is based on the total of all food items for each 1 cm size class of the larvae.

(Pennak 1953), and *Leptodora kindti* averages 3.0 mm long in the Hudson (Limburg and Strayer 1988). Each shift in food documented in Figs. 2 and 3 is a substantial increase in food item size measured on a linear scale. Hjorth (1988) observed a similar shift in size of food items as *Morone* larvae grew. Hjorth (1988) invoked optimal foraging strategy with the larger planktivorous fish preferring prey of the largest possible size to maximize energy input as an explanation for this phenomenon.

Comparing dry weights of food items, when white perch and striped bass larvae switch from primarily a *Bosmina* diet to primarily a copepod diet at 8 mm SL

(Figs. 2 and 3), they are increasing the nutritional content per food item by a factor of 5. Although it is tempting to suggest that this behavior is determined by the size of the fish larvae, it may be that prey availability is changing with time and the *Morone* larvae are simply eating what is available.

When compared over time, as indicated by "river run", the dietary shift can be seen from another perspective (Table 2). In the first 2 river runs (see Table 1 for dates) of this study, both striped bass and white perch ate almost entirely *Bosmina*. *Bosmina* was present in intermediate amounts (19-62% of the diet) in RR 9 and 10 and was relatively insignificant thereafter. Copepods were not eaten in significant amounts until RR 9 and were the most abundant food organisms (>73% of the diet) in RR 11-13. *Leptodora* was present in intermediate quantities in RR 10 and percentages of this cladoceran remained about the same through RR 13 (7-25% of the diet). *Daphnia* made up a high percentage of the diet in RR 10--about as high as *Leptodora*. Striped bass larvae were always slightly larger on average than white perch in each of the river runs. The number of food items per fish dropped sharply when copepods became important in the diet (RR 9; Table 2) and again when *Leptodora* became important in RR 10. A steady decline in numbers of food items per stomach occurred from RR 11 through RR 13 for both *Morone* species.

The above observations suggest that *Morone* larvae may well be switching foods as zooplankton populations crash and are replaced by other taxa. We have little correlative data to support this hypothesis. M.L. Pace (pers. comm.) sampled *Bosmina* biweekly in the Kingston area of the Hudson River in 1992. The percent of *Bosmina*

Table 2. Food habits of larval striped bass (SB) and white perch (WP) from the Hudson River estuary near Kingston, 1992. Data are presented by week of collection where River Run (RR) 7 is the last week in May. Percentages of the three main food items are calculated from the total food items from a given fish species from a given week.

Species	RR	% Bosmina	% Copepoda	% Leptodora	Average food items per fish	Average SL mm	Range SL mm	N
SB	7	100.0	-	-	2.6	3.8	3.2-4.2	19
WP	7	100.0	-	-	3.3	3.6	2.8-4.2	36
SB	8	98.5	1.1	-	9.6	4.6	3.5-5.2	28
WP	8	99.3	0.3	-	7.4	4.2	2.1-5.9	40
SB	9	61.7	35.1	0.6	7.7	4.9	4.0-5.7	20
WP	9	61.7	34.4	0.7	7.0	4.7	2.2-6.2	40
SB	10	19.0	38.0	24.1	4.1	6.8	5.0-8.8	39
WP	10	25.9	37.4	15.6	3.7	5.1	2.5-7.2	40
SB	11	1.1	79.0	17.3	9.8	8.2	3.9-11.3	36
WP	11	0.6	73.5	20.5	4.2	6.5	3.8-9.2	40
SB	12	1.3	85.6	10.5	6.7	8.6	5.0-14.3	34
WP	12	1.6	77.8	17.5	3.5	7.7	4.1-11.5	36
SB	13	12.1	74.7	11.0	4.1	7.8	4.6-10.9	22
WP	13	4.8	88.0	7.2	2.4	5.9	4.3-9.8	35

in striped bass and white perch diets mimics the population decline of *Bosmina* (Fig. 4). Few *Bosmina* are seen in the diet when concentrations in the river fell below 10/L.

Copepods exist at much lower densities, 2.5/L as an average for the summer in the Hudson (Pace et al. 1991), ranging between 1-5/L during the time *Morone* larvae

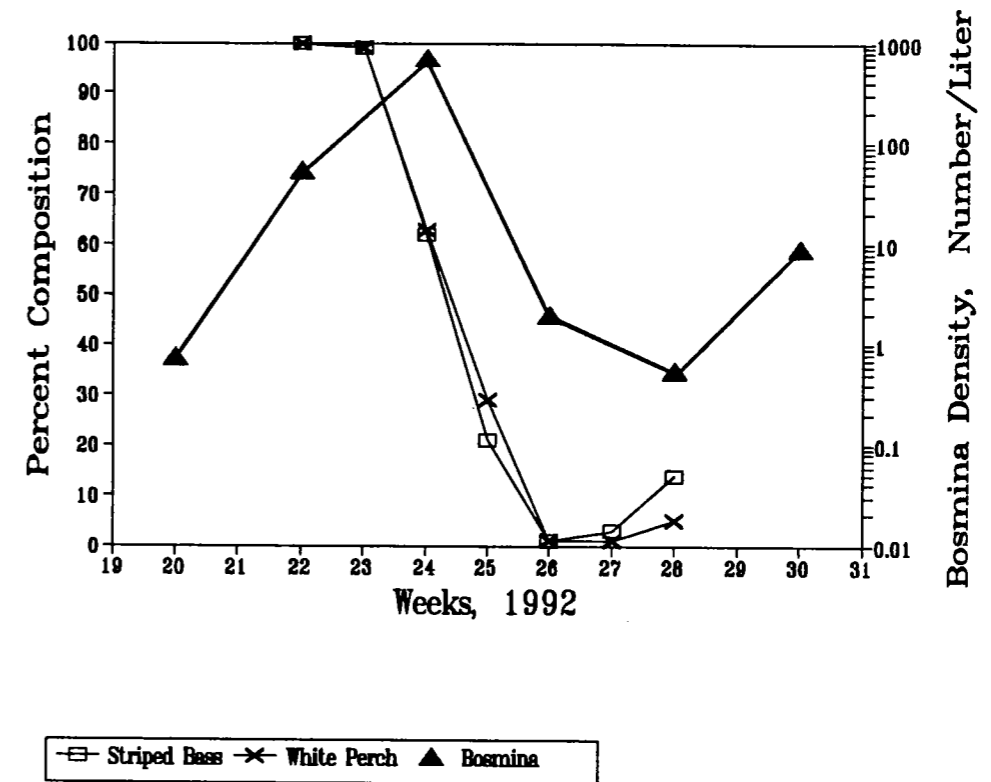


Figure 4. Percent of *Bosmina longirostris* in larval striped bass and white perch stomachs compared to *B. longirostris* densities in the Kingston region of the Hudson estuary.

are likely to be present (Pace et al. 1992). These data include all cyclopoid copepods, however *Morone* larvae seem to be selecting the larger species (i.e., *Diacyclops bicuspidatus*) rather than the more abundant small species (D. Strayer, pers. comm.). The published copepod densities overestimate the abundance of the food resource for *Morone* larvae.

Leptodora kindti reach maximum densities at the end of June (LMS 1975a and 1975b). These densities are up to 0.15/L. These data are 20 years old and may not reflect current conditions in the river. M. Mattson (NAI, pers. comm.) commented on

apparent high densities of *Leptodora* in the 1992 unsorted ichthyoplankton samples.

Large variation in *Leptodora* densities around Kingston (LMS 1975b) indicate extensive patchiness in this zooplankter.

All of the fish we examined were collected between 0200-0500, a result of the logistics of the Long River Ichthyoplankton Surveys. When we looked at the number of food items per fish for each hour collected (Table 3), we could see no differences among hours within species (the high average value for striped bass at 0400 h is due to one piggish 12 mm larva that consumed 97 copepods). Striped bass did eat more food apiece than white perch, but they were also larger (see Table 2). Average number of food items per fish were similar to data reported by Setzler-Hamilton et al. (1981a).

Our calculations suggest that *Morone* larvae ingest from 30-800 μg of zooplankton per day (Table 4). It is difficult to compare these data to literature values because the latter are usually given in calories (Eldridge et al. 1981 and 1982, Martin et al. 1985). Without knowing size and species composition of the copepod component of the diet, further energetic analysis cannot be done.

The smallest daily intake of zooplankton biomass occurred in the first two river runs when larvae are feeding exclusively on *Bosmina*. The fish larvae still retain oil from their yolk sac and use this calorie-rich (Rogers and Westin 1981) food resource as a dietary supplement. When the fish are large enough to take adult copepods (or the copepods become abundant) the zooplankton ingested per day were all over 130 μg (Table 4).

Table 3. Number of food items in stomachs of larval striped bass and white perch related to time of collection. Fishes were collected in the Kingston region of the Hudson River estuary, summer of 1992.

Time of Day	Species	Average # Food Items per Fish	Range # Food Items per fish
0200-0259	Striped Bass	6.4	1-33
	White Perch	4.4	1-17
0300-0359	Striped Bass	6.4	1-26
	White Perch	4.9	1-20
0400-0459	Striped Bass	9.4	1-97
	White Perch	4.3	1-12

Bosmina densities ranged between 50-110/L during the first two river runs (Fig. 4). With a minimum of 19 and a maximum of 92 *Bosmina* per *Morone* larva (Table 4), search volumes ranged from a minimum of 0.38 L/day to a maximum of 0.84 L/day. This presumably is a minimum energy investment on the part of the fish larvae.

Copepods are seen in the range of 2-5/L (Pace et al. 1992). The extremes of search volumes for copepod food resources range from (for white perch in RR 10) 2-5 L/day to (for striped bass in RR 11) 15-37 L/day.

Leptodora are seen in the range of 0.07-0.15/L during the end of June in the vicinity of Kingston in 1973 (LMS 1975a and 1975b). This is equivalent in time to RR 11 in our study. Densities of *Leptodora* were considerably lower in previous and subsequent weeks (LMS 1975a and 1975b). Considerable patchiness is apparent when

Table 4. Nutritional value of the three dominant zooplankters to white perch and striped bass larvae in dry weight (μg). The range in average number of zooplankters eaten per 24 h was derived from literature values for digestion rates.

Species	RR	Food Item	Average # per Fish	Average # per 24 h	Average Consumption $\mu\text{g}/24\text{ h}$	Total Consumption $\mu\text{g}/24\text{ h}$
SB	7	Bosmina	2.6	19-25		34-45
WP	7	Bosmina	3.3	24-32		43-58
SB	8	Bosmina	9.6	70-92		126-166
WP	8	Bosmina	7.4	54-71		97-128
SB	9	Bosmina	4.8	35-46	63-83	
		Copepods	2.7	20-26	180-234	243-317
WP	9	Bosmina	4.3	31-41	56-74	
		Copepods	2.4	18-23	162-206	218-280
SB	10	Bosmina	0.8	6-8	11-14	
		Copepods	1.6	12-15	108-135	
		Leptodora	1.0	7-10	58-83	177-232
WP	10	Bosmina	1.0	7-10	13-18	
		Copepods	1.4	10-13	90-117	
		Leptodora	0.6	4-6	33-50	136-185
SB	11	Copepods	7.7	56-74	504-666	
		Leptodora	1.7	12-16	100-133	604-799
WP	11	Copepods	3.1	23-30	207-270	
		Leptodora	0.9	7-9	58-75	265-345
SB	12	Copepods	5.7	42-55	378-495	
		Leptodora	0.7	5-7	42-58	420-553
WP	12	Copepods	2.7	20-26	180-234	
		Leptodora	0.6	4-6	33-50	213-284
SB	13	Bosmina	0.5	4-5	7-9	
		Copepods	3.1	23-30	207-270	
		Leptodora	0.4	3-4	25-33	239-312
WP	13	Bosmina	0.1	1	2	
		Copepods	2.1	15-20	135-180	
		Leptodora	0.2	1-2	8-16	145-198

comparing sampling stations around Kingston (LMS 1975b). Data for RR 11 striped bass and white perch indicate search volumes of 60-100 L/day for white perch and 107-171 L/day for striped bass.

Meng (1993b) calculated search volume for striped bass larvae from observed swimming speeds and a 5 mm reactive distance as up to 4 L/h (96 L/day). This value is well within our calculated search volumes necessary for the larvae to feed as we observed except for striped bass feeding on *Leptodora*.

DISCUSSION

The foods we observed in stomachs of *Morone* larvae are not necessarily the most abundant zooplankters in the Hudson. Pace et al. (1992) reported that three taxa of rotifers were found in high densities (up to >1000/L), yet we saw none in white perch or striped bass stomachs. Crecco and Blake (1983) were concerned that rotifers were digested rapidly and were not noticed in stomachs of American shad larvae. However, some of the very abundant Hudson River rotifers (i.e., *Keratella* and *Brachionus*) are loricate and the cases should not be too digestible. Also rotifers have been seen in *Morone* larvae in other studies (Takacs 1992, Hjorth 1988, Setzler-Hamilton et al. 1981b). We conclude that rotifers are not a significant food item for *Morone* larvae in the Kingston region.

The smallest larvae we examined from the earlier river runs contained *Bosmina* exclusively. This observation suggests that the very first food items that larval *Morone* ingest is *Bosmina*. Takacs (1992) provided evidence that white perch and

striped bass larvae are in poor physical condition when they are unable to feed on *Bosmina* but instead were consuming rotifers and copepod nauplii. The correspondence of the *Bosmina* bloom with larval *Morone* early development may be very significant in determining survival and perhaps year class strength in the Kingston region.

The *Bosmina* bloom in 1992 produced densities that were much higher than the striped bass or white perch larvae needed to fulfill their energy requirements. This is reflected in the small calculated search volumes (<1 L/day) necessary for the larvae to feed at the levels we observed. Differences in the magnitude of *Bosmina* blooms from year to year may not affect *Morone* larval survivorship as long as *Bosmina* densities are adequate to supply the average numbers/fish that we documented. Therefore, *Bosmina* abundance may not predict *Morone* survival rates.

Bosmina densities in June, when *Morone* larvae are in their early stages, are highest in the Kingston region. Densities decline downstream and are minimal in Haverstraw Bay, RM 35-40 (Pace et al. 1992). Striped bass and white perch larvae can be present in higher densities in the lower estuary (Boreman and Klauda 1988) than at Kingston. These fish larvae in the lower estuary may face an entirely different array of food resources (as seen in Hjorth 1988). If *Bosmina* is a highly important fish food item for *Morone* larvae (Takacs 1992), then we would predict that *Morone* larvae in the lower estuary would be less healthy and have higher mortality rates than in the Kingston region.

Takacs (1992) suggested that there could be significant competitive interaction

between white perch and striped bass larvae because their diets are virtually identical, they inhabit the same space, and white perch are more abundant (10-40 times that of striped bass). All of Takacs (1992) statements are true for the Hudson estuary except for, perhaps, the magnitude of differences in densities. However, competition also implies limited resources. Our calculations of numbers of organisms consumed in 24h and search volumes compared with high population growth rates of *Bosmina* (Pace et al. 1992) all suggest that competition between the two *Morone* species is unlikely to be a significant phenomenon in the Kingston region of the Hudson. Areas in the lower estuary, where *Morone* larvae are more abundant and where high quality initial food organisms (*Bosmina*) are rare, may be areas where significant competitive interactions would occur. Also, *Morone* spp. are not the only planktivorous fish larvae around. Dense populations of river herring larvae (mostly *Alosa pseudoharengus*) are syntopic in the Kingston region (Schmidt et al. 1988) and are probably also consuming *Bosmina* and copepods. In the lower river (Schmidt 1992), bay anchovy larvae (*Anchoa mitchilli*) may be utilizing the same food resources. Perhaps competition with these other species is a more significant issue than intrageneric competition. Setzler-Hamilton et al. (1981a) showed that small clupeid larvae fed on smaller food items than *Morone* larvae, but larger clupeids seem to use the same food resources.

All of the calculations we did in this study assumed that the averages (of fish densities, of zooplankton densities) were meaningful. Colby (1988) stated that marine zooplankton rarely exist at average densities, but rather are highly patchy. The Hudson estuary is very turbulent which would tend to reduce patchiness in planktonic

communities, but Pace et al. (1991) inferred that zooplankton in the Hudson were aggregated at high densities. Pace et al. (1992) also detected patchiness in the Kingston region when sampling over a significant part of a tidal cycle. We must also infer patchiness of the fish larvae as well, but tows in the Long River Ichthyoplankton Survey sample about 300 m³ of water (Schmidt et al. 1988), too large a volume to detect the scale of patchiness that is implied by the zooplankton data.

RECOMMENDATIONS

The methods we used to identify *Morone* larvae and to quantify food habits seem to be practical and rapid as long as one has enough familiarity with zooplankton taxonomy. Anyone doing a similar study should be prepared to identify copepods to species because we lost a lot of information in our study by not doing so.

We raised a number of issues in this study that would be interesting to address. These issues cover several orders of magnitude of scale.

On the smallest scale, the magnitude of temporal and spatial patchiness of zooplankton and *Morone* larvae in the Kingston region is essentially unknown. Our estimates of search volume are based, for the most part, on crude average densities of zooplankton. Simultaneous sampling of fishes and zooplankton on a scale small enough to adequately assess the variance in densities of the different taxa could allow better calculations of search volumes.

Unfortunately, sampling methods adequate to document *Bosmina* densities will not collect larval fishes. Pulling large enough nets fast enough to catch large numbers

of fish larvae obscures the patchiness that we wish to document and does not sample small zooplankters at all. Frequent small volume samples may reduce these problems. Perhaps an appropriately sized block of water could be isolated with a plastic barrier and the entire block pumped through a series of nets with decreasing mesh size, thus accurately assessing density of several size categories of zooplankton including fishes.

The specimens of fishes collected by the utilities' programs are a valuable resource but future studies of *Morone* food habits should not depend on these specimens. For instance, diurnal collections of fishes in the Kingston region are needed to document any diurnal variability in feeding that may exist.

On a river-wide basis, comparisons of *Morone* food habits in different regions of the river would be very valuable. We predict that large differences will be apparent. If these kinds of studies were linked with morphological condition analyses, hypotheses could be developed addressing spatial changes in population dynamics of *Morone* larvae in the Hudson.

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LITERATURE CITED

- Boreman, J. and R.J. Klauda. 1988. Distribution of early life stages of striped bass in the Hudson River estuary, 1974-1979. Pages 53-58 in L.W. Barnthouse et seq., editors. Science, law, and Hudson River power plants: A case study in environmental impact assessment. American Fisheries Society, Monograph 4, Bethesda, Maryland.
- Colby, D.R. 1988. Null hypotheses, models, and statistical designs in the study of larval transport. Pages 149-162 in M.P. Weinstein, editor. Fish and shellfish transport through inlets. American Fisheries Society Symposium 3.
- Crecco, V.A. and M.M. Blake. 1983. Feeding ecology of coexisting larvae of American shad and blueback herring in the Connecticut River. Transactions of the American Fisheries Society 112:498-507.
- Dumont, H.J., I. Van de Velde, and S. Dumont. 1975. The dry weight estimate of biomass in a selection of Cladocera, Copepoda and Rotifera from the plankton, periphyton, and benthos of continental waters. Oecologia 19:75-97.
- Eldridge, M.B., J.A. Whipple, D. Eng, M.J. Bowers, and B.M. Jarvis. 1981. Effects of food and feeding factors on laboratory-reared striped bass larvae. Transactions of the American Fisheries Society 110:111-120.
- Eldridge, M.B., J.A. Whipple, and M.J. Bowers. 1982. Bioenergetics and growth of striped bass, *Morone saxatilis*, embryos and larvae. Fishery Bulletin 80:461-474.
- Englert, T.L. and D. Sugarman. 1988. Patterns of movement of striped bass and white perch larvae in the Hudson River estuary. Pages 148-170 in C.L. Smith, editor. Fisheries Research in the Hudson River. SUNY Press, Albany.
- Fritzsche, R.A. and G.D. Johnson. 1980. Early osteological development of white perch and striped bass with emphasis on identification of their larvae. Transactions of the American Fisheries Society 109:387-406.
- Griffiths, D. 1975. Prey availability and the food of predators. Ecology 56:1209-1214.
- Heimbuch, D.G., D.J. Dunning, and J.R. Young. 1992. Post-yolk-sac larvae abundance as an index of year class strength of striped bass in the Hudson River. Pages 376-391 in C.L. Smith, editor. Estuarine research in the 1980's. SUNY Press, Albany, New York.

- 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 C.L. Smith, editor. Fisheries Research in the Hudson River. SUNY Press, Albany.
- Klauda, R.J., P.H. Muessig, and J.A. Matousek. 1988. Fisheries data sets compiled by Utility-sponsored research in the Hudson River estuary. Pages 7-85 in C.L. Smith, editor. Fisheries Research in the Hudson River. SUNY Press, Albany.
- Lawler, Matusky, and Skelly. 1975a. 1973-1974 ecological studies of the Hudson River in the vicinity of Lloyd, New York. Final Report to the New York State Atomic and Space Development Authority, New York, New York.
- Lawler, Matusky, and Skelly. 1975b. Aquatic ecology studies, Kingston, N.Y. 1973. Final Report to Central Hudson Gas and Electric Co., Kingston, New York.
- Limburg, K.E. and D. Strayer. 1988. Studies of young-of-the-year river herring and American shad in the Tivoli Bays, Hudson River, New York. Pages VIII- 1-62 in J.R. Waldman and E.A. Blair, editors. Polgar Fellowship Reports of the Hudson River National Estuarine Research Reserve Program, 1987. Hudson River Foundation, New York, New York.
- Lippson, A.J. and R.L. Moran. 1974. Manual for identification of early developmental stages of fishes of the Potomac River estuary. Maryland Dept. Natural Resources, Power Plant Siting Program, PPSP-MP-13. Baltimore, Maryland.
- Martin, F.E., D.A. Wright, J.C. Means, and E.M. Setzler-Hamilton. 1985. Importance of food supply to nutritional state of larval striped bass in the Potomac River estuary. Transactions of the American Fisheries Society 114:137-145.
- McHugh, J.J. and R.C. Heidinger. 1977. Effects of light on feeding and egestion time of striped bass fry. Progressive Fish-Culturist 39:33-34.
- Meng, L. 1993a. Estimating food requirements of striped bass larvae: An energetics approach. Transactions of the American Fisheries Society 122:244-251.
- Meng, L. 1993b. Sustainable swimming speeds of striped bass larvae. Transactions of the American Fisheries Society 122:702-708.
- Olney, J.E., G.C. Grant, F.E. Schultz, C.L. Cooper, and J. Hageman. 1983. Pterygiophore-interdigitation patterns in larvae of four *Morone* species. Trans. Am. Fish. Soc. 112:525-531.

- Pace, M.L., S.E.G. Findlay, and D. Lints. 1991. Variance in zooplankton samples: Evaluation of a predictive model. Canadian Journal of Fisheries and Aquatic Science 48:146-151.
- Pace, M.L., S.E.G. Findlay, and D. Lints. 1992. Zooplankton in advective environments: The Hudson River community and a comparative analysis. Canadian Journal of Fisheries and Aquatic Science 49:1060-1069.
- Pennak, R.W. 1953. Fresh water invertebrates of the United States. Ronald Press, New York.
- Potthoff, T. 1984. Clearing and staining techniques. Pages 35-37 in H.G. Moser et seq., editors. Ontogeny and systematics of fishes. Special Publication 1, American Society of Ichthyologists and Herpetologists. Allen Press, Lawrence, Kansas.
- Rogers, B.A. and D.T. Westin. 1981. Laboratory studies on effects of temperature and delayed initial feeding on development of striped bass larvae. Transactions of the American Fisheries Society 110:121-136.
- Schmidt, R.E. 1992. Temporal and spatial distribution of bay anchovy eggs through adults in the Hudson River estuary. Pages 228-241 in C.L. Smith, editor. Estuarine research in the 1980's. SUNY Press, Albany, New York.
- Schmidt, R.E. 1993. Identification of Hudson River *Morone* larvae. Draft Final Report to the Hudson River Foundation. New York, New York.
- Schmidt, R.E., R.J. Klauda, and J.M. Bartels. 1988. Distribution and movements of the early life stages of three species of *Alosa* in the Hudson River, with comments on mechanisms to reduce interspecific competition. Pages 193-218 in C.L. Smith, editor. Fisheries Research in the Hudson River. SUNY Press, Albany.
- Setzler-Hamilton, E.M., P.W. Jones, G.E. Drewry, F.D. Martin, K. Ripple, M. Beaven, and J.A. Mihursky. 1981a. A comparison of larval feeding habits among striped bass, white perch and Clupeidae in the Potomac estuary. Maryland Dept. Natural Resources, Power Plant Siting Program, PPRP-65. Baltimore, Maryland.
- Setzler-Hamilton, E.M., W.R. Boynton, J.A. Mihursky, T.T. Polgar, and K.V. Wood. 1981b. Spatial and temporal distribution of striped bass eggs, larvae, and juveniles in the Potomac estuary. Transactions of the American Fisheries Society 110:121-136.

Takacs, R.L. 1992. An early life history study of *Morone saxatilis* in Chesapeake Bay: Feeding ecology, health condition, and interactions with *M. americana*. MS Dissertation. University of Maryland, College Park, Maryland.