

RECRUITMENT OF JUVENILE MORONE SAXATILIS
REFLECTED IN OTOLITH MICROSTRUCTURE

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Abstract

Otolith microstructure was analyzed to study the recruitment of striped bass (*Morone saxatilis*) in the Hudson River Estuary. Otoliths were extracted from juvenile striped bass caught in July, August, and September, 1994. A total of 63 otoliths were embedded in Spurr's epoxy, sectioned, ground and polished, and visualized on a light microscope equipped with a video projection system. Daily increments were counted to estimate each juvenile's age. The age estimated and standard length (SL) measured for each fish were used to calculate lifetime growth rates. Initial growth rates were estimated from measurements of the otolith's radius to the seventh increment and estimates of the larvae's SL at the time the seventh increment was formed. Hatch dates and growth rates were then compared to the population dynamics of zooplankton sampled during the larval period from May through June, 1994. The hatch dates of *M. saxatilis* larvae, collected during the summer of 1994 and processed by Karin Limburg, were also used in this comparison. The results indicated that a larger proportion of larvae and juveniles caught in July and August hatched during a time in which the zooplankton were experiencing population blooms. The increase in prey abundance during the blooms may have had a positive effect on the growth rates and, thus, recruitment of the striped bass cohorts which hatched right before or during that time. However, it was difficult to separate the effects water temperature also had on larval growth. Both greater food availability and higher temperatures resulted in the higher growth rates observed for cohorts born during and even after the bloom.

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Introduction

Morone saxatilis (striped bass) is a largely anadromous species of fish, which spends the majority of its adult life in the ocean and enters estuaries, such as the Hudson River Estuary, to spawn. Concerns over the impact of power plants on M. saxatilis populations in the Hudson River Estuary have resulted in research focusing on its early life history. Morone saxatilis populations have also become substantial contributors to mixed-stock coastal fisheries due to an increase in their range and abundance since 1980 (Secor and Piccoli, 1996).

A major early life history event for any organism is recruitment, defined as the survivorship of an organism from one life stage to another. Regarding fish, one of the most critical transitions is that from the larval to the juvenile stage. Cowan et al. (1993) conducted a simulation study in which they found the cumulative mortality of feeding larvae and younger life stages to be higher than that of juveniles. These results supported the idea that the year-class strength of M. saxatilis is determined prior to metamorphosis. Similarly, Rutherford and Houde (1995) concluded that recruitment is fixed during the larval stage; Secor and Houde (1995) noted that potential recruitment in M. saxatilis is set by the time larvae reach 8.0 mm standard length.

Major changes in recruitment levels can result from modest changes in daily growth or mortality rates occurring in the larval stage (Houde 1987). Such changes are influenced by environmental factors, for the most part being unaffected by population density (Secor et al. 1995). Larval mortality can result from a number of abiotic and biotic factors. Abiotic factors include water temperature, advection due to storms or flooding, and water salinity. Biotic factors include maternal size and the abundance of prey and predators (Cowan et al. 1993; Rothschild 1986; Houde 1987). Growth rates of larval fishes are thought to be most strongly influenced by temperature and prey abundance. Rutherford and Houde (1995) found that temperature strongly affected larval

cohort dynamics and potential to recruit among M. saxatilis in the Potomac River and Upper Chesapeake Bay. Rutherford (1992) also observed a positive correlation between zooplankton food availability and recruitment success of M. saxatilis in the Chesapeake Bay (Fig. 1). Rothschild (1986) cites other studies which indicate the importance of larval nutrition as a mortality-inducing factor.

During this study I investigated whether or not a similar relationship between prey abundance and larval M. saxatilis recruitment exists in the Hudson River Estuary. The purpose of this study was to determine whether differential food availability has an impact on the recruitment of M. saxatilis from the larval to the juvenile stage. I chose to address this question by looking retrospectively at the recruitment of M. saxatilis juveniles caught in the Hudson River Estuary in July, August, and September, 1994. Otolith microstructure analysis was used to estimate the hatch dates and growth rates of successful recruits. This information was considered along with data on zooplankton population dynamics, timing of larval first feeding, and larval feeding preferences in the Hudson River Estuary.

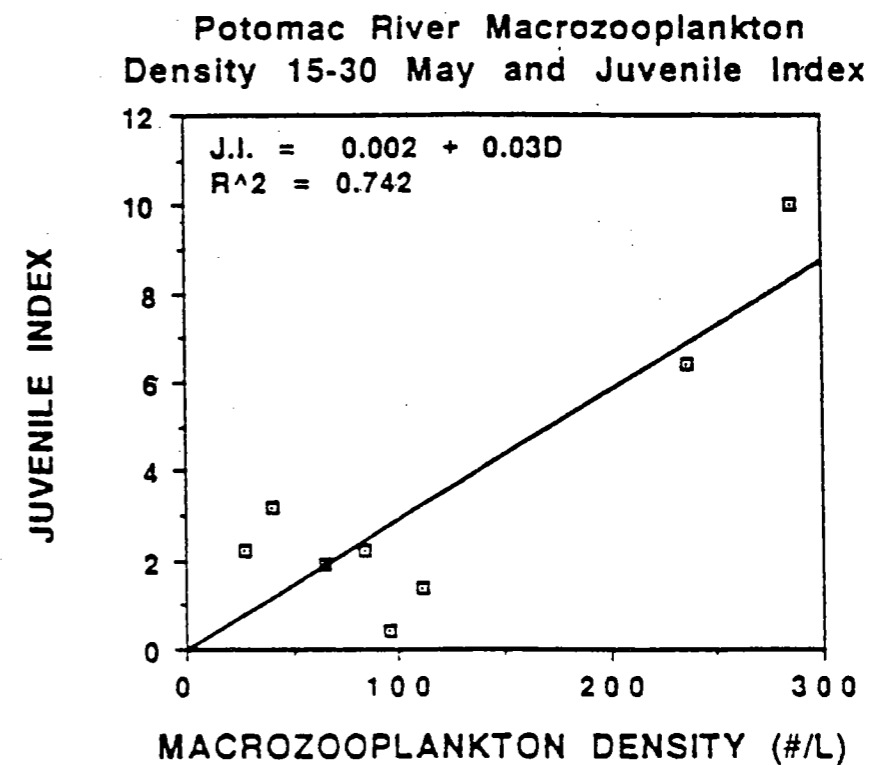


Figure 1. Relationship of recruitment indices of juvenile Morone saxatilis in the Potomac River to macrozooplankton density (#/L). (Source: Rutherford 1992)

Otolith microstructure analysis

Otoliths are calcareous structures which are part of the hearing and balance system of teleosts. Three pairs of these exist, located near the semi-circular canals of the inner ear (Fig. 2). The largest pair, the saggittae is most often used for microstructure analysis (Campana and Neilson 1985). Otoliths are formed by the daily production of growth increments, or rings, which are bipartite (visually 2-banded) structures produced by the differential deposition of calcium carbonate and protein over a 24-hour period (Campana and Neilson 1985). Increments can be counted like rings on a tree section to estimate the age of larval or juvenile fish. The use of otoliths is advantageous over other structures, such as scales or fin rays, because they are the first calcified structures to appear during teleost early development (Campana and Neilson 1985). Pannella first described the presence of daily growth increments in 1971; previously, only yearly growth increments had been observed and used for aging adult fish. Since then, different studies have validated the formation of daily growth increments for a variety of fish species, including *M. saxatilis* (Neilson and Geen 1982; Campana and Neilson 1985; Secor et al. 1995).

A great amount of information can be interpreted from otolith microstructure, the growth sequence of which is often regulated by the same factors - temperature, food abundance, and predator abundance - that influence fish growth and recruitment (Campana and Neilson 1985). Such information often includes age, size at age, growth rates at a given age, and early life history events such as hatch date, time of first feeding, and migration patterns (Campana and Neilson 1985).

Zooplankton dynamics and larval feeding

Previous studies of zooplankton dynamics in the Hudson River Estuary (e.g., Pace et al. 1992) showed an annual sharp increase in two types of zooplankton, copepods and

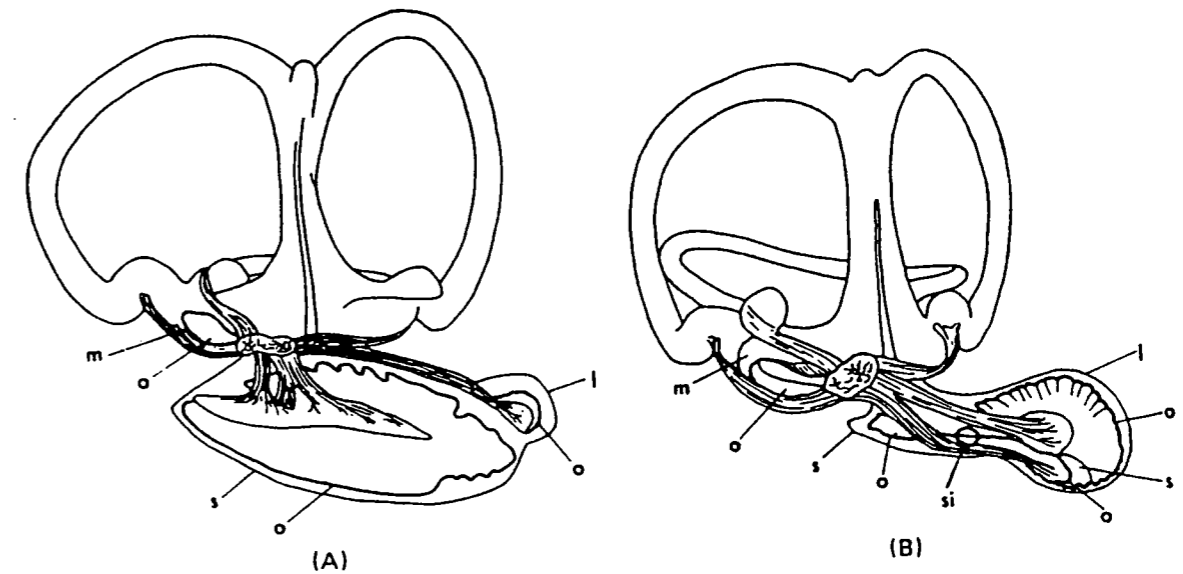


Figure 2. Fish otoliths in semi-circular canals; o=otolith (Source: Moyle and Cech 1988).

Bosmina longirostris, which overlap with the onset of larval *M. saxatilis* feeding. The populations of these zooplankton increase ("bloom") within the first two weeks of June, rapidly declining after approximately one week. The *B. longirostris* bloom occurs in the mid- to upper-region of the estuary and is approximately five times larger than the copepod bloom, which is located further downriver (Fig. 3a,b). Whereas copepods appear to be the favored food item for larval *M. saxatilis* (perhaps because they provide a greater amount of energy per unit consumed), they will feed on *B. longirostris* in proportion to its presence in the immediate environment (Arend 1995). Thus, over a large portion of the river, there is a drastic increase in food availability for larval *M. saxatilis* during a short window of time. The downriver larvae feed primarily on copepods, while those upriver increase their consumption of *B. longirostris* in synchrony with the bloom.

The gut contents of larval *M. saxatilis* were studied using samples collected in the same locations and over the same time period that the zooplankton samples were collected, in 1994 (Limburg et al., submitted). The per capita consumption of *B. longirostris* and copepods by these larvae are shown in Figures 4a and 4b. While Figure 4a shows a close relationship between larval consumption of *B. longirostris* and the zooplankter's population dynamics, Figure 4b indicates that larval consumption of copepods remains high even after the population of copepods has declined (compare with Fig. 3b). These different feeding patterns could be attributed to the preference of larval *M. saxatilis* for copepods.

Figures 3b and 4b suggest two things: 1) the coincident blooms provide a great increase in prey abundance over a large portion of the Hudson River (note that although *B. longirostris* may not be the larvae's favorite food, the zooplankter still significantly increases the prey available for the larvae, particularly those located upriver from the copepod bloom), and 2) the larvae do take advantage of the increase in zooplankton

Zooplankton Densities in the Hudson, 1994

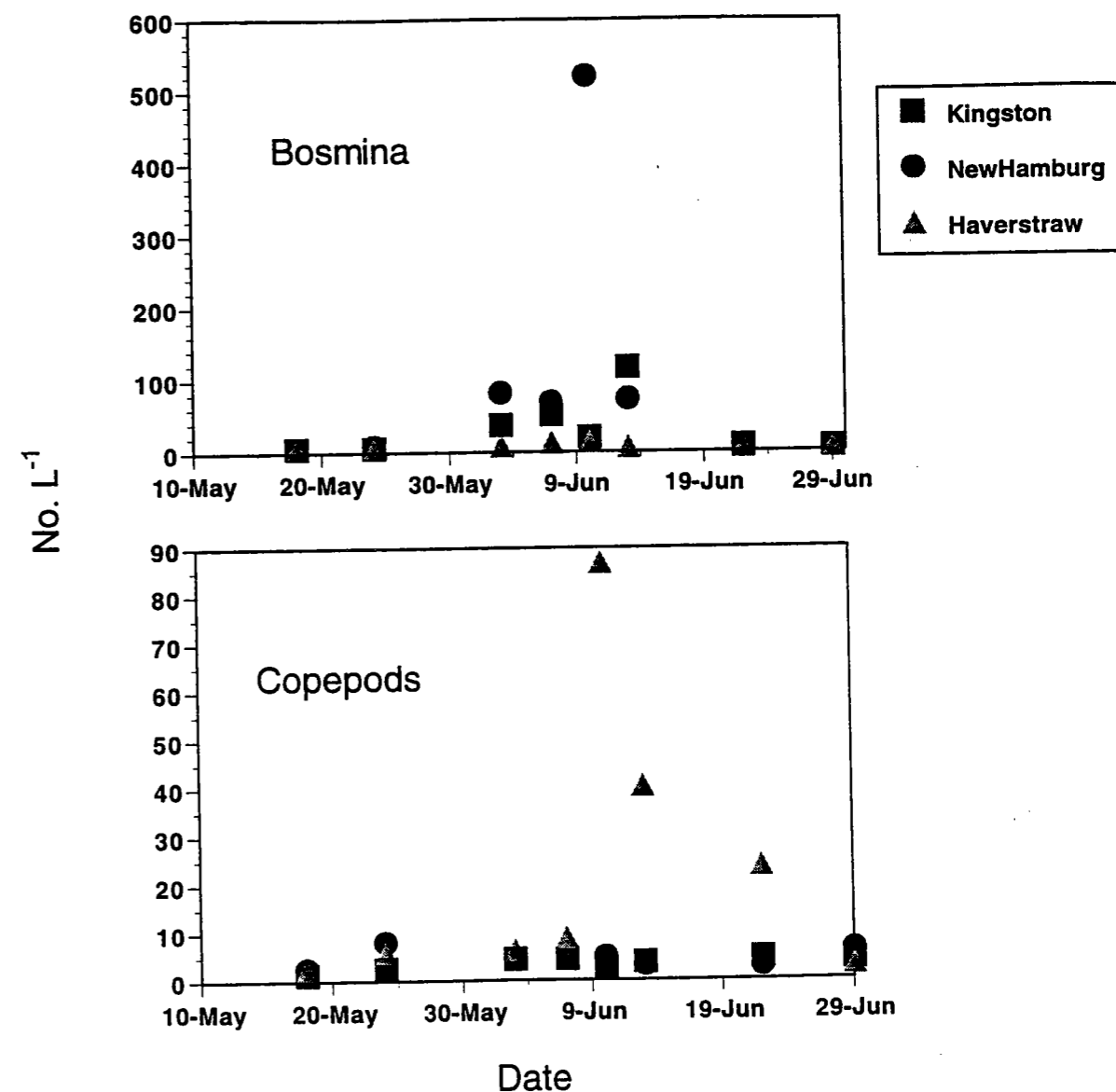


Figure 3. Hudson River densities of (a) *Bosmina longirostris* and (b) copepods sampled in 1994 at Kingston (KM 148), New Hamburg (KM 105), and Haverstraw Bay (KM 65-70). (Source: Limburg, Pace, Fischer, and Arend, submitted)

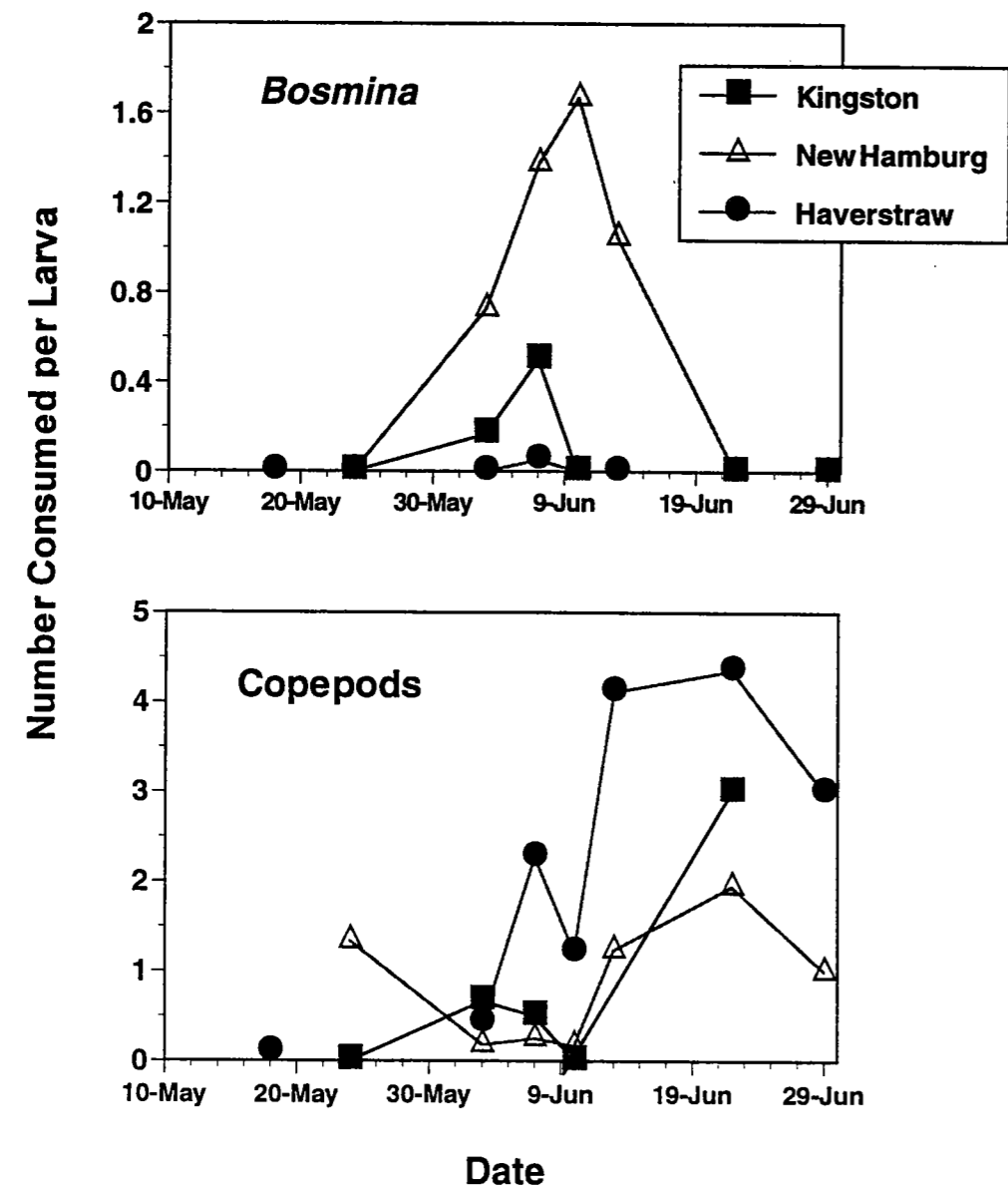


Figure 4. 1994 per capita consumption of (a) *B. longirostris* and (b) copepods by *M. saxatilis* larvae in the Hudson River. (Source: Limburg, Pace, Fischer, and Arend, submitted)

abundance. However, the question remains as to whether this increase in food availability is an important factor in the recruitment success of *M. saxatilis*.

Methods

Otolith microstructure analysis

Sagittal otoliths were extracted from juvenile *M. saxatilis* caught by the NY State Department of Environmental Conservation (DEC) in July, August, and September, 1994. The fish had been collected at river kilometers 40 (river mile (RM) 25), 63 (RM 39), 95 (RM 59), 114-126 (RM 71-78), and 196-201 (RM 122-125), using 200 foot, 0.64 cm² bar mesh beach seines. The total length (TL), fork length (FL), and standard length (SL) of each fish were measured and recorded, along with its site of capture. Otoliths were cleaned in 10% bleach solution, air-dried, and then embedded in Spurr's epoxy along with a randomly assigned identification number. One otolith from each pair was sectioned along the transverse plane using an Isomet saw. Preparation was done as described in Secor et al. (1991). The section was glued to a slide using a low melting point glue, so that it could be flipped in order to grind and polish both sides of the section. Sections were ground and polished down to the otolith's core, using 400 and 600 grit wet/dry sandpaper and a slurry of 0.3 μm alumina powder. Each section was then projected through a light microscope at 300X magnification onto a video screen for analysis. The increments were counted at least two times, taking the average as the official count. On several occasions, independent readings by two people were done in order to verify accuracy. The distance from each otolith's primordium to the edge of the seventh increment was measured along the same radius, to be used for estimating initial growth rate. A total of 63 otoliths were read.

Age Estimation

Houde and Morin (1990) showed that the age of *M. saxatilis* larvae at formation of the first increment varies inversely with water temperature. To estimate age at the formation of the first increment for each individual, I first estimated water temperature at hatch date for the period from 14 April through 19 July 1994 using the equation (Limburg, unpublished data):

$$\text{H}_2\text{O temp} = -17.045 + 0.228(\text{catch day} - \# \text{ increments})$$

$$N = 28; r^2 = 0.98; p < 0.001$$

I then used Houde and Morin's (1990) equation to estimate each fish's temperature-corrected age:

$$\text{Age} = 11.56 - 0.45(\text{H}_2\text{O temp}) + \# \text{ increments}$$

Finally, hatch dates were estimated by subtracting the estimated age of an individual from its date of capture.

Growth rate estimation

The following equation, based on the assumption that striped bass larvae are approximately 4.0 mm standard length (SL) upon hatching, was used to determine the lifetime growth rate of each larva (Secor and Houde 1995):

$$\text{lifetime growth rate} = (\text{SL} - 4.0 \text{ mm})/\text{age}$$

To estimate initial growth rates, larval SL at formation of the seventh increment (SL7) was predicted using a regression determined by Karin Limburg for 1994 larvae. This regression shows a linear relationship between SL and the natural log of otolith width (Fig. 5). Thus, using the otolith measurements and the following equation, I was able to estimate growth rate for this initial period of each larva's life.

$$\text{GR7} = (\text{SL7} - 4.0)/\text{age at formation of seventh increment}$$

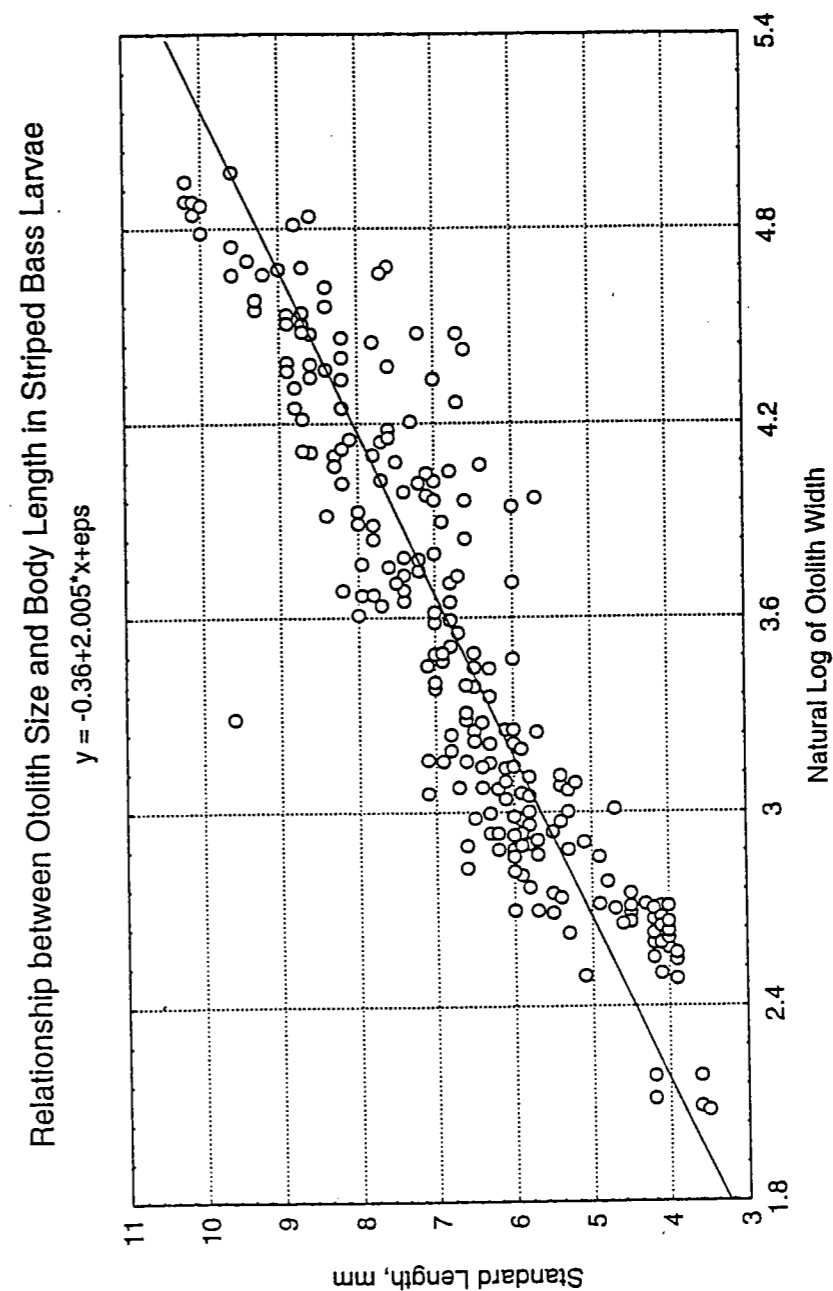


Figure 5. Relationship between standard length (SL) and the natural log of otolith width for 1994 *M. saxatilis* larvae. (Source: Limburg, unpublished data)

Results and Discussion

Data were divided into four populations, the population of larvae sampled and the three populations of the juveniles sampled, i.e., July, August, and September. The individuals within each of the populations were grouped into cohorts, which consist of individuals estimated to have hatched within the same 5-day time period. The cohorts were then associated among 3 larger groups. Those which hatched and began feeding before the bloom were labeled as the "pre-bloom group", and had estimated hatch dates ranging from 5 May, 1994 through the 25 May, 1994. The second group is the "bloom group" and includes cohorts which hatched between 26 May, 1994 and 9 June, 1994. These larvae would have been ideally positioned in time to take advantage of the increased prey availability during the bloom. The third group, "the post-bloom group", hatched between 10 June, 1994 and 9 July, 1994. These cohorts would have hatched too late to have taken advantage of the bloom.

Figure 6 describes cohort frequency per population sampled, with the bloom cohorts highlighted by hatched bars. For all but the September population, this group has a greater representation among the larvae and juveniles sampled. Before conclusions can be drawn from this graph, it is important to note three processes which could have affected the frequencies calculated. First, not all of the fish may have recruited to the sampling gear, especially for the month of July in which the individuals of the post-bloom cohorts would have been too small for capture by the nets used to sample juveniles. A second process is mortality; older cohorts had experienced longer exposure to mortality factors, such as predation. Third, some of the older cohorts might have migrated down-river, out of the sampling sites (Young et al. 1994; Wells et al. 1991).

There exist two possible explanations for the higher representation of bloom cohorts in the larvae, July juvenile, and August juvenile populations. One is that the bloom cohort individuals are experiencing greater recruitment success due to the increase

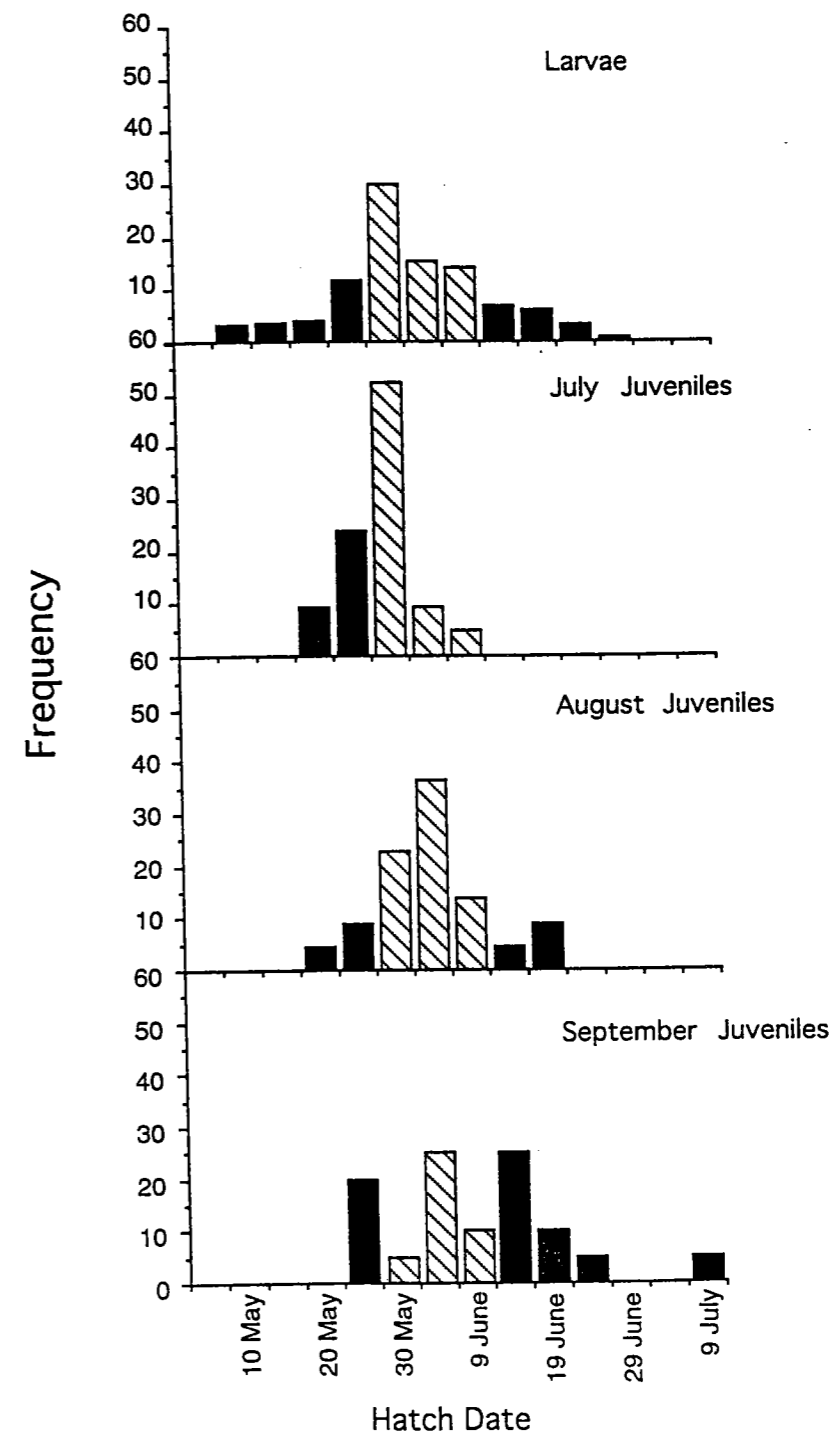


Figure 6. Frequencies of hatch date per 1994 juvenile population sampled. Cohorts associated with the bloom are indicated by the hatched bars.

in prey abundance. With respect to the September juveniles, it is interesting to note that the two non-bloom associated cohorts having high frequencies fall immediately to either side of the cut-off dates for the bloom cohort. These individuals may still have hatched at a time in which they could benefit from the bloom. Additionally, if juvenile migration downriver is a factor, the September sample would have less representation of the pre-bloom and bloom cohorts. The second possibility is that the *M. saxatilis* population has adapted to have the timing of spawning activity coincide with the zooplankton bloom, such that the onset of larval feeding begins as zooplankton populations are increasing.

The average lifetime growth rates for juveniles caught in July, August, and September did not differ substantially (Fig. 7). The growth rates for juveniles caught in September were lower, which is consistent with otolith microstructure observed for that month. Lower water temperatures in September are most likely responsible for the decrease in growth.

A comparison of the average larval growth rates of the juvenile *M. saxatilis* pre-bloom, bloom, and post-bloom cohorts (Fig. 8) shows a slightly increasing trend, which could not be tested for significance due to the small sample size. This increase could be a function of the increase in water temperature over time, which has a positive effect on larval growth. Rutherford and Houde (1995) observed that the later cohorts of a spawning season, which hatched when temperatures were consistently above 17 °C, were more likely to survive.

It is difficult to isolate the possible influence of food abundance from that of temperature on initial growth rates, and it has been observed that temperature has a more pronounced effect on the width of otolith microincrements than does food consumption (Limburg, personal observation). The bloom cohorts could be experiencing higher larval growth rates due to the presence of a greater number of prey, but this may not be the sole cause. A similar explanation could be given for the higher growth rates observed among the larvae of the post-bloom cohorts, since the consumption of copepods remained

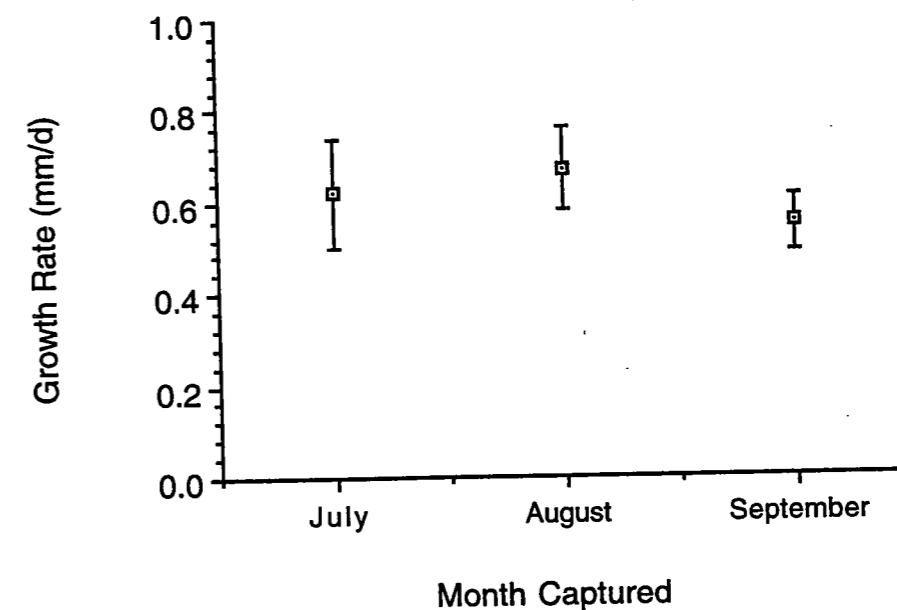


Figure 7. Average lifetime growth rates for juveniles caught in July, August, and September 1994.

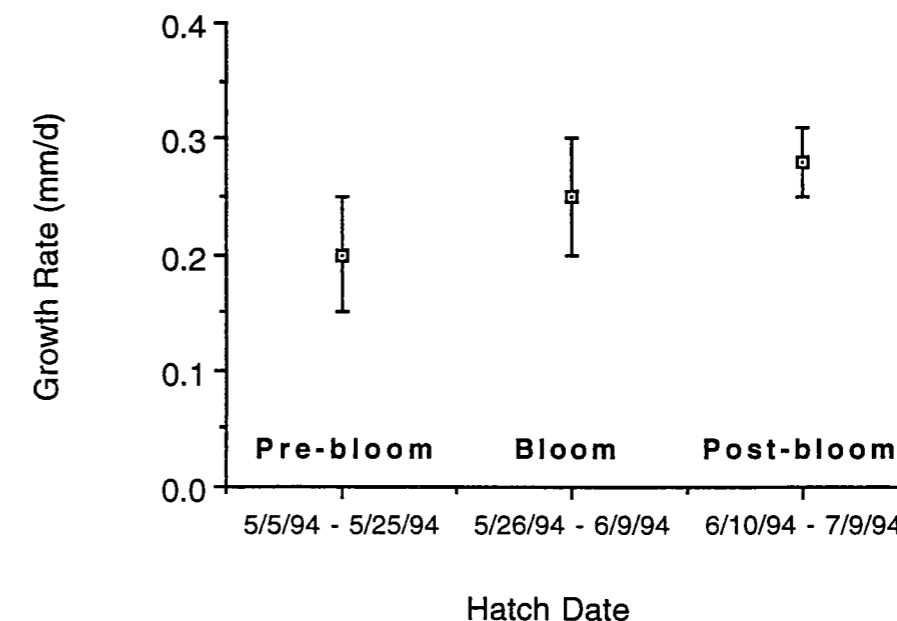


Figure 8. Retrospective larval growth rates for the pre-bloom, bloom, and post-bloom cohorts of juvenile *M. saxatilis*.

high after the bloom (Figs. 3,4) had ended. More information is needed on the growth rates of the copepods relative to their consumption by fish. Larvae in the post-bloom cohorts could receive similar benefits as the bloom cohorts if high prey productivity persists with a continued increase in temperature.

Most likely it is a combination of both greater prey abundance and favorable water temperatures that contribute to a higher survivorship of *M. saxatilis* bloom cohorts. Although the post-bloom cohorts seem to benefit from similar factors as and have higher growth rates than the bloom cohorts, their survivorship is low. This could be due to the presence of a greater number of predators, including older *M. saxatilis* individuals, later in the season. Further studies could try to isolate these two factors to determine their relative importance. However, it would appear that the annual zooplankton bloom, which spans a large portion of *M. saxatilis* spawning ground in the Hudson River Estuary, is important for the recruitment of the fish from the larval to the juvenile stage. Gut content analysis supports this idea by showing that, up to a certain point, there is an increase in feeding with greater food availability (Limburg et al., in preparation). The potential for greater spawning activity that produces the bloom cohorts also gives credence to the idea that food availability is important. In the early 1900's, Hjort hypothesized that the relative timing of spawning and the onset of spring production might have an important impact on the success or failure of a year class (Rothschild 1986). More recent studies stress a strong relationship between time of spawning and water temperature (Kempinger 1988; Messieh 1988). This idea does not, however, rule out the importance of zooplankton production, which is also influenced by temperature (Rutherford and Houde 1994). The favorable temperatures which trigger spawning may also impact the onset of zooplankton productivity.

Further understanding of the recruitment of larval *M. saxatilis* in the Hudson River Estuary, especially with respect to prey dynamics and temperature fluctuations, is useful for future management policy. For example, Secor et al. (1995) have shown that

larval stocking of *M. saxatilis* in most Chesapeake Bay tributaries can significantly increase *M. saxatilis* stocks, provided that larvae are released during a time and in a location in which conditions are favorable for growth and survival. Although hatchery-raised fish are not needed to stock the Hudson River, should the situation change in the future, this knowledge could be applied to the Hudson River ecosystem as well. Should the zooplankton bloom be shown to have a strong, positive effect on the recruitment of the *M. saxatilis* cohorts associated with its occurrence, larval stocking by fisheries managers would be most ideal at this time. Additionally, knowledge of food web interactions are very important in understanding ecosystem dynamics.

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