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A Stock Assessment Program for Chesapeake Bay Fisheries: Development of an Alosa Juvenile Index of Abundance: Annual Report 1991

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A Stock Assessment Program for Chesapeake Bay Fisheries: Development of an Alosa Juvenile Index of Abundance

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PREFACE

This presentation is the annual report for Contract No. NA17FU0196-01 "A Stock Assessment Program for Chesapeake Bay Fisheries: Development of an *Alosa* Juvenile Index of Abundance," for the period 1 May 1991 to 31 May 1992. The fishes of concern were the alewife (*Alosa pseudoharengus*), American shad (*A. sapidissima*), and the blueback herring (*A. aestivalis*).

The abundance of the *Alosa* stocks, once an important component of the landings of Virginia fisheries, have dramatically decreased in the last decade. Commercial landings of *Alosa* species in Virginia throughout the 1980s were the lowest ever recorded. American shad and river herring are also pursued by recreational fishermen in Virginia; however, the extent and success of this activity is largely unknown. Additionally, these species have a vital ecological role. Young-of-the-year *Alosa* are the dominant pelagic prey species in their extensive freshwater and upper estuarine nursery grounds. After spawning, adults return to the sea and are prey of many marine piscivores. It is important that studies of the *Alosa* stocks in Virginia be continued. Current data, as well as historical data, are needed in order that data analyses may make constructive contributions to rational management strategies.

The research presented herein directly addresses many of the research concerns stated in the Shad and River Herring Action Plan and augments on-going monitoring research and extant data bases. These data will be a pertinent contribution to the total data base that is being constructed to assist in the formulation of management strategies for the east coast *Alosa* stocks.

ACKNOWLEDGMENTS

We are indebted to the following Virginia Institute of Marine Science personnel for their assistance in this project: Loisirene Blumberg, Steffany Dawson, Joice Davis, Steve Gornak, Bruce Hill, James Owens, Daniel Redgate, Paul Rudershausen, Phil Sadler, Brian Shaner, Paula Williams, and Hank Wooding. We also express our thanks to the VIMS Vessel Operations Support Staff without whose help our ambitious sampling program would not have been possible.

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1. Daytime pushnet sampling for juvenile <u>Alosa</u>, at current abundance levels, is not feasible. Juvenile American shad and alewife were virtually absent in all daytime samples. Daytime efforts resulted in extremely low, and frequently zero, catches of juvenile blueback herring. When juvenile blueback herring were collected the mean CPUE for the following night cruise was at least an order-of-magnitude greater. There was no apparent relationship between daytime catch results and light intensity.

2. The 1991 juvenile blueback herring indices (i.e., maximum mean CPUE) were as follows: Rappahannock (194.3), James (156.9), Pamunkey (13.3), and Mattaponi (9.5). The index for the Pamunkey River is the lowest observed since annual pushnet monitoring began in 1979 and only once before was an index lower than 9.5 observed on the Mattaponi River.

3. The 1991 juvenile alewife indices were as follows: Rappahannock (6.7), Pamunkey (2.2), Mattaponi (0.5), and James (<0.1). The 1991 indices for both the Pamunkey and Mattaponi rivers are the lowest observed since monitoring began in 1979.

4. The 1991 juvenile American shad indices were as follows: Mattaponi (10.2), Pamunkey (8.5), Rappahannock (0.2), and James (<0.1). The 1991 Mattaponi shad index is also the lowest observed since 1979. The Pamunkey index, however, is near the long-term average and exceeds that observed for 6 of the previous 9 years of sampling.

5. There were no observed major differences in the calculated 1991 daily instantaneous natural mortality rates for all three <u>Alosa</u> species than those calculated since 1979. Blueback herring natural mortality was highest on the Rappahannock (0.103) followed by the James (0.094), Pamunkey (0.040), and Mattaponi (0.031) rivers; alewife natural mortality was highest on the Pamunkey (0.092) followed by the Rappahannock (0.068), and Mattaponi (0.046) rivers; American shad natural mortality was higher on the Pamunkey (0.064) than the Mattaponi (0.057) River.

6. In a two day gear comparison study on the Nanticoke River in Maryland, the Maryland Department of Natural Resources did not collect any juvenile <u>Alosa</u> with their surface trawl during daytime hours. VIMS sampled the same area during the night with the pushnet gear. The mean pushnet catch for blueback herring was 144.1 and 103.4 on days 1 an 2, respectively, and 0.5 and 2.7 for alewife. A follow-up study is planned for 1992.

INTRODUCTION

Historical Background

Alosa stocks, specifically the American shad (*Alosa sapidissima*), and alewife (*A. pseudoharengus*) and blueback herring (*A. aestivalis*), collectively known as river herring, have historically provided Virginia with a major commercial fishery. In 1880, the tributaries of the Chesapeake Bay yielded more than 2,268 metric tons (MT) of shad. In 1896, Virginia ranked second to New Jersey in shad production with 4,990 MT. Usually Virginia ranked first or second in shad production in the early 1900's. In 1908, Virginia's shad catch of 3,311 MT made it the most important fish caught in Virginia, and the catch comprised about one fourth of all shad taken in the United States. The catch of American shad, however, has critically declined since the mid-1970's.

River herring catches in Virginia have had a pattern very similar to that for the shad. In 1920, river herring in Virginia ranked first in quantity and fourth in value, with a catch of 7,258 MT worth 253 thousand dollars. As late as 1969, river herring in Virginia ranked third in quantity and fifth in value, with a catch of 13,608 MT worth 608 thousand dollars (NMFS 1972). Since the early 1970's, however, the fishery has also steadily declined. In 1981, the combined catch of river herring and American shad was the lowest ever recorded and, since that time, there has only been a marginal increase in landings.

Historically, the construction of dams, degradation of the environment, and over-fishing were cited as causes for the decline of fish stocks. To varying degrees, the same explanations are offered as contemporary explanations for further declines in stocks. The decline in *Alosa* landings since the

1970's may be the joint result of the heavy exploitation in the late 1960's, the decimation of the 1972 year class by Tropical Storm Agnes (Loesch and Kriete, 1976), and continued poor recruitment in recent years. Although landings have increased since 1981, they are still low. The use of pesticides and, in particular, the use of herbicides in conjunction with no-till farming may also be, in part, responsible for the reduction of *Alosa* stocks in the Chesapeake Bay region.

It is important that the basic biology and population dynamics of the *Alosa* stocks in the Chesapeake Bay region be studied. Anadromous fishes are a renewable natural resource which have a vital ecological role in addition to their economic importance. Juvenile (young-of-the-year) *Alosa* are the dominant pelagic species in their extensive freshwater and upper estuarine nursery grounds and thus, are important prey for resident piscivores. Durbin et al. (1979) noted that anadromous alewives entering ponds in Rhode Island were an important nutrient source to a system through spawning mortality. After spawning, adults return to the sea and are prey of many predatory marine fishes. Because of the ecologic and economic importance of *Alosa*, it is in the interest of both the State of Maryland and the Commonwealth of Virginia (and other Atlantic coastal states) to conduct *Alosa* studies. Current data, as well as historical data, are needed for constructive contributions to the formulation and application of rational management strategies.

Estimates of relative year-class strength (indices), the subject herein, are an important facet in the studies of stock recruitment. Indices are particularly sensitive to large changes in juvenile (young-of-the-year) abundance, thus, an expectation of a strong or weak year class can be established. If a juvenile index can be shown to vary directly with the spawning stock size over a large range in stock sizes, the index can be used as a surrogate for actual year-class recruitment. Thus, the relationship between spawning stock size and recruitment can be analyzed without waiting years for the completion of recruitment.

Program Background and Objectives

The establishment of juvenile *Alosa* indices by using a pushnet is a modification to a methodology previously used in Virginia waters. Because of the negative phototropic behavior of juvenile *Alosa* (Loesch et al. 1982), a pushnet was used at night to determine a maximal mean catch-per-unit-of-effort (maximal mean CPUE; explained in Procedures). The research was conducted in the Mattaponi and Pamunkey rivers for nine years, and a correlation between the river herring index and CPUE of subsequent recruits to the fishery was about 73%. This activity was not continued in 1988 because of a lack of funding. In 1990, however, NMFS provided the necessary funds to renew the program as well as expand it in 1991 to include the James and Rappahannock rivers.

Expansion of sampling activities to include the James and Rappahannock rivers necessitated an assessment of daytime sampling for several reasons. First, it is often difficult to obtain a boat operator who could navigate the Mattaponi and Pamunkey rivers at night. This personnel problem increased because it was necessary to use two pushnet vessels to sample all the rivers weekly. It is believed that the precision and accuracy of indices can be greatly influenced by the time lapse between sampling periods. Turner and Chadwick (1972) reported deficiencies in the interpretation of their juvenile striped bass index when data were collected at two-week intervals. Secondly, sampling can be conducted at a faster pace in the daytime. This is important because all four rivers are sampled weekly, and the *Alosa* species sorted and counted before the start of the next week's sampling. It is important to establish each weekly mean CPUE promptly so as to recognize the maximal mean CPUE two to three weeks after its occurrence and, thereby, avoid costly extra weeks of sampling. Finally, the James and Rappahannock rivers, unlike the Mattaponi and Pamunkey rivers, are hosts to large commercial vessel traffic both day and night. Thus, night-time sampling in small boats in the James and Rappahannock rivers incurs greater safety risk then does daytime sampling.

The shift from night-time to daytime sampling, the expansion of the scope of the effort to other rivers, and the establishment of a long-term data base necessitates both short-term and long-term objectives. The short-term objectives, the results of which are discussed in this report, are as follows:

1. Establish a conversion factor for the extant data base of *Alosa* indices so as to be compatible with indices from daytime sampling. This objective involves the development of a data base of light intensity values taken with a submersible photometer at the time of sampling.

2. Resume the sampling of juvenile *Alosa* in the Mattaponi and Pamunkey rivers in June 1991 and initiate sampling in the James and Rappahannock rivers in order to estimate relative abundance, growth, and mortality.

4. Initiate comparative sampling with Maryland's Department of Natural Resources (DNR) trawl catches of juvenile *Alosa* so as to develop a gear catch conversion factor to support the development of a bay-wide juvenile *Alosa* index.

The long-term objectives are to provide a methodology for establishing a long-term data base of juvenile *Alosa* indices for the nursery zones of the James, Mattaponi, Pamunkey, and Rappahannock rivers (Figure 1) in order to:

1. Develop juvenile *Alosa* indices based on daytime sampling that are (at the very least) sensitive to good and poor reproductive success.

2. Assess the utility of juvenile indices, over a large range in stock sizes, as a surrogate for actual year-class recruitment in stock-recruitment models.

3. Determine if species-specific indices exhibit a common pattern of change.

4. Determine if patterns of index changes differ among rivers.

5. Integrate the year-class assessments in Virginia with those in Maryland to provide a Bay wide estimation of *Alosa* year-class strength.

METHODS AND MATERIALS

Daytime pushnet sampling for juvenile *Alosa* during the 1990 nursery season was relatively unsuccessful (Dixon and Loesch 1992). Most daytime sampling resulted in zero catch of *Alosa* and, as a result, a meaningful index of abundance for 1990 could not be calculated. Anticipating similar results in 1991, weekly daytime and night-time sampling cruises were scheduled on each river system. This approach supported the day-night catch comparison effort as well as the acquisition of a night-time based index should daytime sampling prove not to be feasible. As discussed in the results section, daytime sampling was unproductive and eventually discontinued. The methodology for data collection is discussed below.

Sampling Design

A stratified random sampling plan (SRS) was employed. Each nursery zone was divided into a series of strata, each 9.3 km (5 nautical miles), and each stratum further divided into five 1.9 km substrata. Perpendicular to this stratification, the 9.3 km sections were divided into three nearly equal parts, a center section and two shoreward sections bounded by the 1.8 m depth contour lines at mean low water (MLW) indicated on the respective navigation charts. Thus, each 9.3 km stratum was partitioned into 15 sites. Three sampling sites were randomly chosen from the 15 in each stratum. This effort allocation design is a modification to the original statement of work. The statement of work called for an effort allocation (i.e., number of replications per stratum) according to the area within the 6-foot contours in each strata. This design was abandoned because all the historical index data for the Pamunkey and Mattaponi Rivers was based on 3 replicates per strata. In addition, juvenile *Alosa* during 1991 in all of the rivers sampled were typically above the zones where the area within the 6-foot contours would have warranted more than 3 replicates.

The nursery zone in each sampling period was demarcated by the last upstream and the last downstream stratum in which juvenile Alosa were captured. A dynamic nursery zone, rather than a static one, and an SRS were chosen because there is a shift in availability of juvenile Alosa within the nursery zone caused in part by low summer river flows and the encroachment of saline water (Loesch and Kriete 1983). Within the limits of the nursery zone, juvenile abundance is generally greatest in the central or near central strata, and this pattern of the distribution of density also shifts as the nursery zone limits change. The use of a SRS design where there is a shift in availability and/or the density distribution avoids the inherent possibilities in a completely randomized (CR) design of expending a large proportion of the sampling effort either in an area where the fish were previously, but not presently, available, or in a limited area of heavy concentration.

To calculate the volume of water sampled, a calibrated flowmeter was mounted in the mid-point of the net. All samples were collected against the current. Previous trials with this arrangement, however, indicated that there was no significant difference in volume of water filtered when samples were taken with or against the current, and the overall mean volume was 655 m^3 (Loesch et al. 1982). In practice, samples of 5-min duration are taken, and adjusted, as flowmeter values indicate, to the standard of 655 m^3 of water filtered (i.e., 1 unit of effort).

Juvenile catch data were also adjusted for a minimum fish size. Small juvenile Alosa capable of passing through the 12.7 mm stretched mesh of the pushnet codend are retained to varying degrees by larger fish and debris in the net. To ascertain escapement, a sleeve of 6.36 mm stretched mesh was loosely fitted over the codend in a series of 25 samples in 1979 (Loesch and Kriete 1983). Only 5.4% of the fish $\leq$ 26 mm were retained in the codend, and a fork length of 27 mm was chosen as a lower limit for catch-effort considerations. It is believed that this limit increases the reliability of the estimates, but it is also recognized that the effect of masking (see Pope et al. 1975) could be confounded in the data. However, the effect is believed to be nonsignificant because the larger counts in the sleeve occurred before the maximal mean CPUE was attained.

Relative Abundance Index

The index that is used is defined as the maximal mean catch-per-unit-of-effort (maximal mean CPUE), i.e., the mean CPUE (by species) in a sampling period that exceeds the mean CPUE in all other weekly sampling periods. The maximal mean CPUE, therefore, reflects the peak in the standard catch curve (Ricker 1975). Annual indexes of juvenile Alosa abundance were at one time derived from a single, daytime, surface-trawl survey in the major Virginia tributaries to Chesapeake Bay. That sampling scheme implied that the proportion of juvenile stock available to the gear at the time of sampling was constant year to year, and fish availability was independent of light intensity. However, Loesch et al. (1982) reported diel migratory activities by juvenile anadromous Alosa, and an association between sky-opacity index values and surface catch of blueback herring. Their findings suggest that the juveniles (or their prey) are negatively phototropic, and the catches made by the surface trawls were inversely related to the degree of light attenuation. The behavior of juvenile Alosa in relation to light intensity was investigated in 1991 via day-night catch comparisons and via the use of a submersible photometer. The sampling design and specifications for the light attenuation monitoring are discussed in the next subsection.

An overall mean CPUE was calculated for each sampling period. The largest of these CPUE values would, normally, be defined as the index of abundance, and referred to as the maximal mean CPUE. A maximal mean CPUE was chosen as an index, in preference to a seasonal mean CPUE, for several reasons. First, a general downstream drift of the larger juveniles in the summer and fall, ahead of the mass migration associated with decreasing river temperatures, has been reported for blueback herring and American shad (Loesch 1969, Marcy 1976). Thus, emigration affects late-season availability in the nursery zones. Second, the effect of increased gear avoidance with increased size is minimized with a maximal mean CPUE index since it occurs relatively early in the total period of juvenile availability in the nursery zones. Third, economic considerations exist. Field programs and the subsequent laboratory work are labor intensive and costly. To isolate the maximal mean CPUE, it is necessary to sample before and after its occurrence. Sampling starts in late May or early June, and for alewife and American shad the maximal mean CPUE occurs between late June and early July, and in late July or early August for blueback herring. However, relatively large catches of juvenile blueback herring can be made in surface waters (day or night) in September and October (Kriete and Loesch 1980; Loesch et al. 1982). Thus, with a maximal mean CPUE index, sampling of juvenile blueback herring would be completed about late August. In contrast, a seasonal index would require sampling through October, possibly through November.

Day-Night Catch Comparison

One of the original program objectives was the development of a model for adjusting current and historical *Alosa* catches to a standard light intensity. Toward this objective, light intensity and water column light attenuation were monitored during all daytime sampling cruises. A LI-COR model LI-1000 Datalogger with a LI-190SA Quantum Sensor for measuring incident light intensity (as recorded on the boat deck) and a LI-192SA Underwater Quantum Sensor for measuring water column light attenuation was used for light intensity monitoring. LI-COR quantum sensors measure Photosynthetically Active Radiation (PAR) in the 400 to 700 nanometer waveband or visible light. The unit of measurement is micromoles (or microEinsteins) per second per square meter ($\mu mol\ s^{-1}\ m^{-2}$ or $\mu E\ s^{-1}\ m^{-2}$).

Incident light intensity and water column light attenuation were monitored at the beginning and end of each 5-minute pushnet sample. Incident light intensity was measured on the deck and water column light attenuation was measured at set depths of 0.5 and 1.5 meters (maximum depth of the pushnet).

Mortality

Estimates of mean CPUE that followed the maximal mean CPUE, but clearly preceded the onset of the seaward migration, would normally be used in conjunction with the maximal value to estimate the instantaneous natural mortality rate (M_d). The $\log_e$ of the ratio of maximal mean CPUE to a subsequent mean CPUE would be used to calculate M when there was only one usable mean CPUE subsequent to the maximal value. Division by the number of days elapsed from the maximal mean CPUE (day 1) to the subsequent mean CPUE gave the daily instantaneous rate of natural mortality (M_d). With two or more usable mean CPUE values following the maximal mean CPUE, catch curves (Ricker 1975) would be used to derive M_d. Assumptions and difficulties in estimating natural mortality via the described methods are discussed in the Results section.

Growth

Increases in mean fork length were used to calculate juvenile Alosa "apparent growth." All juveniles in samples of size N < 50 were measured; for N > 50, a random subsample of 50 fish was taken. Difficulties in interpreting "apparent growth" are discussed in the Results section.

VIMS/MD-DNR Gear Comparison

In contrast to the pushnet sampling gear employed in the VIMS program, the State of Maryland, Department of Natural Resources (MD-DNR) utilizes a sub-surface trawl system during daytime hours to collect juvenile Alosa. Toward eventually developing a bay-wide juvenile Alosa abundance index, a gear fishing power comparison study was undertaken with MD-DNR. The comparison study was performed September 16 and 17, 1991 on Marshyhope Creek, a tributary to the Nanticoke River on Maryland's Eastern Shore. This river system was recommended by MD-DNR because their preliminary results for 1991 indicated that juvenile Alosa were most abundant in the Nanticoke relative to the Patuxent, Chester, and Choptank rivers which they also monitor. Because VIMS had by this date discontinued daytime sampling, a "comparison" consisted of daytime trawls by MD-DNR and night-time pushnet sampling by VIMS over the same sampling area. A completely randomized (CR) sampling design was utilized over a 5-mile section of MarshyHope Creek. The 5-mile section (from the bridge at Brookview to the creek mouth or junction with the Nanticoke River) was partitioned into 1/2 mile blocks (total of 10 blocks). On each day, 15 locations were randomly selected for sampling. Standard 5 minute tows (or "pushes" relative to VIMS' gear) were performed. All samples were preserved in 5% neutral buffered formalin (NBF) for laboratory examination. Planned data analysis included examination of the differences in mean CPUE as well as differences in the characteristics of the populations sampled (i.e., differences in daytime populations as sampled by MD-DNR's trawl system and night-time populations as sampled by VIMS' pushnet gear) via measurements of lengths and weights.

RESULTS AND DISCUSSION

Weekly day-night sampling for juvenile Alosa in the nursery zones of the Mattaponi, Pamunkey, James, and Rappahannock rivers began the week of June 10, 1991. The nursery zone in each river was sampled through the week of July 8 (5 weeks of day-night sample data). After the week of July 8, daytime sampling was discontinued because it became apparent that juvenile Alosa, at current abundance levels, are not available to the pushnet gear during daylight hours. Weekly night-time sampling, however, continued until the maximal mean CPUE was observed on each river. The following summarizes the number of day-night cruises performed on each river:

Mattaponi:	Daytime sampling through July 10 (5 cruises) Night sampling through July 24 (7 cruises)
Pamunkey:	Daytime sampling through July 8 (5 cruises) Night sampling through August 1 (7 cruises)
James:	Daytime sampling through July 8 (5 cruises) Night sampling through October 8 (14 cruises)
Rappahannock:	Daytime sampling through July 10 (4 cruises) Night sampling through August 14 (8 cruises)

Results of the 1991 sampling efforts are discussed in the following subsections according to the major program objectives.

Day-Night Catch Comparison

Through the week of July 8, 1991, a separate day and night sampling cruise was conducted on each river (16 day-night sampling cruises). A total of 246 samples were collected in association with measured light intensity (on deck and at 0.5 and 1.5 meters) during daylight hours. Table 1 presents the day-night sampling results (i.e., mean and standard deviation CPUE) for the three juvenile Alosa species. Juvenile American shad and alewife were virtually absent in all daytime samples. Furthermore, most daytime efforts resulted in insignificant, and frequently zero, catches of juvenile blueback herring. No *Alosa* of any kind were captured during daytime hours on the Mattaponi River. When juvenile blueback herring were collected on daytime cruises on the other river systems, the corresponding mean CPUE for the night cruise was at least an order-of-magnitude greater. The following summarizes the ratio of the mean night-time CPUE to the corresponding mean daytime CPUE of blueback herring for each river:

	Ratio (Night CPUE/Day CPUE)		
Date	James	Rappahannock	Pamunkey
June 10	122.2	-	8.5
June 17	-	-	10.2
June 24	30.7	15.7	-
July 1	137.8	811.0	*
July 8	32.6	48.6	59.0

(- No day or night cruise for comparison)
(* Zero day catch)

The coefficient of variation (CV) for successful daytime collections of blueback herring was also extremely high (200 to 300%) relative to that observed during night-time sampling (60 to 150%). The high daytime CV is strongly indicative of a lack of precision in the sampling results possibly because of the gregarious behavior of juvenile *Alosa*.

Examination of daytime catch results in relation to monitored light intensity at 1.5 meters (i.e., maximum depth of the pushnet collection) revealed no relationships in any of the river systems. Even during high sky opacity conditions (e.g., 100% cloud cover with rain), catches of juvenile blueback herring remained extremely low. Daytime catch results in the James and Rappahannock rivers in relation to light intensity are plotted in Figures 2 and 3, respectively.

The reasons for the extremely limited daytime catches are unknown. Juvenile Alosa, particularly the blueback herring, have been shown to be available to the pushnet gear in significant numbers during the late 1970s (Loesch et al. 1982). Loesch et al., in fact, reported an association between sky-opacity index values and surface catch of blueback herring. They also found that although both the blueback herring and alewife exhibited a diel periodicity (negative phototrophism), the blueback herring remain higher in the water column than do alewives. The vertical density distribution of juvenile American shad, relative to the other Alosa is unknown. It is possible that the low daytime catch rate is, in part, a function of juvenile relative abundance. Since 1980 there has been a significant decline in the relative abundance of juvenile Alosa and 1991 night-time sampling on the Pamunkey and Mattaponi rivers resulted in the lowest mean CPUE for almost all juvenile Alosa since pushnet monitoring began in 1979 (see next subsection for a complete discussion of relative abundance). The ordered mean (high to low) daytime mean CPUE of juvenile Alosa in each river was in accordance with their relative abundance observed during night-time efforts - Rappahannock, James, Pamunkey, and Mattaponi rivers - is somewhat supportive of the hypothesis of daytime availability in accordance with their relative abundance.

Light attenuation as affected by water turbidity may also have an important influence on the availability of juvenile Alosa during daytime hours. Munk et al. (1989) suggested that the vertical distribution of juvenile sea herring (Clupea harengus) is mainly determined by feeding conditions: they move to depths where light is sufficient for feeding, and refinement within that zone is made according to a compromise between optimal light conditions for feeding and optimal prey densities. Blaxter (1968) and Batty (1987) reported a feeding threshold, or the intensity when feeding dropped to 10% of the level at high light intensity, of 0.01 to 0.1 lux (0.02 to 0.002 $uE\ m^{-2}\ s^{-1}$).

Blaxter and Parrish (1965) reported a preferred isolume of 1 lux for optimal feeding and school maintenance. If it is assumed that juvenile river herring behave similarly, the low daytime catch results can possibly be explained by the fact that monitored light intensity at 1.5 m in all of the rivers sampled was rarely less than 1 $uE\ m^{-2}\ s^{-1}$ (51.2 lux) even when sky opacity was high (e.g., completely overcast). Ongoing research (Dixon - unpublished) indicates that juvenile Alosa become available to the pushnet gear in surface water when light intensity drops to approximately 0.01 $uE\ m^{-2}\ s^{-1}$ (0.5 lx) at 1.5 meters. This condition is generally observed approximately 30 to 45 minutes after sunset (or before sunrise).

Light attenuation and relative abundance may act together in controlling the availability of juvenile Alosa to the pushnet gear during daytime hours. It was previously noted that the order of the rivers in terms of relative abundance of juvenile Alosa based on daytime sampling followed that observed during night-time efforts - Rappahannock, James, Pamunkey, and Mattaponi rivers. Almost the same order is obtained when the systems are arranged according to light attenuation. At 1.5 meters the mean amount of light remaining relative to incident light measured on the deck and the mean depth of the Sechii disk reading for each river were as follows:

	% Light Remaining	Secchi Depth
Rappahannock	1.0%	0.41m
Pamunkey	1.9%	0.62m
James	2.1%	0.52m
Mattaponi	3.2%	1.00m

The relative importance of light attenuation and relative abundance in controlling availability is not known at this time. There may also be other factors, unknown at present, that also influence the daytime availability of juvenile Alosa to the pushnet gear.

Based on these observations, daytime pushnet sampling was suspended after the week of July 8. At present, therefore, daytime pushnet sampling for juvenile Alosa to monitor annual relative abundance is not feasible.

Relative Abundance

Mean CPUE values for the adjusted juvenile Alosa nursery zones were calculated for each weekly night-time cruise. These data are presented in Table 2. Weekly night-time sampling continued until the maximal mean CPUE for each species on each river were observed. The number of weeks of sampling, the maximal mean CPUE (i.e., the index), and the date of occurrence of the maximal mean CPUE are as follows:

	No. Weeks	Bluebacks	Alewife	Shad
James	15	156.9 August 5	<0.1 NA	<0.1 NA
Rappahannock	9	194.3 July 8	6.7 July 8	0.2 July 8
Pamunkey	7	13.3 June 17	2.2 June 10*	8.5 June 10*
Mattaponi	7	9.5 June 10*	0.5 June 10*	10.2 June 10*

NA = Not applicable (specimens essentially not collected
* = Initial sampling cruise

The latter dates of maximal mean CPUE for blueback herring are an annual occurrence and reflect their later peak of spawning relative to alewife and American shad. Catch curves for each species are presented in Figures 4 through 8. Sampling on the

James River was unusually long due to the highly erratic catch curve for blueback herring. Although the highest mean CPUE was observed during the week of September 9, the mean value was extremely biased by one unusually large sample of juvenile bluebacks. In general, the coefficient of variation (CV) was observed to increase with time on all rivers. This is particularly notable in both the James and Rappahannock rivers (see Figures 5 and 6). The reasons for the increased CV with time are not known though increased gear avoidance with size increase contributes in some manner.

Reasons for the highly erratic nature of the blueback herring catch curve in the James River are not known. One contributing reason may have been the presence of large numbers of threadfin shad (*Dorosoma petenense*) in the historical center (near Hopewell, VA) of the juvenile *Alosa* nursery zone. Normally, threadfin shad have a significant winter dieoff. For the past three years in Virginia, however, winter temperatures have been unusually mild and threadfin shad have overwintered and tremendously increased in numbers. Throughout the sampling period on the James, the downstream abundance of bluebacks would decline as the numbers of threadfins increased and then increased again as threadfins declined. As a result there were two separate populations of bluebacks - an upstream population (above mile 65) and a downstream population (below mile 55). Blueback displacement, both up and downstream, was observed to increase as the size of the threadfins increased.

Although commercial landings indicate that blueback herring are more numerous than alewife and American shad, the maximal mean CPUE values for juveniles cannot be contrasted among species because of differences in availability. Loesch et al. (1982) found that although both species exhibit a diel periodicity, blueback herring are more susceptible to capture by surface gear than are alewife. The vertical density distribution of juvenile American shad, relative to the other Alosa, is unknown.

The 1991 juvenile Alosa index for each river relative to historical data (i.e., from 1979) are presented in Table 3. Differences in catch numbers by river and a discussion of the relative magnitude of the 1991 catch to historical values are discussed by species in the following subsections.

Blueback Herring (**A. aestivalis**)

The relative order (high to low) of the rivers in supporting juvenile blueback herring are as follows: Rappahannock, James, Pamunkey, and Mattaponi. Historically (i.e., 8 of 10 years), the relative abundance of juvenile bluebacks has been larger in the Pamunkey than the Mattaponi. The reasons for the differences in the relative abundance are not known. No historical data are available for the James and Rappahannock rivers. The 1991 index for both the Pamunkey and Mattaponi rivers (13.3 and 9.5, respectively) were considerably lower than the long term (1979-91) mean (143.2 and 89.1, respectively). The index of 13.3 for the Pamunkey River is the lowest ever observed and only once since 1979 has an index lower than 9.5 been observed for the Mattaponi River.

Alewife (**A. pseudoharengus**)

The relative order (high to low) of the rivers in supporting juvenile alewife are as follows: Rappahannock, Pamunkey, Mattaponi, and James rivers. Only incidental catches of alewife were made on the James River. Historically, the Mattaponi River supports a larger relative abundance (i.e., 6 of 9 years) of juvenile alewife than the Pamunkey River. The reasons for the differences in the relative abundance are not known. The index values observed for 1991 (2.2 for the Pamunkey and 0.5 for the Mattaponi), much like that observed for juvenile bluebacks, is the lowest observed for either river since 1979 (long-term means of 9.4 for the Pamunkey and 16.7 for the Mattaponi).

American Shad **(A. sapidissima)**

The relative order (high to low) of the rivers in supporting juvenile American shad are as follows: Mattaponi, Pamunkey, Rappahannock, and James rivers. Only incidental catches of juvenile American shad were made on the Rappahannock and James rivers. Historically, the Mattaponi River supports a larger relative abundance (9 out of 10 years) of juvenile American shad than the Pamunkey River. Reasons for the consistent differences in relative abundance are not known. The index observed in 1991 on the Mattaponi River (10.2), however, is the lowest observed since 1979 (long-term mean of 26.9) matching the declining trend also observed for bluebacks and alewife. The 1991 index for juvenile American shad on the Pamunkey (8.5), however, is near the long-term average (11.8) and exceeds that observed for 6 of the previous 9 years of sampling.

Natural Mortality

Limited catch of American shad on the James and Rappahannock rivers and alewife on the James River precluded any reasonable estimates of natural mortality. The remaining 9 estimates were derived via Ricker (1975) catch curves except for blueback herring on the James River. The highly erratic catch curve for blueback herring in the James River required the use of the $\log_e$ of the ratio of maximal mean CPUE to a subsequent mean CPUE divided by the number of days elapsed for a reasonable estimate of the daily instantaneous natural mortality rate. Catch curves are characterized by an ascending left limb, a dome, and a descending right limb. The ascending left limb and the dome represent ages incompletely recruited; linearity of the descending right limb is considered as evidence that recruitment and natural mortality are adequately constant for the application of the model. When catch curves do not have a straight descending right limb, there is reason to suspect that recruitment or catchability varies, or that the population is not in equilibrium (Royce 1972). Catch curves for the three Alosa species most often had an upward inflection in the descending right limb (see Figures 4 through 8) that corresponded to the period of depressed mean growth due to recruitment. With secondary recruitment modes the mortality rates can be estimated from one or another period of decline or determined as a mean value. We most often chose the earliest period of decline because it generally allowed the use of the maximal mean CPUE and minimized the errors caused by recruitment, emigration, and gear avoidance.

Estimates of daily instantaneous natural mortality rates (M_d) for juvenile Alosa in the Pamunkey and Mattaponi rivers for the period 1979-1991 and for the James and Rappahannock rivers in 1991 are presented in Table 4. Because of three-week intervals between sampling, the 1980 and 1981 data are not considered reliable (Loesch and Kriete 1983). The following observations for the 1991 juvenile season are noted:

- Blueback herring natural mortality was highest on the Rappahannock River (0.103) followed by the James (0.094), Pamunkey (0.040), and Mattaponi (0.031) rivers. This order is in accordance with the order of relative abundance and may be indicative of density-dependent mortality.
- Blueback herring natural mortality on the Pamunkey and Mattaponi rivers was below the long-term mean (0.052 and 0.054, respectively) for the period 1979-91.
- American shad natural mortality on the Pamunkey (0.064) and Mattaponi (0.057) were only slightly greater than the

long-term means (0.057 and 0.053, respectively) for the period of record.

- Alewife natural mortality on both the Pamunkey (0.092) and Mattaponi (0.046) rivers was high relative to the long-term means (0.068 and 0.039, respectively). The high values, however, may be an artifact of sampling errors due to their low relative abundance compared to historical levels.

- Alewife natural mortality was highest on the Pamunkey followed by the Rappahannock (0.068) and Mattaponi rivers. Because of the relatively low catch of alewives on all rivers, however, no speculation on causes in the differences is offered.

Crecco et al. (1982) reported that American shad larval mortality was inversely related to age. They estimated daily Z values (M_d herein) of 0.202 among prolarvae 3-5 days old, 0.113 among 9-16 day old larvae, and 0.090 among advanced larvae 17-25 days old. The latter age group ranged from about 18.5 to 23.5 mm in length. Thus, our estimates of lower mortality rates for juveniles appear reasonable.

Growth

Growth curves (Figures 9 through 11) were constructed from the juvenile fork length data. The extremely limited catch of American shad in the James and Rappahannock rivers and alewife in the James River, precluded a meaningful analysis. Two aspects of these curves must be interpreted from the life history of the *Alosa*. During the season, there is a tendency for the larger juveniles to migrate downstream (Loesch 1969, Marcy 1976). Thus, growth will be underestimated if these individuals leave the nursery zone. The other aspect of *Alosa* behavior that affects estimates of juvenile growth (and mortality) is their protracted spawning period. Juveniles collected in June in the Virginia nursery zones are primarily products of the early spawners. From mid-July to mid-August, depending on the time of spawning and the growth rate, the juveniles produced by the bulk of the spawners become susceptible to capture by the pushnet. The result of this recruitment is an apparent decrease in the growth rate or an apparent decrease in the mean fork length. This apparent "negative growth" was reported in the previous annual reports for the juvenile Alosa program, for juvenile blueback herring in the Susquehanna River (Whitley 1961), and in the Connecticut River (Loesch 1969); it is also apparent in the juvenile American shad growth curve presented by Marcy (1976). "Negative growth" is apparent in Figure 9 for juvenile blueback herring and in Figure 11 for juvenile American shad in the Pamunkey River. Thus, observed growth determined from body length is only apparent growth because of the effects of recruitment and emigration. Because of these effects, estimates of instantaneous growth rates using body length data are not possible.

The mean fork length estimates for the first four weeks of sampling, when the problems of recruitment and emigration should have had the least effect, indicate the following:

- Juvenile blueback herring, on the average, were largest on the James River and smallest on the Mattaponi River; intermediate mean sizes were the same in the Rappahannock and Pamunkey rivers.
- Juvenile alewife mean sizes, on the average, were approximately the same in the Rappahannock, Pamunkey and Mattaponi rivers; however, the limited catch of alewife in the Pamunkey and Mattaponi rivers makes any comparisons tenuous.
- American shad were generally larger in the Pamunkey River than in the Mattaponi River.

These findings are in agreement with data for the period 1979 - 1987 (e.g., see Loesch and Kriete 1983; Blumberg and Loesch 1987). The Mattaponi River is the clearest of the rivers sampled (see previous discussion on light attenuation); this condition could reflect a limiting food supply which is responsible for the smaller observed mean juvenile fork lengths.

VIMS/MD-DNR Gear Comparisons

Comparative sampling with MD-DNR's trawl system was conducted on September 16 and 17, 1991. Sampling took place within a 5-mile section of Marshyhope Creek, a tributary to the Nanticoke River on Maryland's Eastern Shore. MD-DNR sampled during daylight hours. VIMS personnel employed the pushnet during evening hours over the same area. A completely randomized (CR) sampling design was utilized with the goal of collecting 15 samples by each gear on each day. Following are the results of the catch comparison (mean and standard deviation CPUE):

	Pushnet (VIMS)	Trawl (MD-DNR)
September 16:		
No. samples	15	13
Bluebacks	144.1 (232.4)	0
Am. Shad	0	0
Alewife	0.5 (1.1)	0
September 17:		
No. samples	6*	15
Bluebacks	103.4 (168.5)	0
Am. Shad	0	0
Alewife	2.7 (3.1)	0

(*sampling discontinued because of approaching thunderstorms)

The catch results reflect the negative phototropic behavior of blueback herring and alewife. Only a minimal catch of alewives and American shad, because of late season emigration from the nursery zone and net avoidance, were expected at this time of the year. The results are similar to research conducted by VIMS in the late 1970's that demonstrated the effect of light on the catchability of juvenile Alosa (Loesch et al. 1982) and the high efficiency of the pushnet compared to trawl systems for collecting juvenile pelagic fish (Kriete and Loesch 1980). Kriete and Loesch, in fact, reported a ratio of blueback herring catches (numbers of fish) for simultaneous sampling during daylight hours with the pushnet and two identical surface Cobb trawls was 23:3:1.

The fact that no Alosa were collected by the MD-DNR trawl system precludes, at this time, the development of a gear catch conversion factor. Because MD-DNR was highly successful with their trawl system on Marshyhope Creek from early to mid-summer 1991, another gear comparison study is planned for the summer of 1992.

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Table 1. Mean and standard deviation catch-per-unit-of-effort (CPUE) per 1991 sampling cruise for day-night pushnet catch comparisons of juvenile Alosa in the Pamunkey, Mattaponi, James and Rappahannock rivers.

River	Date	Time	Bluebacks		Am. Shad		Alewife	
Pamunkey	6/10/91	day	1.3	(3.7)	0		0	
		night	11.1	(13.2)	8.5	(6.5)	2.2	(3.1)
	6/17/91	day	1.3	(4.8)	0		0	
		night	13.3	(11.4)	1.7	(2.0)	0.1	(0.2)
	6/27/91	day	0.1	(0.5)	0		0	
		night	*		*		*	
	7/02/91	day	0		0.1	(0.3)	0	
		night	8.8	(7.2)	2.8	(3.7)	0.1	(0.5)
	7/08/91	day	0.1	(0.3)	0.1	(0.3)	0	
		night	5.9	(6.2)	8.4	(11.1)	0.1	(0.3)
Mattaponi	6/12/91	day	0		0		0	
		night	9.5	(12.8)	10.2	(8.3)	0.5	(0.7)
	6/19/91	day	0		0		0	
		night	8.3	(20.9)	1.2	(1.4)	0	
	6/25/91	day	0		0		0	
		night	6.7	(5.5)	1.2	(1.8)	0.2	(0.6)
	7/03/91	day	0		0		0	
		night	4.7	(6.3)	2.6	(2.8)	0.3	(0.6)
	7/10/91	day	0		0		0	
		night	3.6	(6.6)	2.5	(1.3)	0	
James	6/13/91	day	0.5	(1.5)	0		0	
		night	61.1	(61.3)	0		0	
	6/19/91	day	1.0	(1.7)	0		0	
		night	*		*		*	
	6/26/91	day	2.4	(4.6)	0		0	
		night	73.7	(41.9)	0.1	(0.2)	0.1	(0.2)
	7/01/91	day	0.4	(1.4)	0		0	
		night	55.1	(65.7)	0		0	
	7/08/91	day	4.6	(7.5)	0		0	
		night	150.1	(186.6)	0		0.1	(0.3)

Table 1. (Continued)

River	Date	Time	Bluebacks	Am. Shad	Alewife
Rappahannock					
	6/17/91	day	6.9 (16.8)	0	0.1 (0.2)
		night	*	*	*
	6/27/91	day	5.4 (7.8)	0.1 (0.3)	0
		night	84.9 (56.1)	0.1 (0.2)	2.3 (5.5)
	7/03/91	day	0.2 (0.5)	0	0
		night	162.2 (145.6)	0.1 (0.2)	3.8 (4.2)
	7/10/91	day	4.0 (8.4)	0	0
		night	194.3 (175.6)	0.2 (0.4)	6.7 (7.7)

* No sampling conducted due to vessel breakdown or thunderstorms.

Table 2. Mean and standard deviation CPUE for juvenile <u>Alosa</u> per 1991 night-time sampling cruise on the Mattaponi, Pamunkey, James, and Rappahannock rivers.

River	Date	Bluebacks	Am. Shad	Alewife
Mattaponi	6/12/91	9.5 (12.8)	10.2 (8.3)	0.5 (0.7)
	6/19/91	8.3 (20.9)	1.2 (1.4)	0
	6/25/91	6.7 (5.5)	1.2 (1.8)	0.2 (0.6)
	7/03/91	4.7 (6.3)	2.6 (2.8)	0.3 (0.6)
	7/10/91	3.6 (6.6)	2.5 (1.3)	0
	7/17/91	4.1 (6.3)	1.1 (1.3)	0
	7/23/91	2.6 (3.5)	0.2 (0.4)	0
Pamunkey	6/10/91	11.1 (13.2)	8.5 (6.5)	2.2 (3.1)
	6/18/91	13.3 (11.4)	1.7 (2.0)	0.1 (0.2)
	7/01/91	8.8 (7.2)	2.8 (3.7)	0.1 (0.5)
	7/08/91	5.9 (6.2)	8.4 (11.1)	0.1 (0.3)
	7/15/91	8.1 (9.2)	3.1 (5.2)	0
	7/22/91	11.0 (9.4)	0.5 (0.7)	0
	8/01/91	8.9 (13.8)	1.6 (1.6)	0
James	6/13/91	61.1 (61.3)	0	0
	6/25/91	73.7 (41.9)	0.1 (0.2)	<0.1 (0.2)
	7/01/91	55.1 (65.7)	0	0
	7/08/91	150.1 (186.6)	0	0.1 (0.3)
	7/15/91	43.6 (44.0)	<0.1 (0.2)	<0.1 (0.2)
	7/22/91	126.9 (178.1)	0	0.1 (0.3)
	7/31/91	72.9 (69.0)	0	0
	8/07/91	156.9 (282.1)	0	0.1 (0.2)
	8/12/91	65.2 (112.4)	0	0.3 (0.5)
	8/19/91	126.2 (117.3)	0	0
	8/28/91	48.3 (103.1)	0	0
	9/04/91	77.1 (97.3)	0	0
	9/10/91	168.3 (363.7)	0	0
	10/08/91	93.9 (173.9)	0	0
Rappahannock	6/26/91	84.9 (56.1)	0.1 (0.2)	2.3 (5.5)
	7/03/91	162.2 (145.6)	0.1 (0.2)	3.8 (4.2)
	7/10/91	194.3 (175.6)	0.2 (0.4)	6.7 (7.7)
	7/17/91	165.2 (176.4)	0	5.5 (5.8)
	7/24/91	72.1 (100.9)	0	1.7 (2.5)
	8/02/91	148.9 (164.0)	0	3.0 (2.2)
	8/08/91	104.8 (127.5)	0.1 (0.2)	2.7 (3.4)
	8/14/91	29.5 (44.1)	0	1.9 (2.5)

Table 3. Annual index of abundance (maximal mean CPUE) for juvenile <u>Alosa</u> in the Mattaponi and Pamunkey rivers, 1979-1991, and James and Rappahannock rivers, 1991.

		Maximal CPUE		
River	Year	Alewife	Blueback	American Shad
Mattaponi	1979	6.0	73.0	38.1
	1980	2.9*	4.6*	38.8*
	1981	10.0*	11.6	18.0*
	1982	38.0	289.0	21.1
	1983	36.2	36.1	16.5
	1984	28.1	220.8	34.4
	1985	31.3	206.2	35.9
	1986	11.5*	20.7	36.6
	1987	2.8	19.9	18.9
	1988	#	#	#
	1989	#	#	#
	1990	+	+	+
	1991	0.5*	9.5*	10.2*
	MEAN	16.7	89.1	26.9
Pamunkey	1979	6.7	224.8	57.4
	1980	3.6	87.9	7.1
	1981	6.5*	16.7	5.3*
	1982	28.3*	408.2	3.0*
	1983	4.2	120.7	7.5
	1984	7.1*	88.9	2.5
	1985	12.6	154.6	15.5
	1986	13.2*	99.3	8.9
	1987	9.1*	217.9	2.1
	1988	#	#	#
	1989	#	#	#
	1990	+	+	+
	1991	2.2*	13.3	8.5*
	MEAN	9.4	143.2	11.8
James	1991	<0.1	156.9	<0.1
Rappahannock	1991	6.7	194.3	<0.2

* Maximal mean CPUE occurred in the first sampling period
\# No index data available due to lack of program funding
\+ Insufficient data to calculate a meaningful index value

Table 4. Estimates of instantaneous daily mortality for juvenile <u>Alosa</u> in the Mattaponi and Pamunkey rivers, 1979-1991, and James and Rappahannock rivers, 1991.

River	Year	Alewife	Blueback	American Shad
Mattaponi	1979	0.036	0.034	0.040
	1980	0.330	0.022	0.056
	1981	0.105	+	0.080
	1982	0.036	0.077	0.042
	1983	0.038	0.041	0.030
	1984	0.042	0.030	0.056
	1985	0.038	0.035	0.053
	1986	0.036	0.047	0.080
	1987	0.043	0.140	0.063
	1988	#	#	#
	1989	#	#	#
	1990	+	+	+
	1991	0.046	0.031	0.057
	MEAN*	0.039	0.054	0.053
Pamunkey	1979	0.040	0.040	0.060
	1980	0.041	0.031	0.080
	1981	0.058	0.016	0.043
	1982	0.043	0.046	0.050
	1983	0.068	0.052	0.078
	1984	0.036	0.078	0.057
	1985	0.067	0.055	0.098
	1986	0.050	0.043	0.050
	1987	0.148	0.065	+
	1988	#	#	#
	1989	#	#	#
	1990	+	+	+
	1991	0.092	0.040	0.064
	MEAN*	0.068	0.052	0.057
James	1991	+	0.094	+
Rappahannock	1991	0.068	0.103	+

* The 1980 and 1981 data were omitted from the mean value (see text).
+ Data were too few for a reasonably objective estimate of mortality.
# No sampling conducted due to a lack of program funding.

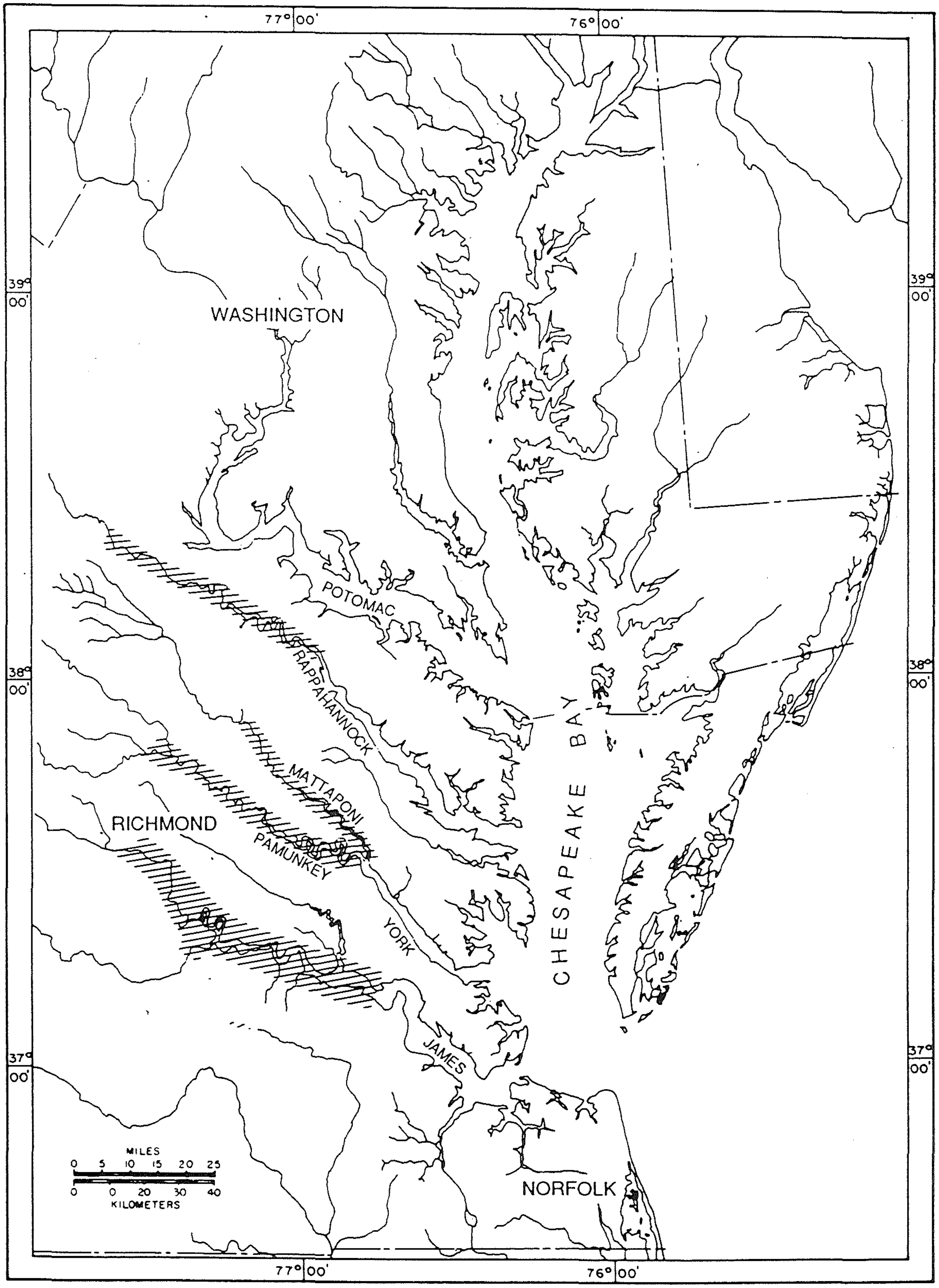
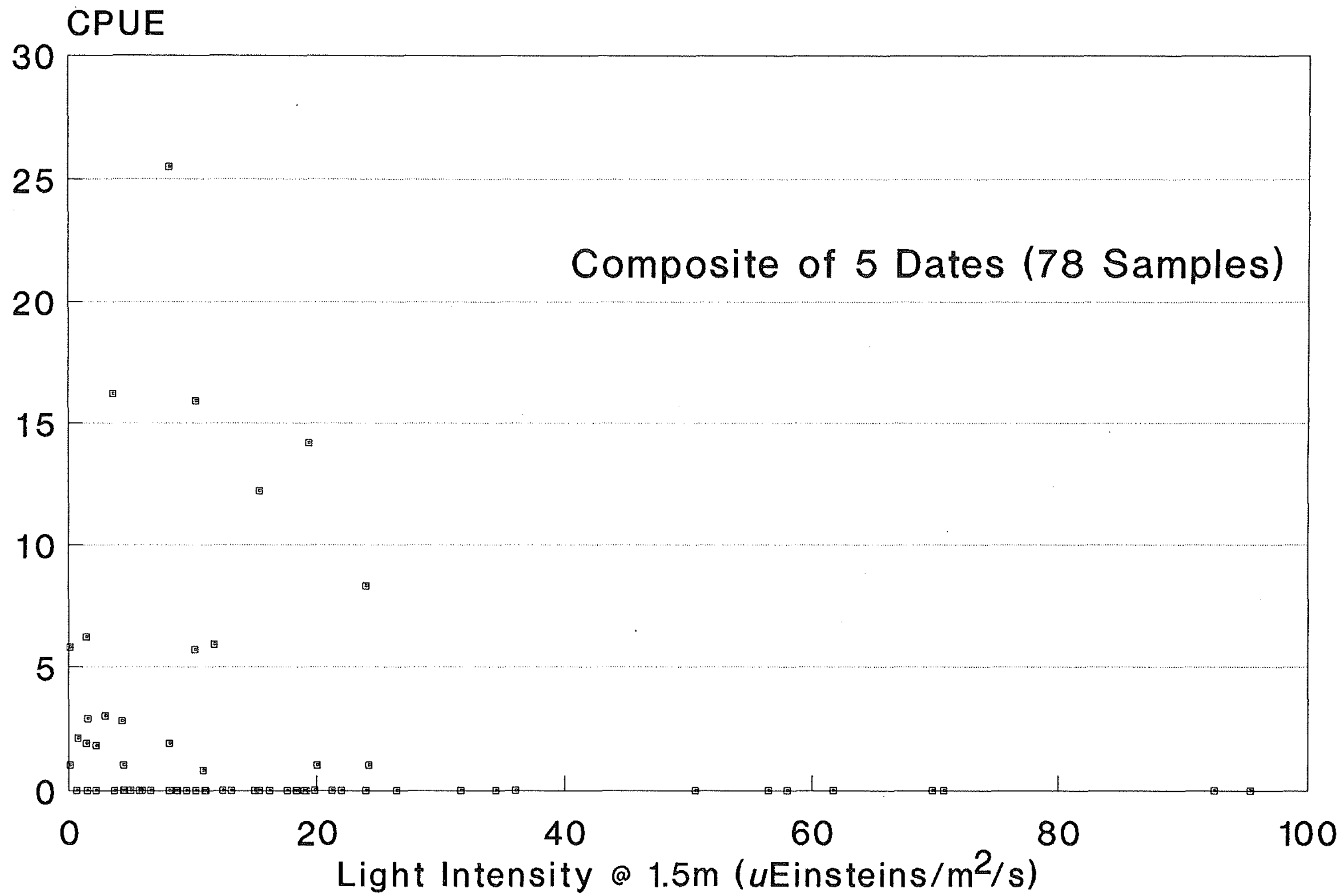


Figure 1. Nursery zone locations for Juvenile *Alosa* Sampling Program.

Figure 2 - CPUE vs. Light Intensity

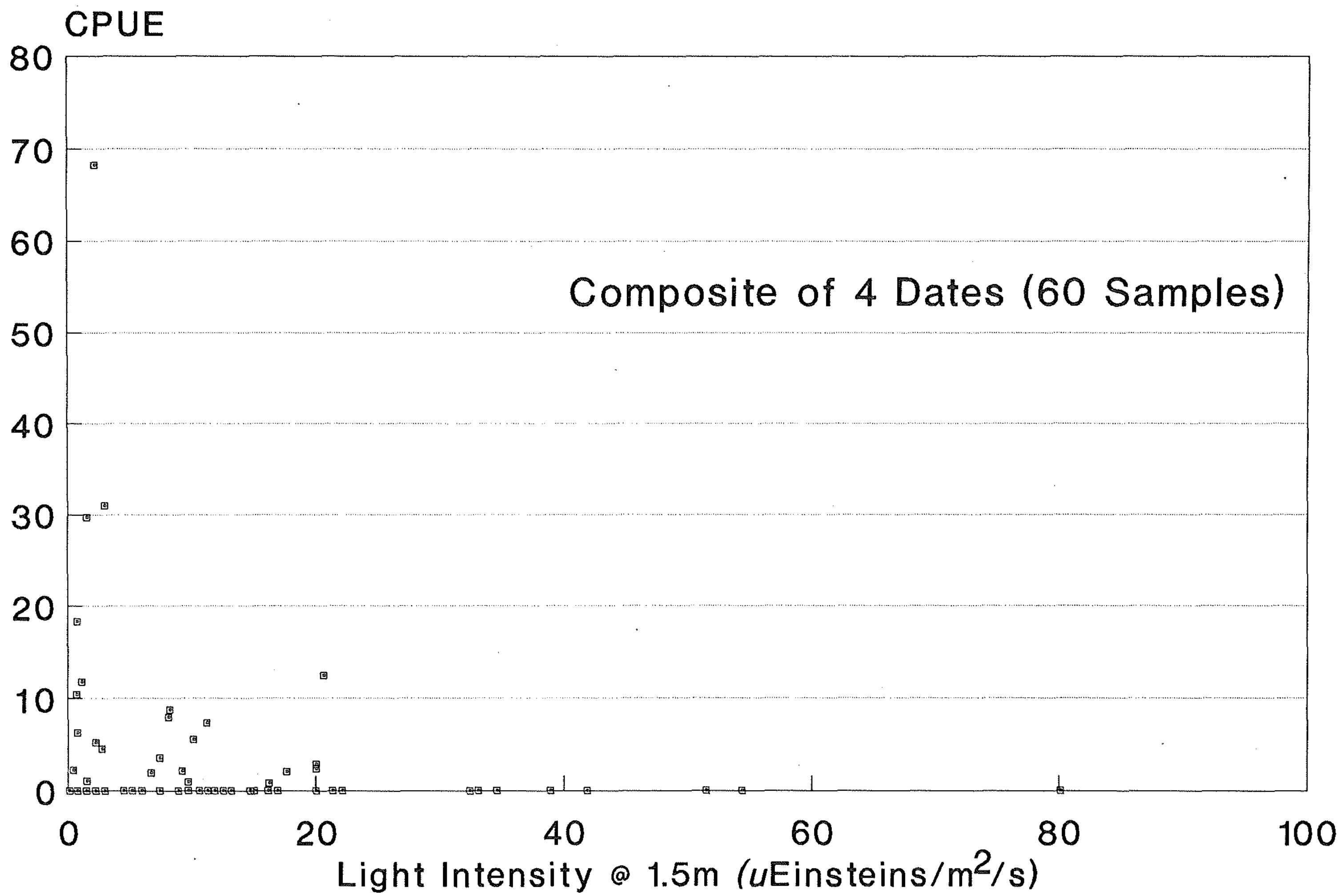
James River - Blueback Herring



June 13 - July 8, 1991

Figure 3 - CPUE vs. Light Intensity

Rappahannock River - Blueback Herring



June 17 - July 10, 1991

Figure 4 - Juvenile *Alosa* Catch Curve
Blueback Herring (Pamunkey-Mattaponi R.)

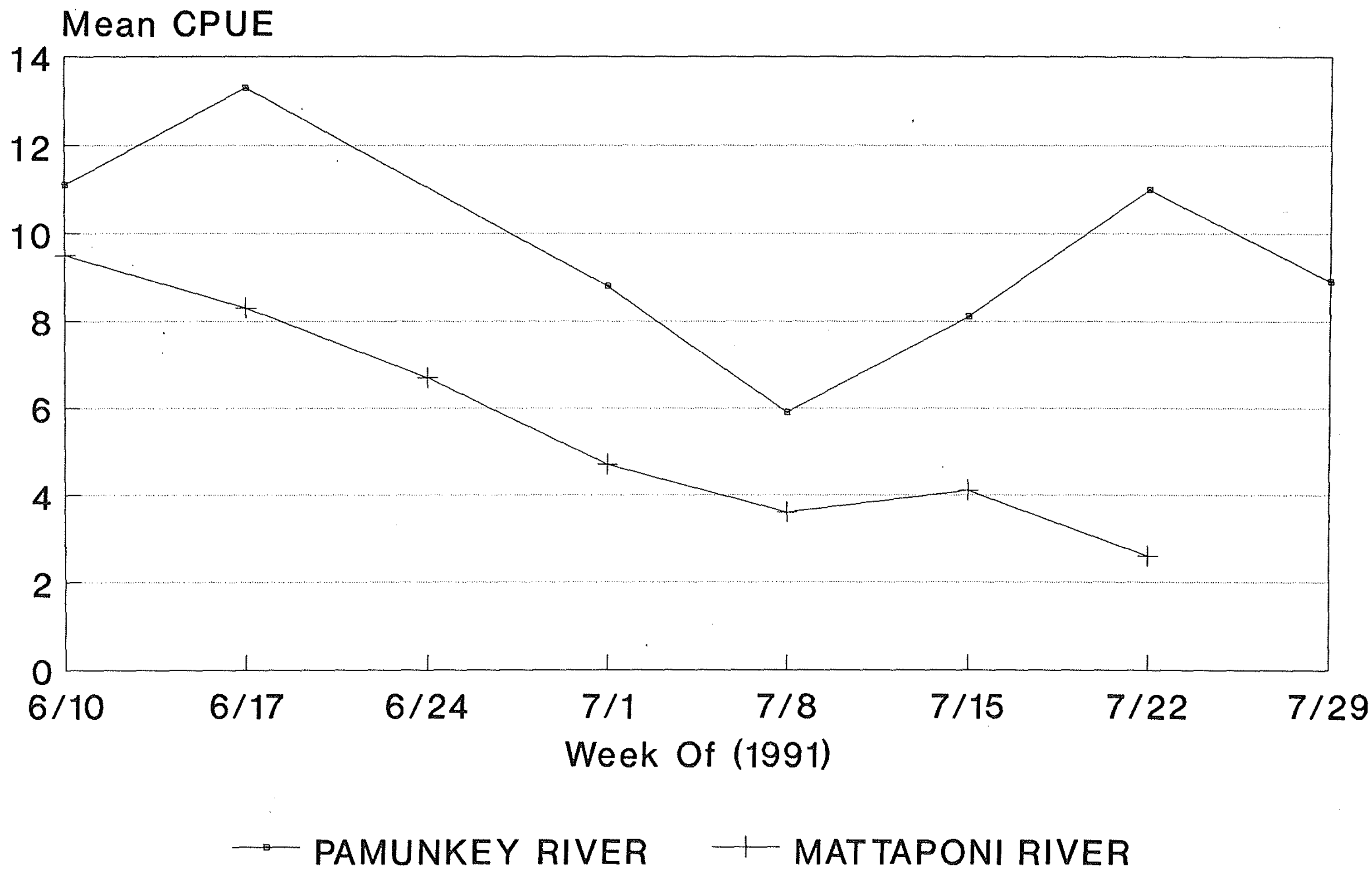


Figure 5 - Juvenile *Alosa* Catch Curve
Blueback Herring (James River)

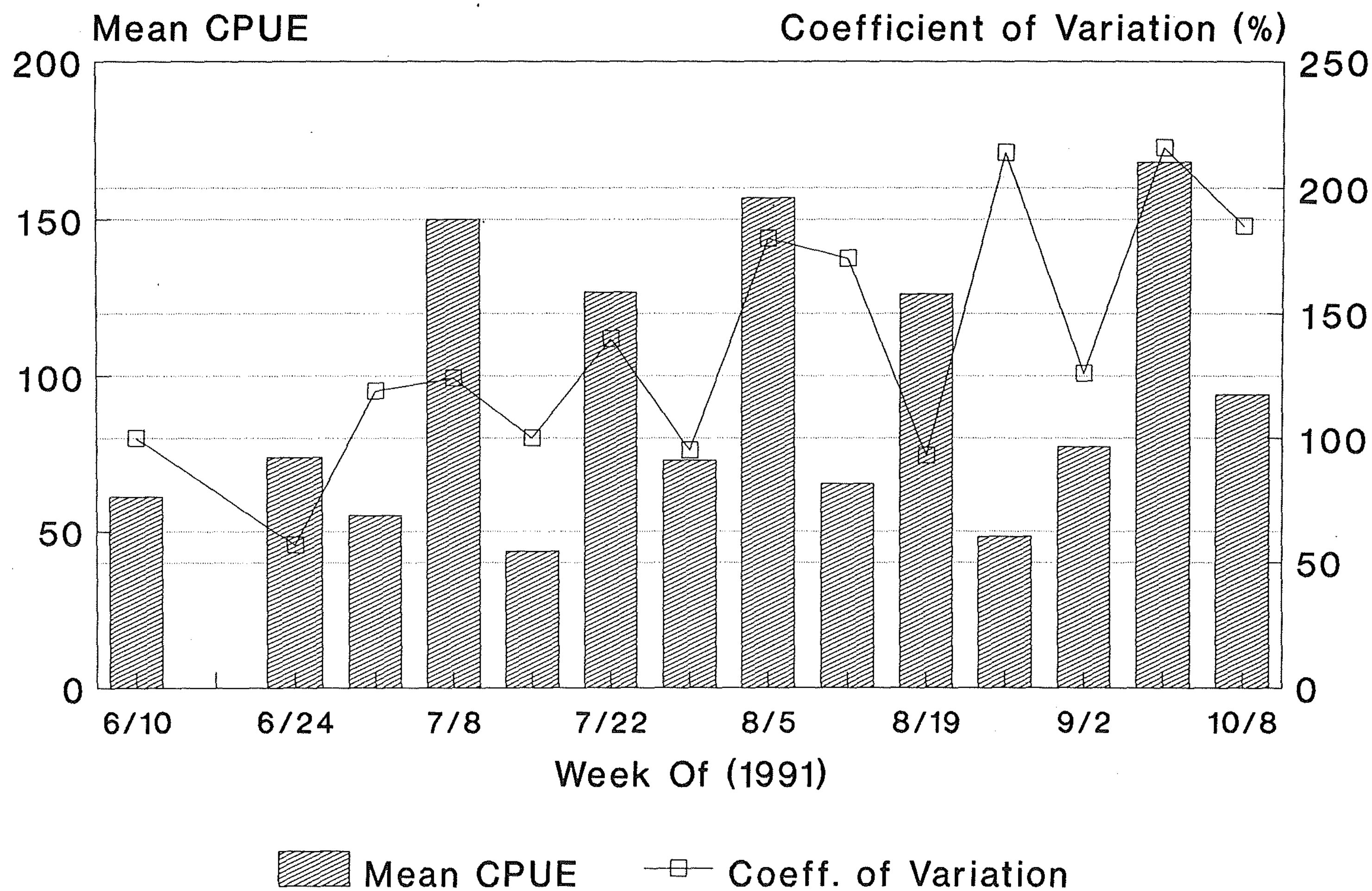


Figure 6 - Juvenile *Alosa* Catch Curve
Blueback Herring (Rappahannock R.)

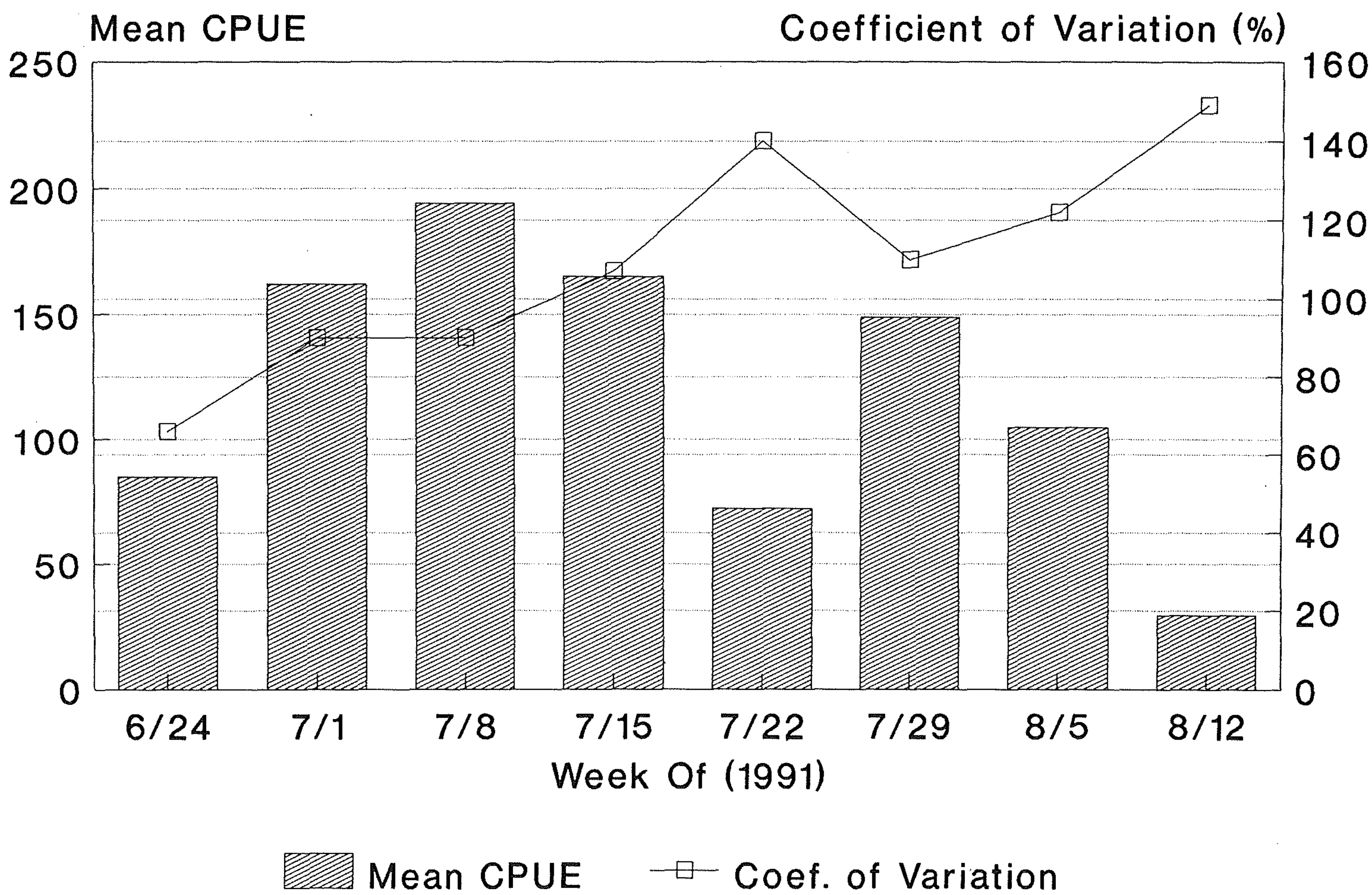


Figure 7 - Juvenile *Alosa* Catch Curve

Alewife (All Rivers)

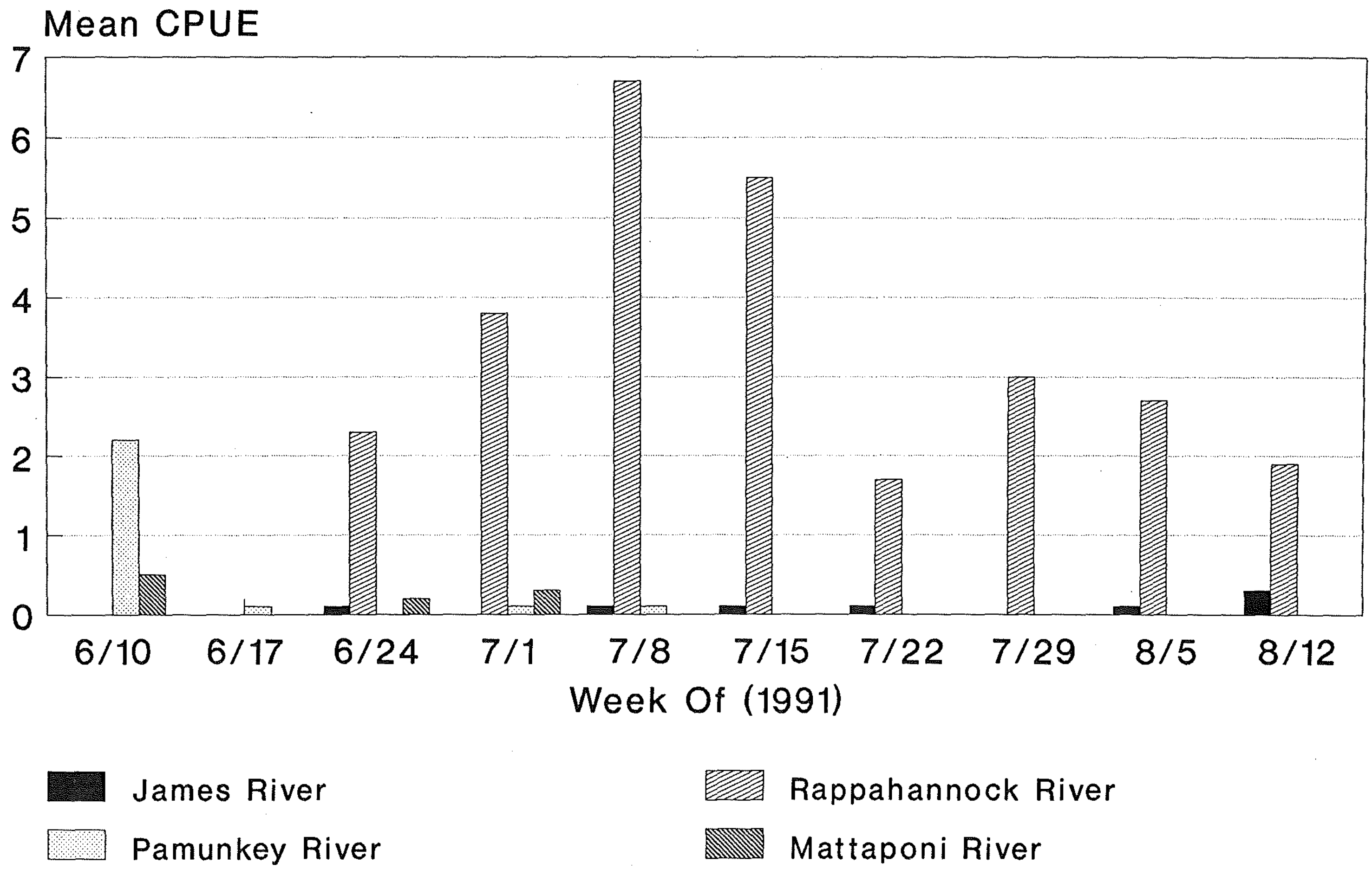


Figure 8 - Juvenile *Alosa* Catch Curve

American Shad (All Rivers)

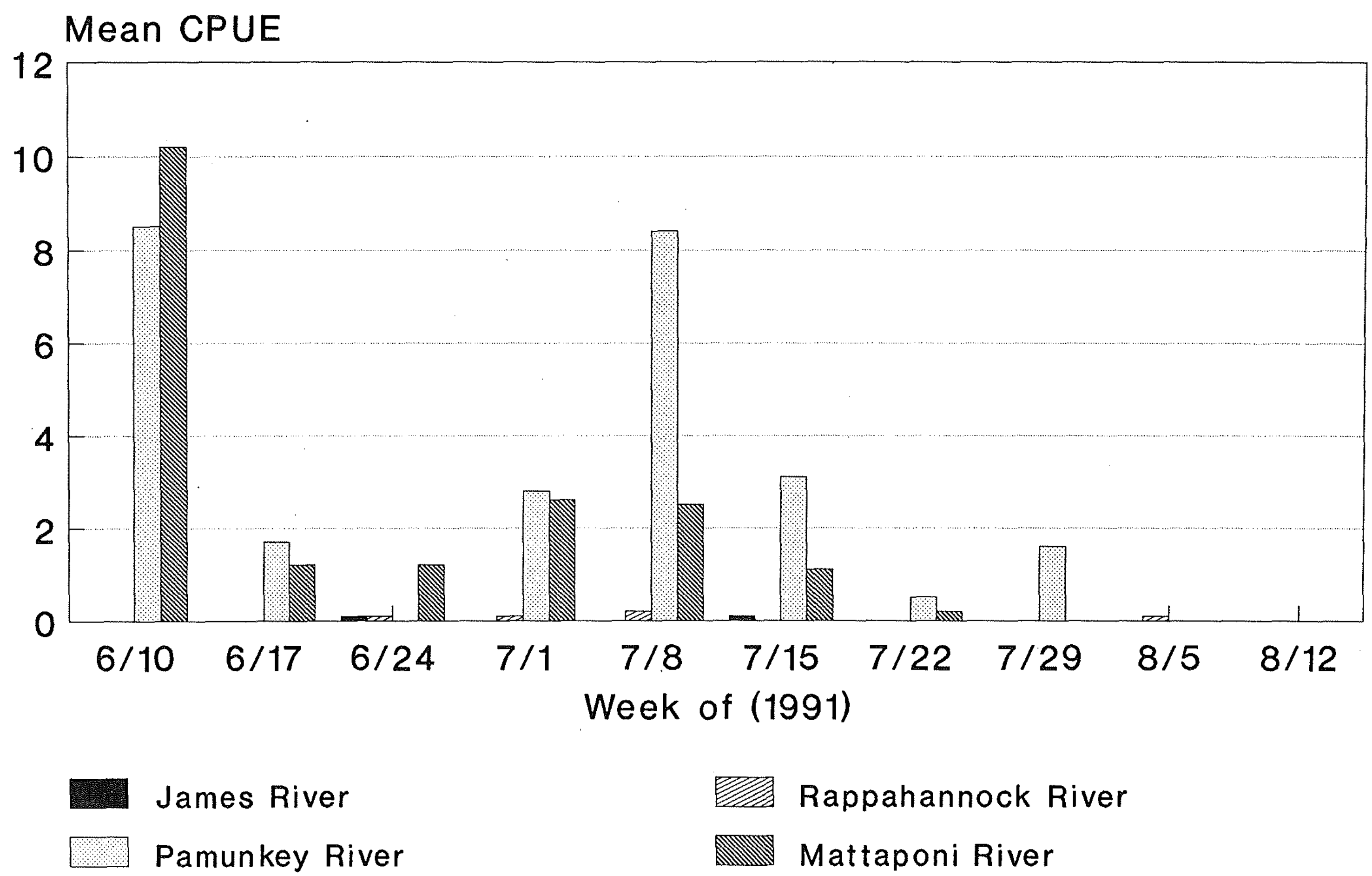


Figure 9 - Apparent Growth Curve
Blueback Herring (All Rivers)

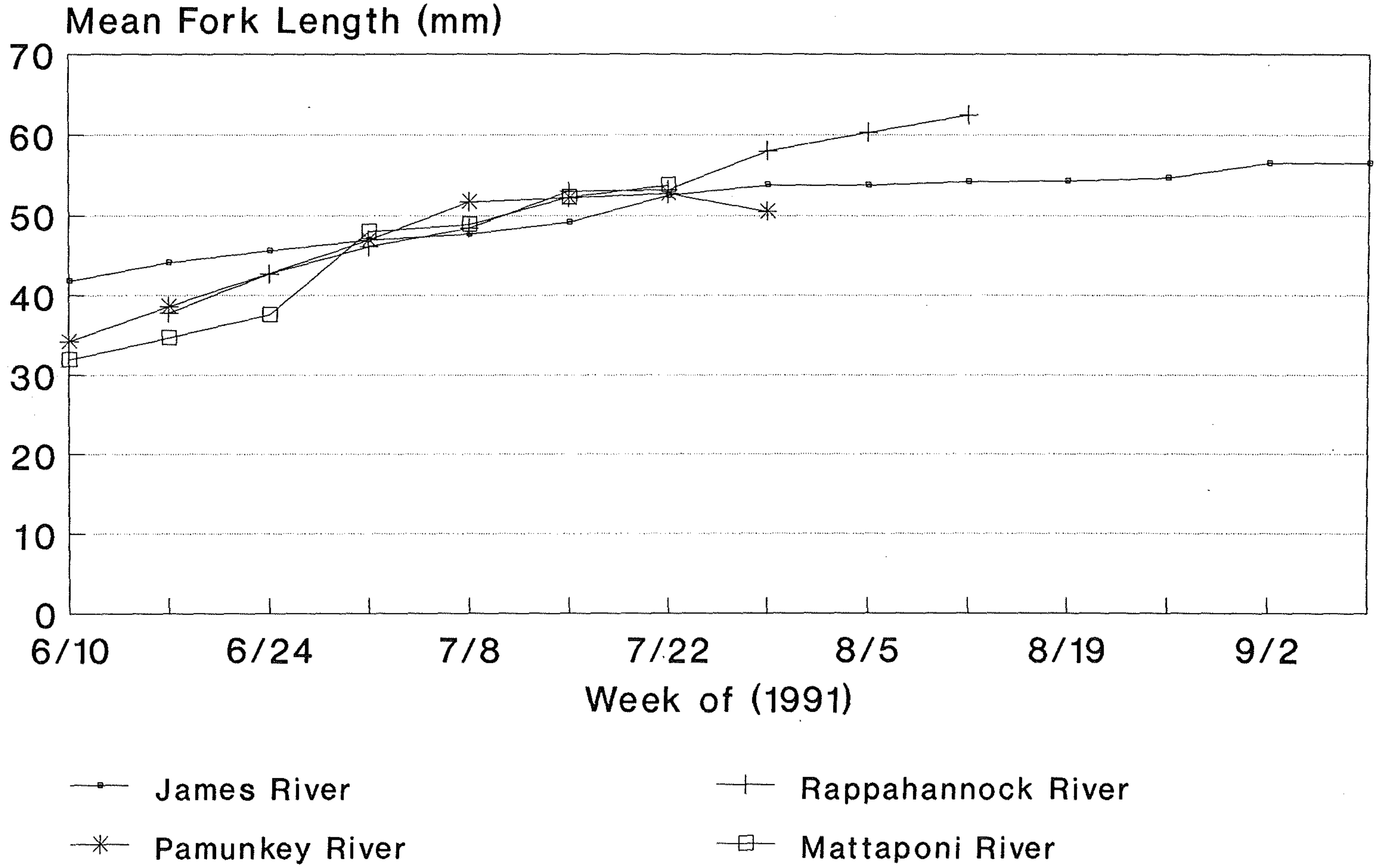
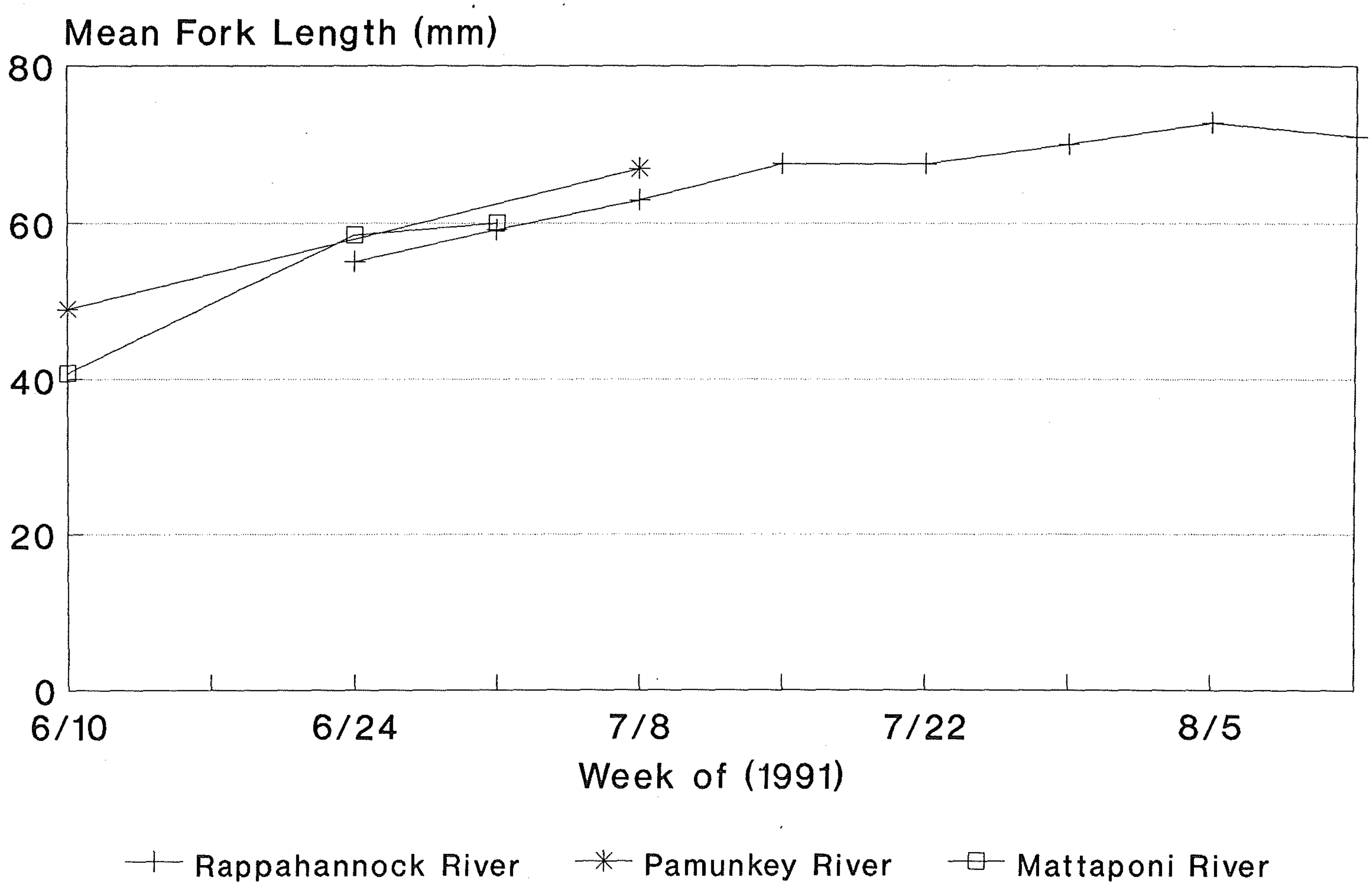


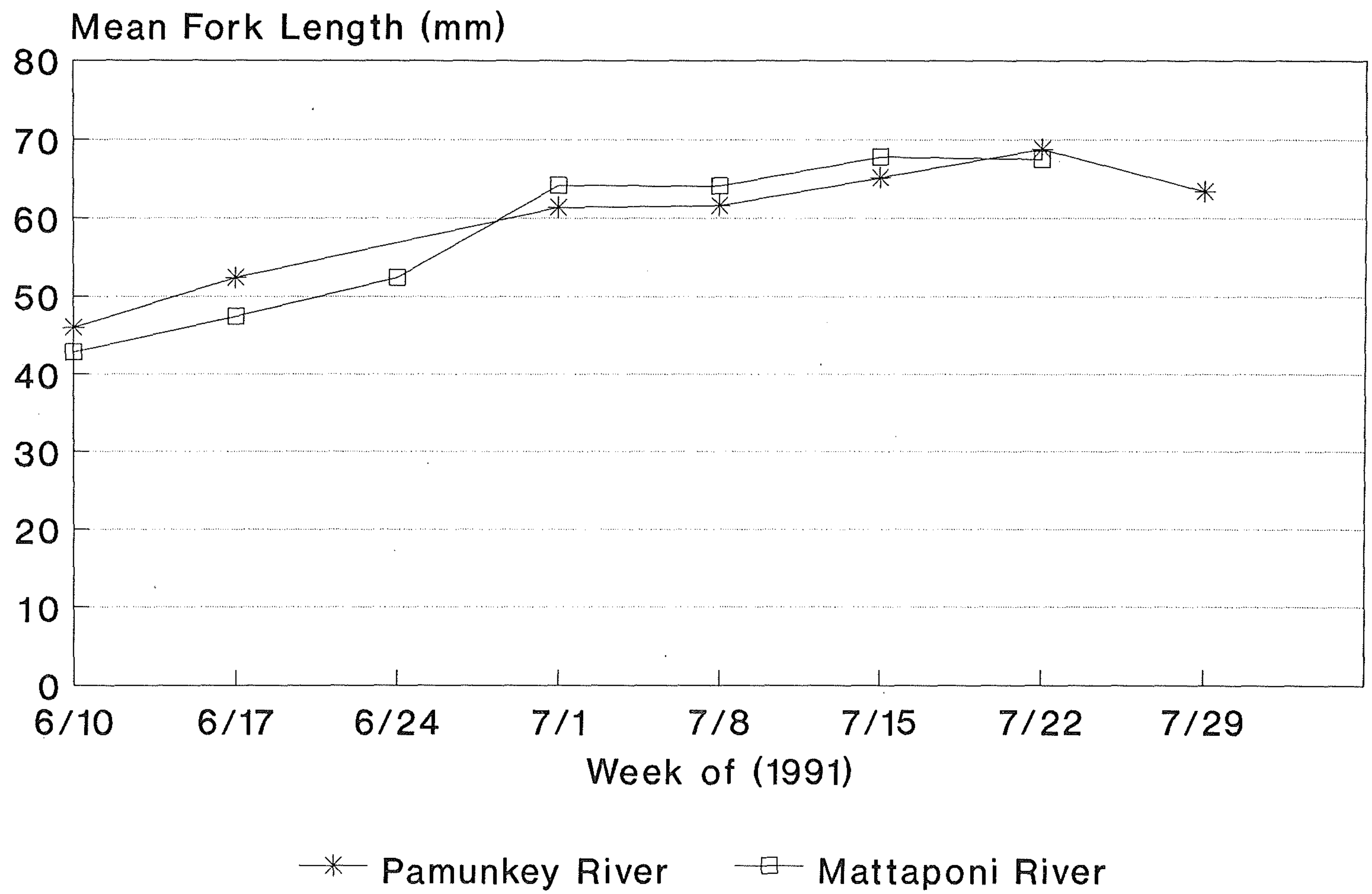
Figure 10 - Apparent Growth Curve

Alewife (All Rivers)



Insignificant Catch on James River

Figure 11 - Apparent Growth Curve
American Shad (Pamunkey - Mattaponi)



No Catch on James and Rappahannock R.