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A Stock assessment program for Chesapeake Bay fisheries: Development of an Alosa juvenile index of abundance : 1995 and 1996 index sampling results

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A Stock Assessment Program for Chesapeake Bay Fisheries - Development of an *Alosa* Juvenile Index of Abundance: 1995 and 1996 Index Sampling Results

Completion report for Contract No. CF96-8
Project Period:
July 1, 1996 - June 30, 1997

Submitted to
Virginia Marine Resources Commission
Commercial Fishing License Fund Board
P.O. Box 756
Newport News, VA 23607

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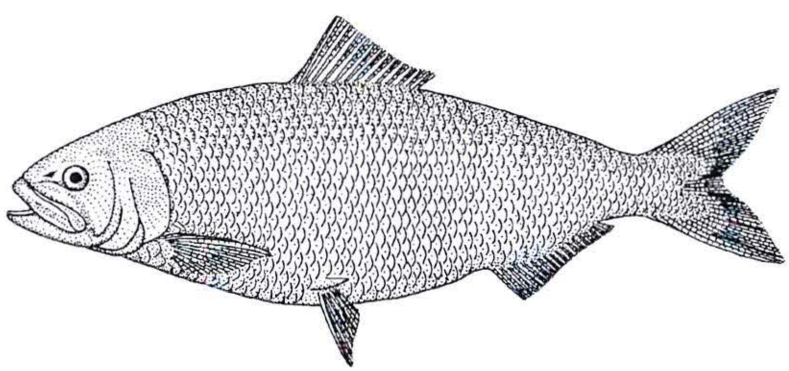

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PREFACE

This presentation is the completion report for Contract No. CF96-8, "A Stock Assessment Program for Chesapeake Bay Fisheries: Development of an *Alosa* Juvenile Index of Abundance," for the period 1 July 1996 to 30 June 1997. Included are the results of 1995 sampling, funded directly by the Virginia Institute of Marine Science (VIMS), but not previously reported. The fishes of concern were the alewife (*Alosa pseudoharengus*), American shad (*A. sapidissima*), and the blueback herring (*A. aestivalis*).

The results presented here directly address many of the research concerns stated in the Atlantic States Marine Fisheries Commission (ASMFC) 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 formulation of management strategies for the east coast *Alosa* stocks now under consideration by the ASMFC Shad and River Herring Technical Committee.

ACKNOWLEDGMENTS

Dr. Joseph Loesch (Professor Emeritus, Department of Fisheries Science) initiated this program, developed and refined the sampling protocol, and supervised the collection of juvenile *Alosa* sp. until his retirement in May 1997. The authors bear responsibility for accuracy and analysis of the data presented in this report, however. We are indebted to the following VIMS personnel for their assistance in this project: Mary Lynn Aiken, Gail Darouse, Phil Sadler, and Joice Davis. We also express our thanks to the VIMS Vessel Operations Support Staff without whose help our sampling program would not have been possible. We also would like to express our thanks and appreciation to Mr. Lloyd Harrell of Lanesville, VA for allowing us to use his private launch facilities on the Pamunkey River. The location of his ramp greatly reduced our on-water travel time to sampling sites on the river.

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EXECUTIVE SUMMARY

1. The 1996 juvenile *Alosa* indices (i.e., maximal geometric mean CPUE) for the Mattaponi and Pamunkey rivers exceeded the long-term mean indices for each species. In particular, the 1996 juvenile American shad index for the Mattaponi River (144.2) was greater than five-times the long-term (1979-present) mean and nearly triple the previous high index observed in 1994 (51.5). Similarly, the 1996 Pamunkey River juvenile shad index (31.5) was greater than four times the long-term mean with the only higher index having been observed in 1979. A period of record high index was also observed for juvenile alewife in the Mattaponi River. The apparent reproductive success of *Alosa* sp. in 1996 was consistent with the strong reproductive success reported for striped bass (*Morone saxatilis*) in the Virginia portion of the Chesapeake Bay for 1996 (Austin et al., 1997).

2. The 1995 and 1996 indices and long-term mean indices by river and species were as follows:

Species	River	1995	1996	Historical Mean (1979-1996)
Blueback herring	Pamunkey	5.9	66.1	45.5
	Mattaponi	0.4	63.6	34.0
Alewife	Pamunkey	0.1	4.4	3.0
	Mattaponi	0.1	22.4	7.1
American shad	Pamunkey	2.2	31.5	7.4
	Mattaponi	6.4	144.2	26.4

3. Although the 1995 juvenile indices were relatively weak, the strong rebound in 1996, coupled with the strong indices observed in 1993 and 1994, suggested a 3- or 4-year

period of high recruitment of *Alosa* stocks in Virginia's rivers following the low levels observed through the 1980s. Juvenile shad indices have shown an increasing trend beginning in 1993. The extent to which bay-wide adult shad commercial harvest restrictions and stocking of larval shad in the Pamunkey River have contributed to the increasing juvenile shad indices is not known at this time.

4. Correlation analysis suggested a pattern in the annual relative abundance of juvenile *Alosa* between the Mattaponi and Pamunkey rivers. Correlations (r) for each species exceeded 0.66. Correlation results suggested that a common factor contributes to reproductive success and the establishment of juvenile year-class strength in the York River system.

5. Estimates of instantaneous mortality derived from catch-curve analysis suggested that natural mortality of juvenile blueback herring was low in 1995 and 1996 relative to long-term mean values. A similar pattern was observed for juvenile American shad but catch curves were more variable. Mortality of juvenile alewife could not be estimated in 1995 but was also low in 1996. The possible causes of these patterns are unknown.

6. Although Dixon et al. (1995) reported that the relationship between annual juvenile shad indices and their ensuing contribution to the York River fishery was weak, further analysis is required. Should a relationship exist, continued sampling would afford the opportunity to monitor the recovery of shad stocks. Juvenile river herring monitoring for 1996 also indicates potential recovery of these stocks from the depressed levels observed through the 1980s. Because previous analyses (Dixon et al., 1995; Loesch and Dixon, 1996) suggest a strong relationship between juvenile river herring abundance and their ensuing contribution to the fishery, continued sampling would also afford the opportunity to monitor a potential recovery in these stocks as well.

INTRODUCTION

Historical Background

Alosa stocks, especially the American shad (*Alosa sapidissima*), have historically provided Virginia with a major commercial fishery (Walburg and Nichols, 1967; Atran et al., 1983; Loesch and Atran, 1994). 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. In 1970, nearly 4,000 MT were landed in Virginia (VMRC, 1988 and 1996). The catch of American shad, however, has critically declined since the mid-1970's (Figure 1). In response to the steady decline in landings, VMRC imposed restrictive harvest regulations from 1991 through 1993 and a total moratorium in 1994.

Catches of alewife (*A. pseudoharengus*) and blueback herring (*A. aestivalis*), collectively known as river herring, have fluctuated in a pattern very similar to that for the shad (Figure 2). 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 (Atran et al., 1983). As late as 1969, river herring ranked third in quantity and fifth in value, with a catch of 13,608 MT worth 608 thousand dollars National Marine Fisheries Service, 1972. Since the early 1970's, however, the fishery has also steadily declined (Figure 2). In 1981, the combined catch of river herring and American shad was the lowest ever recorded and there has only been a marginal increase in landings since that time.

Historically, the construction of dams, degradation of the environment, and over-fishing were cited as causes for the decline of fish stocks (Loesch, 1987; ASMFC, 1985). The same explanations, to varying degrees, are offered as contemporary explanations for further declines in stocks (Loesch and Atran, 1994). 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, harvest is severely depressed relative to the historical record (Figures 1 and 2).

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 estuaries nursery grounds and thus, are important prey for resident piscivores (Loesch, 1987). 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 economic and ecological 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.

Indices of juvenile abundance are an important element in studies of stock recruitment. Development of a useful index is dependent upon accurate delineation of late larval and juvenile nursery areas and the availability (catchability) of these life stages to sampling gear. A juvenile index is not an absolute measure of abundance but a surrogate of population size that is best interpreted as a relative measure in a time series of data. Often, an historical record of strong and weak years of recruitment is reflected as a discernible pattern in the age composition of adult populations. Indices that are particularly sensitive to changes in young-of-the-year abundance can be applied to predictions of future year-class strength. If a juvenile index can be shown to vary directly with the fishery stock size over a large range in stock sizes, the index can be applied to studies of density-dependent processes.

Program Background

Annual monitoring of juvenile *Alosa* is conducted with a pushnet collection system as developed in the late 1970s (Kriete and Loesch, 1980). Because of the negative phototropic behavior of juvenile *Alosa* (Loesch et al., 1982; Dixon, 1996), the pushnet is used at night to determine a maximal mean (arithmetic and geometric) catch-per-unit-of-effort (maximal mean

CPUE). The research was conducted in the Mattaponi and Pamunkey rivers from 1979 through 1987. Sampling was not conducted in 1988 and 1989 because of a lack of funding. The National Marine Fisheries Service (NMFS) funded the program from 1990 to 1992, and again in 1994 (Dixon et al., 1995). In 1991 and 1992, the James and Rappahannock rivers were included in the monitoring program. Internal funds provided by VIMS were used to continue the program on the Pamunkey and Mattaponi rivers in 1993, 1995, and 1997. Results of the 1997 efforts are not reported here.

Preliminary analysis of sampling in the period 1979-1994 have yielded promising results (Dixon et al., 1995; Loesch and Dixon, 1996). Blueback herring and alewife indices were strongly correlated within the Mattaponi and Pamunkey rivers ($r = 0.85$ and 0.89, respectively). The blueback herring and alewife indices between rivers were also reasonably strong ($r = 0.83$ and 0.69, respectively). The relationships suggest that a common factor controls the annual relative abundance of river herring in the two adjacent river systems. Based on a limited time series (1979-1985), correlations between species-specific and combined juvenile river herring indices and recruitment to the York River pound net fishery were also strong. The index for alewife in the Pamunkey and Mattaponi rivers were strongly correlated to the recruitment of their respective year classes in pound net landings ($r = 0.93$ and 0.99, respectively). The correlation of the index to recruitment for blueback herring was reasonably strong for the Pamunkey River ($r = 0.75$), but weak for the Mattaponi River ($r = 0.42$). When the species-specific indices are combined and reported as a river herring index, the recruitment correlation for the Pamunkey and Mattaponi rivers is reasonably strong ($r = 0.78$ and 0.87, respectively). When the data are combined for species and rivers, as in commercial landings reports, the correlation between the annual index and year class recruitment is also strong ($r = 0.86$). The relationships of the species-specific and combined river herring indices to year-class recruitment indicates that the index is probably determined after year class strength is established (Loesch and Dixon, 1996).

Similar analyses for American shad yielded less promising results. However, potential problems in recorded landings and age-class data may have obscured potential relationships (Dixon et al., 1995). Correlation analysis suggests that there is a weak pattern in the annual relative abundance of juvenile American shad between the Pamunkey and Mattaponi rivers ($r = 0.67$). American shad indices were weakly correlated ($r < 0.46$) with landings of females in the

York River staked gill net fishery. No relationships were suggested between the individual river juvenile shad indices or the combined indices and recruitment to the fishery, either for virgin females or when the year class was the dominant class in the fishery. Several factors individually or collectively may have contributed to the failure to detect a possible relationship including low catchability of juvenile shad by the pushnet, inaccurate reporting and potentially flawed analysis of landings data for the staked gill net fishery, historical errors in age determinations (Dixon et al., 1995), or high levels of juvenile mortality. Historical York River staked gill net American shad landings data are currently being reviewed and corrected, as necessary. Following the review, the relationship between juvenile shad indices and recruitment to the fishery will be re-examined.

Program Objectives

The short-term program objectives for the present contract year (1996) included:

1. Determine juvenile index values for *Alosa* (American shad, blueback herring, and alewife) in the Mattaponi and Pamunkey rivers.
2. Estimate natural mortality for each species in each river.
3. Re-examine the annual relationship in juvenile relative abundance between rivers.
4. Re-examine the relationship between the maximal mean CPUE and a seasonal mean CPUE.

The long-term program objectives are to provide a methodology for establishing a long-term data base of juvenile *Alosa* indices for the nursery zones of the Mattaponi, Pamunkey, James, and Rappahannock rivers (Figure 3) in order to:

1. Develop juvenile *Alosa* indices 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

Study Area

The Pamunkey and Mattaponi rivers occupy adjacent watersheds in the southeastern coastal plain region of Virginia. The two rivers converge at West Point, VA to form the York River which flows approximately 28 miles to its juncture with the Chesapeake Bay at Tue Point. The Pamunkey River drains a watershed of 1,081 square miles (i.e., above the USGS gaging station near Hanover, VA.) and has an average discharge rate (1941 to present) of 1,007 cubic feet per second (with a range during the period of record from 12 to 40,300 ft^3/s). The Pamunkey is formed by the junction of North and South Anna rivers in central Virginia and flows approximately 100 miles to its union with the Mattaponi. The Mattaponi River drains a watershed of 601 square miles (i.e., above the gaging station near Beulahville, VA.) and has an average discharge rate (1941 to present) of 593 ft3/s (with a range of 5.9 to 16,900 ft3/s)(USGS, 1992). The Mattaponi is formed by the junction of the Matta, the Po, and the Ni rivers in northeastern Virginia and flows approximately 120 miles to its union with the Pamunkey. Tidal waters extend about 45 miles up the Pamunkey and 30 miles up the Mattaponi. The change from brackish to fresh water occurs from 5 to 10 miles above West Point in each river.

Water clarity is one of the major physical differences in the two rivers that may affect the abundance of juvenile *Alosa*. Water clarity may also affect availability of juvenile *Alosa* to the pushnet gear. Water clarity in the Mattaponi is much greater than in the Pamunkey. Light penetration measurements in 1991 (Dixon and Loesch, 1992; Dixon, 1996) showed that the mean percent light remaining at 1.5 m (i.e., depth of pushnet) in the Mattaponi was 3.2% as compared to 1.9% in the Pamunkey. The mean Sechii depth in the Mattaponi was 1.0 m compared to 0.6 m in the Pamunkey. The greater water clarity in the Mattaponi may be a reflection of a limiting food supply that can affect larval mortality, and larval and juvenile growth.

Sampling Design

All sampling was conducted with a bow-mounted pushnet on a 20-ft deep-v center-console fiberglass boat powered by a 150-hp outboard engine. The pushnet is a 5.2-m long (body 3.0-m, cod end 2.2-m), four-panel, 1.5 x 1.5-m Cobb trawl net modified to fit the pushnet frame. The net is constructed of 1.9-cm stretch mesh, number 110 knotless nylon netting in the body and 1.27-cm stretch mesh, number 126 knotless nylon netting in the cod end. The pushnet design and its attributes for sampling juvenile pelagic fishes is described in Kriete and Loesch (1980).

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.

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.

Dixon (1996), working with juvenile blueback herring in the Pamunkey and Mattaponi rivers, provided evidence to support the dynamic nursery zone sampling method. He showed a linear relationship ($P < 0.001$) between the annual size of the nursery zone and the annual index in both rivers, and that the variation in the size of the nursery zone was well explained by the change in the annual index ($r^2 = 0.72$ and 0.64 for the Pamunkey and Mattaponi Rivers, respectively). Dixon's (1996) results indicate that crowding of individuals, which would inflate the index during years of low relative abundance and small nursery zone size, does not occur.

His results further support the dynamic nature of the nursery zone, the field sampling methodology, and calculation of mean CPUE for each sampling date.

Sampling was performed on a weekly basis beginning in the first week of June and continued until the maximal mean CPUE was definitively observed. All sampling was performed at night because of the negative phototactic behavior of juvenile *Alosa* (Loesch et al., 1982; Dixon, 1996). Sampling began 45 minutes after sunset. This is the time at which availability of juvenile *Alosa* is maximized to the pushnet (Dixon, 1996). Sampling began in the upstream strata (i.e., between RM 69 and 65 on the Pamunkey and 59 and 55 on the Mattaponi rivers) and proceeded downstream (with 3 randomly selected stations within each strata) until saline water was encountered or until no more juveniles were collected in a 9.3 km strata. Although stations within strata were selected randomly, the actual order of sample collection was non-random. Random order collection (e.g., potentially sampling at RM 69 then 35 then back to 68, etc.) is logistically impossible. For the Pamunkey River, a typical sampling cruise included 15 to 18 samples while 12 to 15 samples were typically collected on the Mattaponi River.

The water volume filtered was calculated for all samples to standardize the catch to a per-unit-of-effort (CPUE) basis. A calibrated flowmeter was mounted in the mid-point of the net to record distance traveled and calculate the filtered water volume. All samples were collected against the current. Previous trials with this arrangement 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-minute duration at 1200 rpms (~ 1 m/s) are standardized to 655 m^3 of water filtered (i.e., 1 unit of effort) using the flowmeter readings.

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 (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 geometric 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).

An overall geometric 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; Limburg, 1996). 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 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, and, possibly, into or through November.

The relationship between the maximal mean CPUE and a seasonal mean (i.e., 1 June through 15 August) was evaluated for each species in the Pamunkey and Mattaponi rivers with index data collected through 1994 (Dixon et al., 1995). All correlation coefficients (*r*) equaled or exceeded 0.90, and most equaled or exceeded 0.95, indicating a strong linear relation between the maximum and seasonal geometric mean CPUE. Correlations were also relatively unchanged when the data for calculating the maximum mean CPUE were excluded in the calculation of the seasonal means, thereby insuring independence of the variables. Lower coefficients of variation (CVs) for all maximum mean CPUEs compared to the CVs for the seasonal means indicate a greater level of precision, or narrower confidence intervals, associated with the maximum mean CPUE. These results indicate that the maximum mean CPUE is as good an indicator of relative abundance as a seasonal mean. Considering that the use of the maximum mean CPUE avoids sample bias associated with downstream drift and gear avoidance by larger juveniles, and minimizes sampling expenses, its use as an index of annual relative abundance is well supported.

Mortality

Estimates of mean CPUE that followed the maximal mean CPUE were used in conjunction with the maximal value to estimate the instantaneous natural mortality rate (M_d) according to the catch curve method of Ricker (1975). When there was only one usable mean CPUE subsequent to the maximal value, the $\log_e$ of the ratio of maximal mean CPUE to a subsequent mean CPUE was used to calculate M_d. 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. Assumptions and difficulties in estimating natural mortality via the described methods are discussed in the Results section.

Relative Growth

Increases in mean fork length were used to examine relative patterns of growth of juvenile *Alosa*. All juveniles in samples of size $N < 50$ were measured; for $N > 50$, a random subsample of 50 fish was taken. Plots of mean size per sampling date were examined for species- or river-specific trends.

Index Pattern Between Rivers

Parametric and nonparametric correlation (Pearson and Spearman Rank correlation coefficients, respectively) analysis was used to determine if there was a pattern in the species-specific indices between the Mattaponi and Pamunkey rivers. The log (X+1) transformation of the data was used to assess the parametric relation in the indices.

Relationship Between the Maximum Mean CPUE and a Seasonal Mean CPUE

Utilizing the data collected since 1979, seasonal geometric mean CPUEs were calculated for the period June 1 through approximately August 15, the date when pushnet sampling typically is complete, for each *Alosa* species in both the Pamunkey and Mattaponi rivers. To measure relative precision, the coefficient of variation (CV) was also calculated for each maximum and seasonal estimate. The relationship between the maximum and seasonal geometric mean CPUEs was investigated using parametric and nonparametric correlation analysis (r and r_s, respectively). A strong relationship between the variables would be indicated if the correlation coefficients equaled or exceeded 0.90. A strong relationship would also support the use of the maximum mean CPUE as an index of annual relative abundance as compared to a seasonal value.

Non-Target (By-catch) Species

The tidal freshwater areas of the Pamunkey and Mattaponi rivers also support an extensive assemblage of other freshwater and estuarine fish, both juvenile and adult life-stages, that are susceptible to pushnet collection. Dawson (1992) provides details on the historical extent and distribution of non-*Alosa* species in these rivers. Catch of all non-target species (FL > 27 mm) is reported on a CPUE basis following the method used for juvenile *Alosa*. Arithmetic mean CPUE were calculated for each species on each sample date. These values are tabulated without analysis.

RESULTS AND DISCUSSION

Weekly sampling for juvenile *Alosa* in the nursery zones of the Mattaponi and Pamunkey rivers began the first week of June in 1995 and 1996. The nursery zone (Figure 3) in each river was sampled weekly until the maximal mean CPUE was observed. The time of sampling and the number of sample dates on each river were:

	1995	1996
Mattaponi:	May 30 through July 26 (8 dates)	June 5 through August 6 (10 dates)
Pamunkey:	May 31 through August 21 (13 dates)	June 6 through August 5 (9 dates)

Results of the 1995 and 1996 sampling efforts are presented and discussed in the following subsections.

Relative Abundance

Geometric mean CPUE values for the adjusted juvenile *Alosa* nursery zones were calculated for each weekly sample. The data for 1995 and 1996 are presented in Tables 1-2 and plotted as catch curves in Figures 4-6. Weekly sampling continued until the maximal mean CPUE for each species on each river was observed. The maximal geometric mean CPUE and the date of its occurrence were:

River	Year	Maximal geometric mean CPUE (date)		
		Blueback	Alewife	Amer. shad
Pamunkey	1995	5.9 (August 8)	0.1 (June 27)	2.2 (June 14)
	1996	66.1 (July 16)	4.4 (June 13)	31.5 (June 13)
Mattaponi	1995	0.4 (July 9)	0.1 (June 13)	6.4 (June 5)
	1996	63.6 (July 23)	22.4 (July 23)	144.2 (June 17)

Index values for juveniles of the three species are assumed to have no relationship because of species-specific 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 distribution of juvenile American shad is unknown.

The 1995 and 1996 juvenile *Alosa* indices for each river relative to historical data (i.e., from 1979) are presented in Table 3 (historical arithmetic mean derived indices are presented in Table 4). Figures 4 through 6 graphically present the historical index data for blueback herring, alewife, and American shad in each river, respectively. Differences in catch by river and a discussion of the relative magnitude of the 1995 and 1996 catch to historical values are discussed by species in the following subsections.

Blueback Herring (*A. aestivalis*)

The 1995 indices for both the Mattaponi and Pamunkey rivers (0.4 and 5.9, respectively) was as weak as the lowest values observed since the program began in 1979. In contrast, the 1996 indices (63.6 and 66.1, respectively) were strong, considerably higher than the long-term (1979-96) mean (34.0 and 45.5, respectively). The strong indices for juvenile blueback herring were consistent with the strong indices observed for juvenile alewife and American shad, as subsequently discussed.

Alewife (*A. pseudoharengus*)

Juvenile alewife indices for the Mattaponi and Pamunkey rivers were extremely weak in 1995 (0.1 in both rivers) and strong in 1996 (22.4 and 4.4, respectively). The 1996 index in both rivers exceeded the long-term (1979-96) mean values (7.1 and 3.0, respectively) and the index observed for the Mattaponi was the highest during the period of record. The higher catch of juvenile alewife in the Mattaponi River compared to the Pamunkey River is consistent with historical results. Since 1979, the Mattaponi River has supported a greater relative abundance of juvenile alewife than the Pamunkey River. The reasons for the differences are not known.

American Shad (*A. sapidissima*)

The 1995 indices in the Mattaponi and Pamunkey rivers were extremely weak (6.4 and 2.2, respectively) and the 1996 indices (144.2 and 31.5, respectively) were exceptionally strong.

The 1996 Mattaponi juvenile shad index was greater than five times the long-term (1979-96) mean and nearly triple the previous high index observed in 1994 (51.5). Similarly, the 1996 Pamunkey index was greater than four times the long-term mean (7.4) with the only higher index (though not statistically different) being observed in 1979 (32.0). The between river pattern in relative abundance of juvenile American shad is also consistent with historical results. Since 1979, the Mattaponi River has supported a greater relative abundance (14 out of 15 years of index monitoring) of juvenile American shad than the Pamunkey River. The reasons for the consistent differences in relative abundance are not known.

The indices observed in 1996 continue a generally increasing trend in juvenile shad abundance that began in 1993. The 1996 Mattaponi River index greatly exceeded the previous high observed in 1994 which exceeded the previous high observed in 1993. In response to the drastic decline in commercial landings of American shad in Virginia since the 1970s, VMRC imposed restrictive harvest regulations in 1991 and a complete moratorium in 1994. The extent to which these restrictions have resulted in increased escapement, spawning success, and the observed increase in the juvenile American shad index is not known at this time. It is also not known if the Virginia Department of Game and Inland Fisheries stocking of larval American shad, which began in the Pamunkey River in 1994, has contributed to the apparent increase in the 1994 through 1996 Pamunkey River juvenile shad index. Sagittal otoliths removed from shad juveniles collected in the Pamunkey River are currently being examined for the presence of oxytetracycline (OTC) marks in hatchery-reared larvae.

The strong indices observed in 1996 for juvenile American shad, blueback herring, and alewife are also consistent with the exceptionally strong index reported for juvenile striped bass in the Virginia portion of the Chesapeake Bay. Austin et al. (1997) reported that the 1996 juvenile striped bass index was the highest ever observed in Virginia exceeding the previous high by a factor greater than three. Striped bass spawn during the same period and in the same area as *Alosa*. The exceptional spawning success of Virginia's anadromous fish species in 1996 may be the collective result of harvest restrictions and excellent climatic conditions coupled with an abundant food supply that promoted high larval survival. Assuming the juvenile indices of American shad will be reflected in the future as a discernable pattern in adult age composition, strong year classes might be expected to appear in the years 2000 or 2001 when the 1996 juvenile year class sexually matures and returns to the river system for spawning.

Hickory shad (*A. mediocris*)

Historically, juvenile hickory shad are rarely observed in pushnet samples. None were collected in 1995 and 1996 in either river. The virtual absence of hickory shad juveniles, although adults are captured in York River pound and staked gill nets, indicates that juveniles likely utilize other riverine habitat not sampled during the index monitoring program. Information on the early life history of hickory shad is extremely limited.

Natural Mortality

Natural mortality estimates were derived via Ricker (1975) catch curves. Usually, 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 were 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 (as affected by emigration and increased gear avoidance by larger fish) varies, or that the population is not in equilibrium (Royce, 1972). Catch curves for the three *Alosa* species in both rivers often exhibit a near-linear descending right limb in their catch curve. In these instances, the Ricker model is applied to estimates of daily instantaneous mortality.

Estimates of daily instantaneous natural mortality for juvenile *Alosa* in the Pamunkey and Mattaponi rivers for the period 1979-1996 are presented in Table 5. 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 1995 and 1996 juvenile season are noted:

- The right limb of the catch curve for blueback herring in the Pamunkey River was descending and nearly linear in both years (Figure 4). In the Mattaponi River, low catches presented a generally flat curve and mortality was not calculated in 1995. The data were more variable and tended to be non-linear in 1996. Natural mortality in the Pamunkey River was estimated as 0.026 (2.6%/d) in 1995 and 0.011 (1.1%/d) in 1996. These estimates are considerably lower than the long-term (1979-96) mean rate of 0.042 (4.3%/d). For 1996, the estimated rate in the Mattaponi was 0.042 (4.3%/d), near the long-term mean rate of 0.048 (4.9%/d).

- Limited capture of juvenile alewife in both rivers during 1995 precluded calculation of a reasonable estimate of natural mortality. In 1996, the right limb of the catch curve in the Pamunkey River was descending and nearly linear, but more variable and non-linear on the Mattaponi River. Mortality estimates were: 0.097 (10.2%/d) and 0.022 (2.2%/d) for the Mattaponi and Pamunkey rivers, respectively. The long-term mean estimates were 0.046 (4.7%/d) and 0.057 (5.9%/d), respectively.

- The catch curves of American shad were generally variable, non-linear and lacked a discernable descending right limb. In addition, length data (see Relative Growth section below) suggested early emigration of juveniles from the rivers. Natural mortality in the Pamunkey River was estimated as 0.012 (1.2%/d) in 1995 and 0.014 (1.4%/d) in 1996. These estimates are considerably lower than the long-term (1979-96) mean rate of 0.049 (5.0%/d). For the Mattaponi River, the estimated rates were 0.037 (3.8%/d) in 1995 and 0.015 (1.5%/d) in 1996. These estimates are also lower than the long-term mean rate of 0.046 (4.7%/d).

Crecco et al. (1983), based on otolith microstructure analysis, reported mortality of juvenile American shad (40 to 80 days old) to be between 1.8 and 2.0 percent/day in the Connecticut River during the period 1979-82. They also noted that their rates were similar to rates reported in the literature for other juvenile fish which ranged from 1.2 to 2.9% per day. Despite the fact that our estimated mortality rates are based on the less rigorous decline in CPUE method, they are very similar to the rates reported by Crecco et al. (1983). Dixon (1996) showed that natural mortality estimates based on daily age analysis of juvenile blueback herring in the Rappahannock River during 1991 and 1992 were slightly lower than estimates derived with the catch curve or decline in CPUE method used herein. The existence of multiple length cohorts (due to multiple birth date distributions) can artificially lower natural mortality estimates derived from the method (Essig and Cole, 1986; Dixon, 1996.

Relative Growth

Mean length (FL) of juvenile *Alosa* by 1995 and 1996 sample date in each river are presented in Tables 6a and 6b, respectively. Relative changes in mean length for the three juvenile *Alosa* species in 1995 and 1996 are presented in Figures 10a-b through 12a-b. The analysis indicate the following:

- Mean fork length of all three juvenile *Alosa* species during all weekly samples was greater in the Pamunkey than in the Mattaponi. This may be due to an earlier spawn or faster growth rate during the period (i.e., larval to early juvenile life stage) prior to recruitment to the pushnet sampling gear. The observed relative difference in mean fork length during weekly sampling cruises is consistent with observations in all previous annual surveys.

- A deflection in the plot of mean length of American shad on each sampling date on Pamunkey River was evident in 1995 during mid-July through early August. This is likely the result of gear avoidance and early emigration from the nursery zone as discussed below. There was no evidence for the appearance of a late season spawned cohort in the catch data. After early June, all juveniles collected exceeded the minimum fork length of 27-mm for catch analysis, indicating that recruitment to the pushnet gear was complete.

During the season, there is a tendency for the larger juveniles to migrate downstream and become unavailable to the sampling gear (Loesch, 1969; Marcy, 1976). In addition, *Alosa* spawn over a protracted period, usually 6 to 15 weeks. Juveniles collected in early June in the Virginia nursery zones are primarily products of the early spawners. From mid-June to late-July, depending on the time of spawning and the growth rate, the juveniles produced by the later spawners become susceptible to capture by the pushnet. The result of this recruitment pattern is an apparent decrease in mean FL. This so-called "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 was also observed in the juvenile American shad growth curve presented by Marcy (1976).

Index Pattern Between Rivers

Pearson and Spearman Rank correlation coefficients for the relationships in index pattern between the Mattaponi and Pamunkey rivers for the period 1979-1996 were as follows:

Species	Pearson's r^1	Spearmans's r_s
Blueback herring	0.76	0.66*
Alewife	0.72	0.73*
American shad	0.66	0.52

1 Log (X+1) transformed data.

* Significant ($P < 0.05$).

Results suggest that there is a weak pattern in the annual relative abundance of juvenile *Alosa* in the two rivers. A strong pattern in annual relative abundance between the rivers may not be expected, given the differing physiographic features of the two river systems. Although the two systems occupy adjacent watersheds, the Pamunkey watershed is nearly twice the size of the Mattaponi watershed (1,081 and 601 square miles, respectively). Average discharge rates similarly differ with the Pamunkey rate equaling 1,007 ft^3/s while the Mattaponi rate is 593 ft^3/s (USGS, 1992). Differing watershed characteristics may directly affect water clarity and feeding success of emerging larvae, as well as the availability and distribution of zooplankton. Light penetration measurements in 1991 (Dixon and Loesch, 1992; Dixon, 1996) showed that the mean percent light remaining at 1.5 m (i.e., the sampling depth of the pushnet) in the Mattaponi was 3.2% as compared to 1.9% in the Pamunkey. In those years, the mean Sechii depth in the Mattaponi was 1.0 m compared to 0.6 m in the Pamunkey. The greater water clarity in the Mattaponi may be a reflection of a limiting food supply that can affect larval mortality. Given these apparent differences in adjacent watersheds, a strong common pattern in relative abundance of juveniles may not be expected.

Relationship Between the Maximum Mean CPUE and a Seasonal Mean CPUE

For the period 1979-1996, Table 7 summarizes the geometric maximum and seasonal mean CPUEs for each *Alosa* species in the Pamunkey and Mattaponi rivers. Coefficients of variation (CVs) for each estimate in the Mattaponi River are summarized in Table 8. Correlation coefficients for the relationship between the maximum and seasonal geometric mean CPUEs are presented in Table 9.

All correlation coefficients equal or exceed 0.90 and most equal or exceed 0.95, indicating a strong linear relation between the maximum and seasonal geometric mean CPUE. Correlations were also relatively unchanged when the data for calculating the maximum mean CPUE were not included in the calculation of the seasonal means, thereby insuring independence of the variables. Examination of the CV values also indicate a much greater level of precision attained with the maximum mean CPUE compared to the seasonal mean. As presented in Table 8, CVs for the maximum mean CPUE were always less than , and frequently more than half as much as, the seasonal mean CPUE. Confidence intervals for the maximum mean CPUE, therefore, would be much narrower than those developed for the seasonal values. Results indicate that the maximum mean CPUE is as good an indicator of annual relative abundance as a seasonal mean. Considering that the use of the maximum mean CPUE also avoids sample bias associated with downstream drift and gear avoidance of larger juveniles, as well as minimizes economic expenditures, its use as an index of annual relative abundance is well supported.

Relative Abundance of Non-Target (By-catch) Species

The arithmetic mean CPUEs of pushnet by-catch by species for 1995 and 1996 are presented by sampling date in Tables 10a and 10b, respectively. Predominant non-target species that also utilize freshwater *Alosa* nursery zone in the Pamunkey and Mattaponi rivers include:

Atlantic menhaden (*Brevoortia tyrannus*)
Gizzard shad (*Dorosoma cepedianum*)
Striped bass (*Morone saxatilis*)
White perch (*Morone americana*)
Bay anchovy (*Anchoa mitchilli*)
Inland silverside (*Menidia beryllina*)
Hogchoker (*Trinectes maculatus*)
Channel catfish (*Ictalurus punctatus*)
White catfish (*Ameiurus catus*)
Eastern silvery minnow (*Hybognathus regius*)
Spottail shiner (*Notropis hudsonius*)

Detailed information on relative abundance and distribution of by-catch in the Mattaponi and Pamunkey Rivers for the period 1979 through 1991 is presented and discussed in Dawson (1992).

LITERATURE CITED

ASMFC (Atlantic States Marine Fisheries Commission). 1985. Fishery management plan for anadromous alosid stocks of the eastern United States: American shad, hickory shad, alewife, and blueback herring: phase II in interstate management planning for migratory alosids of the Atlantic Coast. Washington, DC. 347 pp.

Atran, S. M., J. G. Loesch, and W. H. Kriete, Jr. 1983. An overview of the status of *Alosa* stocks in Virginia. VIMS Marine Resources Report No. 82-10. The College of William and Mary, Virginia Institute of Marine Science, School of Marine Science, Gloucester Point, VA. 52 pp.

Austin, H. M., A. D. Estes, and D. M. Seaver. 1997. Estimation of juvenile striped bass relative abundance in the Virginia portion of the Chesapeake Bay, Annual Progress Report, January 1996 - December 1996. F87R4. Prepared for U.S. Fish Wildlife Service, Sportfish Restoration Program. The College of William and Mary, Virginia Institute of Marine Science, School of Marine Science, Gloucester Point, VA.

Crecco, V. A., T. F. Savoy, and L. Gunn. 1983. Daily mortality rates of larval and juvenile American shad (*Alosa sapidissima*) in the Connecticut River with changes in year-class strength. Trans. Am. Fish. Soc. 40:1719-1728.

Dawson, S. I. 1992. Juvenile pelagic fish communities in the Mattaponi and Pamunkey rivers, Virginia. Masters Thesis. School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA.

Dixon, D. A. 1996. Contributions to the life history of juvenile blueback herring (*Alosa aestivalis*): phototactic behavior and population dynamics. Doctoral Dissertation. School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA.

Dixon, D. A., J. D. Goins, B. W. Hill, and J. G. Loesch. 1995. A stock assessment program for Chesapeake Bay fisheries: development of an *Alosa* juvenile index of abundance. Annual Report for 1994. NMFS Contract No. NA46FU0393. Virginia Institute of Marine Science, School of Marine Science. Gloucester Point, VA. 46 pp.

Dixon, D. A. and J. G. Loesch. 1992. A stock assessment program for Chesapeake Bay fisheries: development of an *Alosa* juvenile index of abundance. Annual Report for 1991. NMFS Contract No. NA90AA-H-SF671. Virginia Institute of Marine Science, School of Marine Science. Gloucester Point, VA. 42 pp.

Durbin, A. G., S. W. Nixon, and C. A. Oviatt. 1979. Effects of the spawning migration of alewife, *Alosa pseudoharengus*, on a freshwater ecosystem. Ecology 60:8-17.

Essig, R. J., and C. F. Cole. 1986. Methods for estimating larval fish mortality from daily increments in otoliths. Trans. Amer. Fish. Soc. 115: 34-40.

Havey, K. A. 1973. Production of juvenile alewives, *Alosa pseudoharengus*, at Love Lake, Washington County, Maine. Trans. Am. Fish. Soc. 102:434-437.

Kriete, W. H., Jr. and J. G. Loesch. 1980. Design and relative efficiency of a bow-mounted pushnet for sampling juvenile pelagic fishes. Trans. Amer. Fish. Soc. 109(6):649-652.

Limburg, K. E. 1996. Growth and migration of 0-year American shad (*Alosa sapidissima*) in the Hudson River estuary: otolith microstructure analysis. Can. J. Fish. Aquat. Sci. 53:220-238.

Loesch, J. G. 1969. A study of the blueback herring, *Alosa* aestivalis (Mitchill) in Connecticut waters. Doctoral dissertation. University of Connecticut, Storrs, Connecticut.

Loesch, J. G. 1987. Overview of life history aspects of anadromous alewife and blueback herring in freshwater habitats. American Fisheries Society Symposium 1:89-103.

Loesch, J. G. and W. H. Kriete Jr. 1976. Biology and management of river herring and shad in Virginia. Nat. Mar. Fish. Serv. Comp. Rep. AFC-8-1 to 8-3. Virginia Institute of Marine Science, Gloucester Point, Virginia. 226 pp.

Loesch, J. G. and W. H. Kriete Jr. 1983. Anadromous fisheries research, Virginia. Nat. Mar. Fish. Serv. Comp. Rep. AFC-10-1 to 10-4. The College of William and Mary, Virginia Institute of Marine Science, School of Marine Science, Gloucester Point, Virginia. 56 pp.

Loesch, J. G., W. H. Kriete Jr., and E. J. Foel. 1982. Effects of light intensity on the catchability of juvenile anadromous *Alosa* species. Trans. Amer. Fish. Soc. 111:41-44.

Loesch, J. G. and S. M. Atran. 1994. History of *Alosa* fisheries management: Virginia, a case study. Pages 1-6 *in* J. E. Cooper, R. T. Eades, R. J. Klauda, and J. G. Loesch, editors. Proceedings of the anadromous *Alosa* symposium, Tidewater Chapter, American Fisheries Society, Bethesda, MD.

Loesch, J. G., and D.A. Dixon. 1996. Development and application of a juvenile index of abundance for anadromous rive herring. Poster Presentation. Third World Fisheries Congress Annual Meeting, Sydney, Australia. August 1996. The College of William and Mary, Virginia Institute of Marine Science, School of Marine Science, Gloucester Point, Virginia.

Marcy, B. C., Jr. 1976. Early life history studies of American shad in the lower Connecticut River and the effects of the Connecticut Yankee plant. Amer. Fish. Soc. Monogr. 1:141-168.

Pope, J. A., A. R. Margetts, J. M. Hamley, and E. F. Akyuz. 1975. Manual of methods for fish stock assessment. Part III. Selectivity of fishing gear. FAO Fish. Tech. Pap. 41, Rev. 1. 64 pp.

Ricker, W. E. 1975. Computations and interpretations of biological statistics of fish populations. Fish. Res. Bd. Can. Bull. 919. 382 pp.

Royce, W. F. 1972. Introduction to the fishery sciences. Academic Press, N.Y. 351 pp.

USGS (U.S. Geological Service). 1992. Surface water data records for water-year 1991. U.S. Department of the Interior, Geological Survey, Washington, D.C.

Virginia Marine Resources Commission (VMRC). 1996. Annual summary (preliminary) of Virginia landings. Newport News, VA. 3 p.

Virginia Marine Resources Commission (VMRC). 1988. Virginia historical commercial landings: American shad. VMRC Technical Report No. 88-03. Fisheries Management Division, Newport News, VA. 31 p.

Walburg, C. H. and P. R. Nichols. 1967. Biology and management of the American shad and status of the fisheries, Atlantic coast of the United States, 1960. U. S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. No. 550. 105 pp.

Whitley, R. R. 1961. The Susquehanna fishery study, 1957-1960. A report on the desirability and feasibility of passing fish at Conowingo Dam. Maryland Dept. Res. Educ., Contrib. No. 169. Solomons, Maryland. 81 pp.

Table 1a. Geometric mean CPUE for juvenile *Alosa* on each sampling date in 1995 on the Mattaponi and Pamunkey Rivers.

River	Date	Blueback herring	Alewife	American shad
Mattaponi	5/30/95	0	0	4.3
	6/05/95	0.2	0	6.4
	6/13/95	0	0.1	5.0
	6/19/95	0	0.1	4.9
	6/28/95	0.3	0.1	6.4
	7/09/95	0.4	0	1.5
	7/18/95	0.2	0	5.0
	7/26/95	0.2	0	2.1
Pamunkey	5/31/95	0	0	1.3
	6/07/95	0	0	1.0
	6/14/95	0	0	2.2
	6/20/95	0	0	0.3
	6/27/95	1.1	0.1	1.1
	7/05/95	2.8	0	1.6
	7/10/95	1.4	0	0.3
	7/19/95	4.7	0	0.7
	7/25/95	4.2	0.1	1.1
	7/31/95	5.8	0	1.4
	8/08/95	5.9	0	0.2
	8/14/95	5.1	0	1.1
	8/21/95	5.0	0	0.5

Table 1b. Geometric mean CPUE for juvenile *Alosa* on each sampling date in 1996 on the Mattaponi and Pamunkey Rivers.

River	Date	Blueback herring	Alewife	American shad
Mattaponi	6/05/96	0	0	111.7
	6/11/96	0	0	91.3
	6/17/96	7.7	0.7	144.2
	6/26/96	35.2	9.9	73.1
	7/01/96	22.7	6.2	111.2
	7/10/96	23.7	13.8	76.4
	7/17/96	34.1	4.5	118.9
	7/23/96	63.6	22.4	71.9
	7/29/96	17.1	6.2	56.0
	8/06/96	33.6	5.1	66.0
Pamunkey	6/06/96	4.0	1.8	17.5
	6/13/96	11.1	4.4	31.5
	6/23/96	38.4	2.5	14.6
	6/28/96	24.5	1.2	12.9
	7/07/96	55.0	1.4	10.9
	7/16/96	66.1	3.6	21.5
	7/22/96	59.1	3.2	16.9
	7/30/96	36.3	1.2	7.4
	8/05/96	21.0	0.8	10.5

Table 2a. Arithmetic mean CPUE for juvenile *Alosa* on each sampling date in 1995 on the Mattaponi and Pamunkey Rivers.

River	Date	Blueback herring	Alewife	American shad
Mattaponi	5/30/95	0	0	11.7
	6/05/95	0.3	0	13.7
	6/13/95	0	0.1	8.9
	6/19/95	0	0.1	7.7
	6/28/95	0.5	0.1	14.8
	7/09/95	0.6	0	2.5
	7/18/95	0.2	0	6.9
	7/26/95	0.3	0	3.0
Pamunkey	5/31/95	0	0	2.8
	6/07/95	0	0	2.2
	6/14/95	0	0	3.2
	6/20/95	0	0	0.7
	6/27/95	1.6	0.1	3.5
	7/05/95	6.3	0	2.4
	7/10/95	2.8	0	0.4
	7/19/95	7.3	0	1.0
	7/25/95	6.0	0.1	1.6
	7/31/95	25.6	0	2.5
	8/08/95	12.7	0	0.3
	8/14/95	12.4	0	1.3
	8/21/95	14.2	0	0.6

Table 2b. Arithmetic mean CPUE for juvenile *Alosa* on each sampling date in 1996 on the Mattaponi and Pamunkey Rivers.

River	Date	Blueback herring	Alewife	American shad
Mattaponi	6/05/96	0	0	174.0
	6/11/96	0	0	154.1
	6/17/96	34.4	4.2	220.3
	6/26/96	64.7	20.5	81.7
	7/01/96	56.9	16.5	133.1
	7/10/96	54.4	16.4	97.0
	7/17/96	70.1	8.0	154.4
	7/23/96	116.7	30.0	90.2
	7/29/96	35.1	12.9	68.2
	8/06/96	58.8	6.8	79.7
Pamunkey	6/06/96	37.8	16.8	43.3
	6/13/96	108.5	11.1	47.7
	6/23/96	68.6	5.0	17.6
	6/28/96	81.7	1.9	22.7
	7/07/96	90.1	2.2	15.2
	7/16/96	93.0	5.9	43.2
	7/22/96	74.3	4.5	18.3
	7/30/96	77.9	2.5	14.2
	8/05/96	37.1	1.9	13.1

Table 3. Annual index of abundance (maximal geometric mean CPUE) for juvenile *Alosa* in the James and Rappahannock Rivers, 1991-1992[1], and Mattaponi and Pamunkey Rivers, 1979-1996.

River	Year	Maximal geometric mean CPUE		
		Blueback herring	Alewife	American shad
James	1991[1]	66.1	<0.1	<0.1
	1992[1]	3.4	0	<0.1
	Mean	34.8	<0.1	<0.1
Rappahannock	1991[1]	122.0	3.7	0.2
	1992[1]	45.9	1.2	0.5
	Mean	84.0	2.5	0.4
Mattaponi	1979	24.4	2.9	24.3[2]
	1980	3.8[2]	1.3[2]	18.5[2]
	1981	9.0	5.0[2]	13.5[2]
	1982	92.3	18.3	9.3
	1983	17.1	3.2	7.3
	1984	93.4	19.0	22.6
	1985	127.2	13.6	26.0
	1986	15.5	7.1	26.1
	1987	14.6	0.8	7.3
	1988	[3]	[3]	[3]
	1989	[3]	[3]	[3]
	1990	[4]	[4]	[4]
	1991	4.6	0.3[2]	7.0[2]
	1992	0.2	0	1.5
	1993	5.1	0.2	30.3
	1994	38.8	12.8	51.5
	1995	0.4	0.1	6.4
	1996	63.6	22.4	144.2
	Mean	34.0	7.1	26.4

River	Year	Maximal geometric mean CPUE		
		Blueback herring	Alewife	American shad
Pamunkey	1979	49.1	3.5	32.0[2]
	1980	50.2[2]	2.9[2]	3.5[2]
	1981	6.1[2]	2.7[2]	3.3[2]
	1982	177.2	11.6[2]	1.9[2]
	1983	59.4	1.9	3.6
	1984	25.0	0.9	1.0
	1985	61.2	5.9	10.1[2]
	1986	33.3	3.7[2]	4.4
	1987	80.1	2.9[2]	0.4
	1988	[3]	[3]	[3]
	1989	[3]	[3]	[3]
	1990	[4]	[4]	[4]
	1991	7.5	1.2[2]	6.3[2]
	1992	<0.1	0	0.1
	1993	2.3	0.1	0.7
	1994	59.3	3.9	9.5[2]
	1995	5.9	0.1	2.2
	1996	66.1	4.4	31.5
	Mean	45.5	3.0	7.4

1 There was no index sampling on the James and Rappahannock Rivers prior to 1991 or after 1992.
2 Maximal mean CPUE occurred in the first sampling period.
3 No index data available due to lack of program funding.
4 Insufficient data to calculate a meaningful index value.

Table 4. Annual index of abundance (maximal arithmetic mean CPUE) for juvenile *Alosa* in the James and Rappahannock Rivers, 1991-1992[1], and Mattaponi and Pamunkey Rivers, 1979-1996.

River	Year	Maximal arithmetic mean CPUE[2]		
		Blueback herring	Alewife	American shad
James	1991[1]	156.9	<0.1	<0.1
	1992[1]	43.8	0	<0.1
	Mean	100.4	<0.1	<0.1
Rappahannock	1991[1]	194.3	6.7	0.2
	1992[1]	121.6	1.6	0.6
	Mean	158.0	4.2	0.4
Mattaponi	1979	67.3	5.7	37.8[3]
	1980	8.4[3]	2.9[3]	35.6[3]
	1981	11.7	10.0[3]	17.8[3]
	1982	291.3	31.5	21.8
	1983	36.1	6.1	15.4
	1984	220.8	27.6	35.1
	1985	206.2	29.3	34.0
	1986	24.6	11.9[3]	35.3
	1987	20.6	1.2	13.7
	1988	[4]	[4]	[4]
	1989	[4]	[4]	[4]
	1990	[5]	[5]	[5]
	1991	9.5[3]	0.5[3]	10.2[3]
	1992	0.3	0	2.6
	1993	6.2	0.4	47.7
	1994	90.9	17.4	62.0
	1995	0.6	0.1	14.8
	1996	116.7	30.0	220.3
	Mean	74.1	11.6	40.3

River	Year	Maximal arithmetic mean CPUE[2]		
		Blueback herring	Alewife	American shad
Pamunkey	1979	255.4	7.6	57.6[3]
	1980	87.2[3]	3.6[3]	7.0[3]
	1981	16.7	6.5[3]	5.4[3]
	1982	408.3	28.4[3]	3.0[3]
	1983	127.4	3.2	7.5
	1984	88.9	1.1	1.9
	1985	153.4	12.6	15.5[3]
	1986	93.8	11.0[3]	7.2
	1987	173.8	5.4[3]	0.5
	1988	[4]	[4]	[4]
	1989	[4]	[4]	[4]
	1990	[5]	[5]	[5]
	1991	13.3	2.2[3]	8.5[3]
	1992	<0.1	0	0.2
	1993	3.3	0.1	0.9
	1994	103.5	5.1	22.1[3]
	1995	25.6	0.1	3.5
	1996	108.5	16.8[3]	47.7
	Mean	110.6	6.9	12.6

1 There was no index sampling on the James and Rappahannock Rivers prior to 1991 or after 1992.
2 Some values differ from previous (pre-1992) reports as a result of a comprehensive QC of historical data performed in 1991.
3 Maximal mean CPUE occurred in the first sampling period.
4 No index data available due to lack of program funding.
5 Insufficient data to calculate a meaningful index value.

Table 5. Estimates of instantaneous daily mortality (M_d) for juvenile *Alosa* in the James and Rappahannock Rivers, 1991-1992[1], and Mattaponi and Pamunkey Rivers, 1979-1996. ***(NOTE: Mortality estimates based on arithmetic catch curves).***

River	Year	Blueback herring	American shad	Alewife
James	1991[1]	0.094	[2]	[2]
	1992[1]	0.166	[2]	[2]
	Mean	0.130	[2]	[2]
Rappahannock	1991[1]	0.103	[2]	0.068
	1992[1]	0.047	0.015	0.034
	Mean	0.075	0.015	0.051
Mattaponi	1979	0.034	0.040	0.036
	1980	0.022	0.056	0.330
	1981	[2]	0.080	0.105
	1982	0.077	0.042	0.036
	1983	0.041	0.030	0.038
	1984	0.030	0.056	0.042
	1985	0.035	0.053	0.038
	1986	0.047	0.080	0.036
	1987	0.140	0.063	0.043
	1988	[3]	[3]	[3]
	1989	[3]	[3]	[3]
	1990	[2]	[2]	[2]
	1991	0.031	0.057	0.046
	1992	[2]	0.044	[2]
	1993	0.005	0.037	[2]
	1994	0.041	0.049	0.047
	1995	[2]	0.037	[2]
	1996	0.042	0.015	0.097
	Mean	0.048[4]	0.046[4]	0.046[4]

River	Year	Blueback herring	American shad	Alewife
Pamunkey	1979	0.040	0.060	0.040
	1980	0.031	0.080	0.040
	1981	0.016	0.043	0.058
	1982	0.046	0.050	0.043
	1983	0.052	0.078	0.068
	1984	0.078	0.057	0.036
	1985	0.055	0.098	0.067
	1986	0.043	0.050	0.050
	1987	0.065	[2]	0.148
	1988	[3]	[3]	[3]
	1989	[3]	[3]	[3]
	1990	[2]	[2]	[2]
	1991	0.040	0.064	0.092
	1992	[2]	[2]	[2]
	1993	0.040	0.021	[2]
	1994	0.045	0.016	0.023
	1995	0.026	0.012	[2]
	1996	0.011	0.014	0.022
	Mean	0.042	0.049	0.057

[1] There was no index sampling on the James and Rappahannock Rivers prior to 1991 or after 1992.
[2] Data were too few for a reasonably objective estimate of mortality.
[3] No sampling conducted due to lack of funding.
[4] The 1980 and 1981 data were omitted from the mean value (see text).

Table 6a. Mean length (mm FL) and extremes in length of juvenile *Alosa* on each sample date in 1995 on the Mattaponi and Pamunkey Rivers.

River	Sample date	Blueback herring	Alewife	American shad
Mattaponi	5/30/95	[1]	[1]	29.2 (27-40)
	6/05/95	33.8 (30-37)	[1]	33.6 (27-48)
	6/13/95	[1]	38	40.6 (28-54)
	6/19/95	[1]	53	45.8 (30-66)
	6/28/95	35.0 (30-47)	55	44.8 (28-68)
	7/09/95	34.3 (30-38)	[1]	46.8 (30-67)
	7/18/95	38.0 (31-42)	[1]	57.1 (30-78)
	7/26/95	48.0 (47-49)	[1]	59.3 (41-78)
Pamunkey	5/31/95	[1]	[1]	34.7 (27-43)
	6/07/95	[1]	[1]	41.5 (31-53)
	6/14/95	[1]	[1]	44.7 (30-68)
	6/20/95	[1]	[1]	45.8 (38-60)
	6/27/95	32.8 (27-46)	52	48.5 (34-68)
	7/05/95	38.2 (27-49)	[1]	60.7 (43-80)
	7/10/95	43.8 (28-50)	[1]	60.6 (47-76)
	7/19/95	44.9 (29-54)	[1]	58.6 (35-93)
	7/25/95	47.1 (35-58)	79	54.1 (38-94)
	7/31/95	47.8 (29-63)	[1]	52.5 (32-90)
	8/08/95	48.9 (35-63)	[1]	54.0 (47-67)
	8/14/95	49.8 (35-60)	[1]	64.4 (41-92)
	8/21/95	54.0 (35-64)	[1]	62.4 (49-80)

[1] Species not collected on sample date.

Table 6b. Mean length (mm FL) and extremes in length of juvenile *Alosa* on each sample date in 1995 on the Mattaponi and Pamunkey Rivers.

River	Sample date	Blueback herring	Alewife	American shad
Mattaponi	6/05/96	[1]	41	33.9 (27-53)
	6/11/96	[1]	[1]	33.0 (27-54)
	6/17/96	32.1 (27-41)	33.6 (28-52)	34.2 (27-61)
	6/26/96	32.4 (27-41)	36.8 (31-46)	37.2 (27-63)
	7/01/96	32.3 (27-43)	40.9 (28-50)	37.4 (27-65)
	7/10/96	36.8 (29-48)	44.6 (32-73)	41.2 (27-65)
	7/17/96	35.7 (27-45)	45.4 (35-64)	40.5 (29-67)
	7/23/96	37.3 (27-48)	44.8 (34-78)	40.9 (30-64)
	7/29/96	40.1 (29-52)	49.0 (42-75)	41.9 (27-64)
	8/06/96	39.2 (30-47)	47.5 (42-62)	45.9 (34-64)
Pamunkey	6/06/96	28.5 (27-34)	32.8 (29-41)	34.4 (27-47)
	6/13/96	33.8 (27-43)	37.3 (30-47)	35.6 (27-56)
	6/23/96	39.3 (27-48)	46.7 (41-60)	43.6 (27-65)
	6/28/96	41.9 (27-52)	47.5 (39-57)	39.0 (27-70)
	7/07/96	[2]	51.2 (44-62)	48.0 (31-70)
	7/16/96	[2]	54.9 (47-72)	46.2 (28-73)
	7/22/96	[2]	54.5 (49-69)	48.8 (27-80)
	7/30/96	[2]	55.9 (50-63)	44.4 (30-80)
	8/05/96	47.7 (28-55)	55.8 (52-62)	46.7 (29-74)

[1] Species not collected on sample date.

[2] Fork length data not recorded because of data base problems.

Table 7. Summary of maximum and seasonal (June 1 - August 15) geometric mean CPUEs for juvenile blueback herring, alewife, and American shad in the Pamunkey and Mattaponi rivers: 1979-1996.

River	Year	Blueback herring		Alewife		American shad	
		Maximum CPUE	Seasonal CPUE	Maximum CPUE	Seasonal CPUE	Maximum CPUE	Seasonal CPUE
Pamunkey	1979	49.1	40.6	3.5	1.8	32.0	10.6
	1980	50.2	34.1	2.9	1.2	3.5	1.7
	1981	6.1	4.9	2.7	1.3	3.3	1.3
	1982	177.2	131.6	11.6	6.1	1.9	0.7
	1983	59.4	31.1	1.9	1.3	3.6	1.9
	1984	25.0	14.5	0.9	0.5	1.0	0.8
	1985	61.2	31.6	5.9	3.7	10.1	4.9
	1986	33.3	20.6	3.7	2.9	4.4	3.2
	1987	80.1	50.7	2.9	0.8	0.4	0.1
	1988	*	*	*	*	*	*
	1989	*	*	*	*	*	*
	1990	*	*	*	*	*	*
	1991	7.5	5.2	1.2	0.2	6.3	2.2
	1992	0.1	0.02	0.0	0.0	0.1	0.03
	1993	2.3	0.9	0.1	0.03	0.7	0.3
	1994	59.3	36.7	3.9	1.6	9.5	2.8
	1995	5.9	2.0	0.1	<0.1	2.2	0.9
	1996	66.1	28.5	4.4	2.1	31.5	14.8
Mattaponi	1979	24.4	13.5	2.9	1.0	24.3	11.4
	1980	3.8	2.2	1.3	0.8	18.5	9.0
	1981	9.0	2.5	5.0	1.8	13.5	3.7

River	Year	Blueback herring		Alewife		American shad	
		Maximum CPUE	Seasonal CPUE	Maximum CPUE	Seasonal CPUE	Maximum CPUE	Seasonal CPUE
Mattaponi (cont'd)	1982	92.3	52.5	18.3	11.8	9.3	5.2
	1983	17.1	6.2	3.2	2.2	7.3	4.3
	1984	93.4	33.3	19.0	8.4	22.6	11.1
	1985	127.2	50.6	13.6	7.7	26.0	11.8
	1986	15.5	5.9	7.1	3.1	26.1	12.1
	1987	14.6	3.7	0.8	0.4	7.3	6.2
	1988	*	*	*	*	*	*
	1989	*	*	*	*	*	*
	1990	*	*	*	*	*	*
	1991	4.6	2.3	0.3	0.1	7.0	1.9
	1992	0.2	0.03	0.0	0.0	1.5	0.5
	1993	5.1	2.8	0.2	0.1	30.3	17.1
	1994	38.8	14.6	12.8	3.5	51.5	19.3
	1995	0.4	0.1	0.1	<0.1	6.4	4.2
	1996	63.6	12.8	22.4	4.0	144.2	88.9

* No sampling was conducted in 1988 and 1989; late program funding in 1990 precluded the collection of reasonable sample data.

Table 8. Summary of coefficients of variation[1] (CV) for maximum and seasonal mean CPUEs for blueback herring, alewife, and American shad in the Mattaponi River: 1979-1996.

Year	Blueback herring		Alewife		American shad	
	Maximum CPUE	Seasonal CPUE	Maximum CPUE	Seasonal CPUE	Maximum CPUE	Seasonal CPUE
1979	49%	54%	80%	151%	36%	61%
1980	69%	85%	113%	164%	46%	68%
1981	39%	184%	62%	123%	26%	146%
1982	32%	59%	39%	52%	60%	71%
1983	48%	123%	69%	108%	44%	71%
1984	38%	102%	32%	51%	28%	50%
1985	25%	64%	47%	62%	24%	50%
1986	35%	106%	40%	85%	27%	46%
1987	31%	108%	110%	181%	53%	85%
1988	*	*	*	*	*	*
1989	*	*	*	*	*	*
1990	*	*	*	*	*	*
1991	52%	100%	150%	329%	42%	100%
1992	180%	470%	0%	0%	87%	158%
1993	31%	83%	252%	258%	29%	42%
1994	47%	74%	29%	95%	16%	46%
1995	95%	42%	30%	18%	156%	148%
1996	32%	75%	26%	89%	21%	19%

[1] CVs were calculated based on log (X+1) data.

Table 9. Summary of Pearson (r) and Spearman rank (r_s) correlation coefficients for the relationship between the maximum and seasonal mean CPUE (log-transformed values) for juvenile blueback herring, alewife, and American shad in the Pamunkey and Mattaponi rivers: 1979-1996.

Species	River	Correlation coefficients[1]	
		r	r_s
Blueback herring	Pamunkey	0.99	0.88
	Mattaponi	0.97	0.98
Alewife	Pamunkey	0.95	0.95
	Mattaponi	0.95	0.97
American shad	Pamunkey	0.98	0.98
	Mattaponi	0.96	0.95

1 Because the variables in the correlation analysis are not independent (i.e., the field data used to calculate the maximum mean CPUE was also included in the calculation of the seasonal mean), correlation analyses were also performed between the variables when the seasonal mean was calculated excluding the field data when the maximum mean CPUE was observed. Correlation coefficients in the revised analysis were relatively unchanged from those listed above and ranged from 0.90 to 0.98.

Table 10a. Arithmetic mean CPUE of non-target species by sample week in 1995.

River	Species	Sample week number (beginning June 1, 1995; shaded weeks not sampled)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Pamunkey	Atlantic menhaden	4.2	8.9	8.1	4.7	1.7	0	0.5	0.8	0.2	0	0	0	1.1
	Banded killifish					0.1	0.1		0.1	0.1		0.2	0.1	
	Bay anchovy	13.5	22.3	1.6	5.9	5.5	0.6	17.5	51.0	95.7	27.8	72.2	93.4	131.3
	Channel catfish								0.1	0.1			0.1	
	E. silvery minnow	1.4	0.1	0.1	0.2	0.4			0.1	1.0	0.1		0.1	
	Gizzard shad								0.1	0.1		0.2	0.2	0.1
	Hogchoker			0.1	0.1		0.2		0.1	0.1	0.1			0.1
	Inland silverside	0.5	0.1	0.1	0.1	1.2	0.8	3.0	4.2	5.4	4.7	1.7	1.9	2.3
	Satinfin shiner		0.1					0.1						
	Spottail shiner	2.0	0.1	0.3	0.4	0.7	0.5	0.1	0.2	0.7		0.1	0.6	0.2
	Striped bass				0.3	0.1	0.1		0.1				0.1	
	Sunfishes								0.1		0.1	0.1	0.2	0.2
	Tesselated darter									0.1				
	Threadfin shad								0.2	0.5	0.1	0.1		
	White catfish					0.1	0.1						0.1	
	White perch			0.2					0.1					

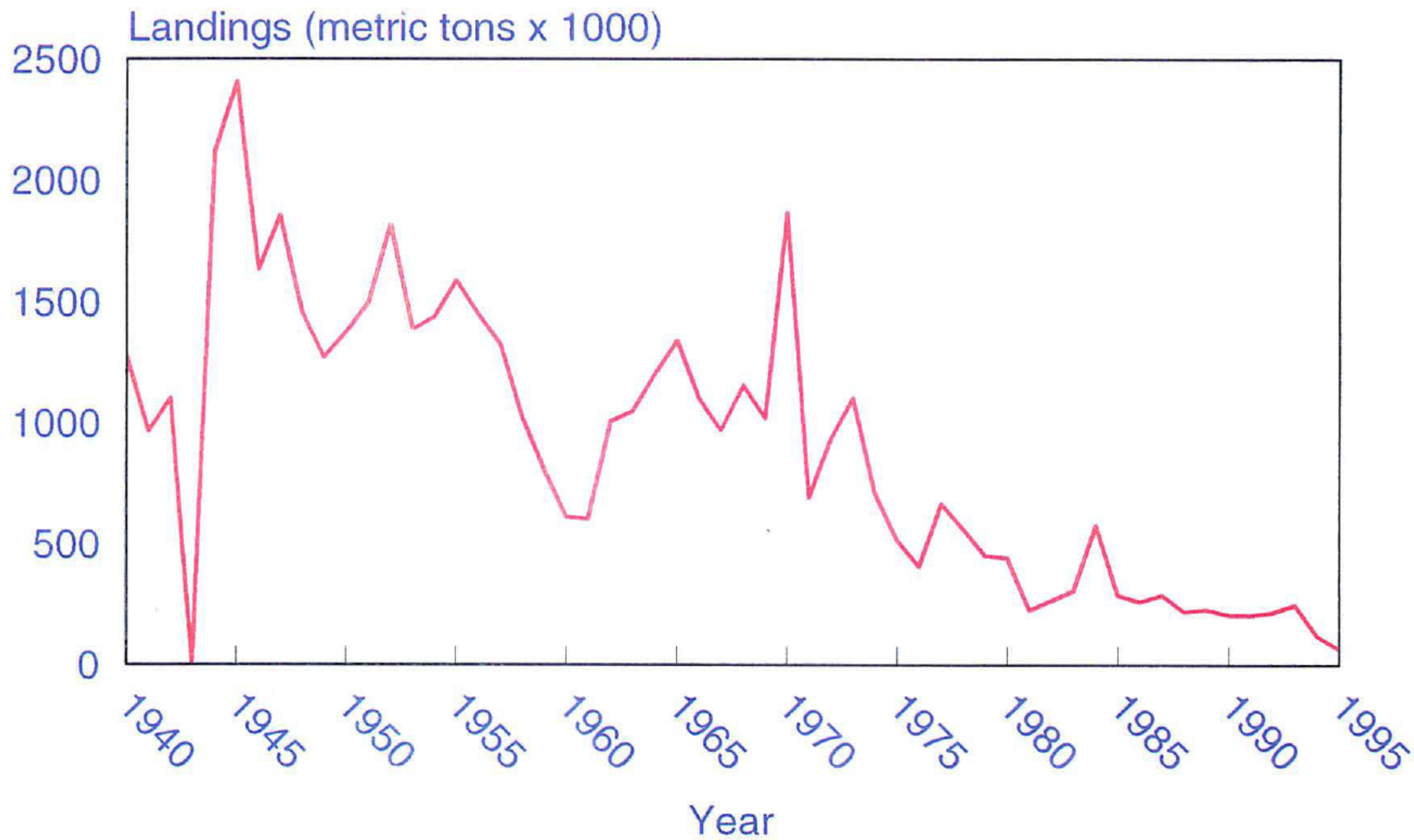
River	Species	Sample week number (beginning June 1, 1995; shaded weeks not sampled)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Mattaponi	Atlantic menhaden	1.3	1.5	5.0	5.0		1.2	0	0.1	0.3				
	Atlantic needlefish						0.2			0.2				
	Banded killifish						0.2	0.6	0.1					
	Bay anchovy	55.4	54.5	26.6	21.4		4.1	24.9	22.5	38.8				
	Channel catfish		0.2		0.8				0.1	1.0				
	E. silvery minnow		0.2				0.2							
	Gizzard shad						0.1							
	Hogchoker		0.2	0.3					0.2					
	Inland silverside	1.1	0.7	0	0.5		0.6	0.9	1.1	5.3				
	Satinfin shiner	0.1												
	Spottail shiner	1.1	0.2		0.3		0.9	0.8	0.6	1.4				
	Striped bass	0.1		0.4	0.4		0.6	0.6	0.6	0.8				
	Sunfishes							0.1		0.2				
	Tesselated darter													
	Threadfin shad													
	White catfish		0.1				0.5		0.3	0.1				
	White perch								0.1	0.1				

Table 10b. Arithmetic mean CPUE of non-target species by sample week in 1996.

River	Species	Sample week number (beginning June 1, 1996; shaded weeks not sampled)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Pamunkey	Atlantic menhaden	7.1	12.6	5.5	4.4	1.1	0.4	0.1	0.4	0.1				
	Atlantic needlefish	0.1	0.1											
	Banded killifish				0.1									
	Bay anchovy					13.4	19.1	42.9	66.7	51.0				
	Channel catfish					0.6		0.1						
	E. silvery minnow		0.5	0.2		2.1	0.7	0.4	0.1					
	Gizzard shad													
	Hogchoker	0.1	0.1	0.1	0.2	0.2	0.2	0.2		0.1				
	Inland silverside	0.7	0.3	0.1	0.2	0.2	0.4	0.3	0.1	0.4				
	Satinfin shiner		0.1				0.1							
	Spottail shiner		0.5	1.6	16.3	3.9	1.9	0.4	0.3	0.1				
	Striped bass	1.3	7.3	35.6	11.4	26.0	11.8	9.9	2.0	1.0				
	Sunfishes													
	Threadfin shad													
	White catfish						0.6	0.6	0.1	0.5				
	White perch			1.2	3.5	6.3	4.8	3.5	0.7	0.9				

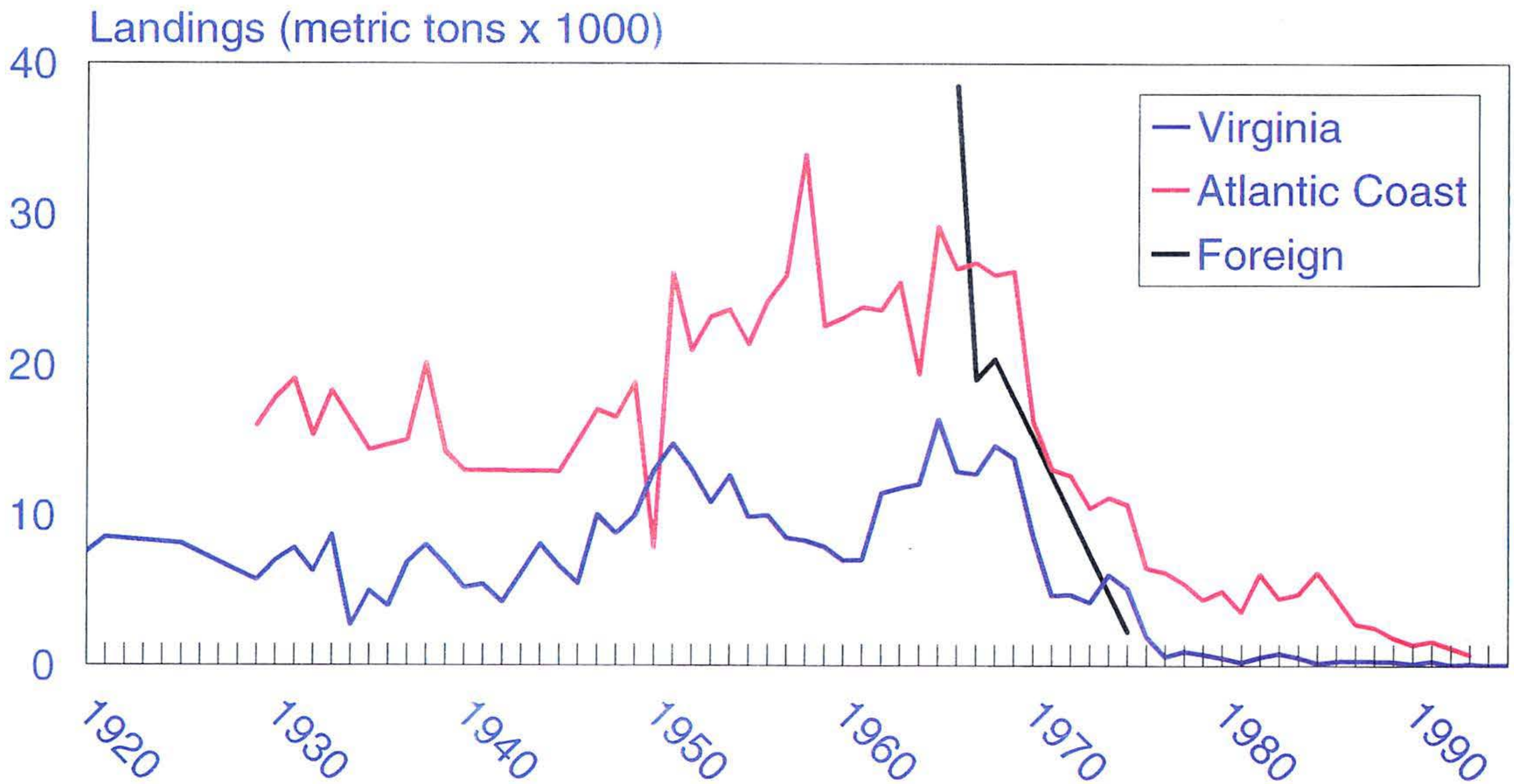
River	Species	Sample week number (beginning June 1, 1996; shaded weeks not sampled)												
		1	2	3	4	5	6	7	8	9	10	11	12	13
Mattaponi	Atlantic menhaden	1.9	8.4	8.1	4.9	6.7	1.6	0.1	0.3	0.2	0.1			
	Atlantic needlefish			0.1			0.1							
	Banded killifish													
	Bay anchovy		0.2				3.5	3.1	10.5	10.9	15.5			
	Channel catfish					0.9	2.8	0.5	1.8		3.0			
	E. silvery minnow			0.4	0.1			0.1						
	Gizzard shad													
	Hogchoker		0.2	0.2		0.6		0.5	0.1	0.1	0.1			
	Inland silverside	0.5	0.1	0.3	0.2	0.3	0.2	0.1	0.1		0.7			
	Satinfin shiner		0.1	0.2	0.1					0.2				
	Spottail shiner	0.4		1.7	2.3	3.5	0.5	1.5	1.0	0.1	0.1			
	Striped bass	0.5	12.3	16.4	1.8	14.8	13.7	12.9	5.4	1.4	2.8			
	Sunfishes													
	Tesselated darter					0.1		0.1						
	Threadfin shad													
	White catfish					0.1		0.8	0.1	0.8	0.1			
	White perch							2.3	0.4	0.4	0.3			

Figure 1. Commercial American shad landings in Virginia: 1940 - 1995



Source: VMRC

Figure 2. Commercial river herring landings in Virginia, the Atlantic Coast, and by foreign fleets: 1920-1995



Source: VMRC

Figure 3. Nursery zone locations.

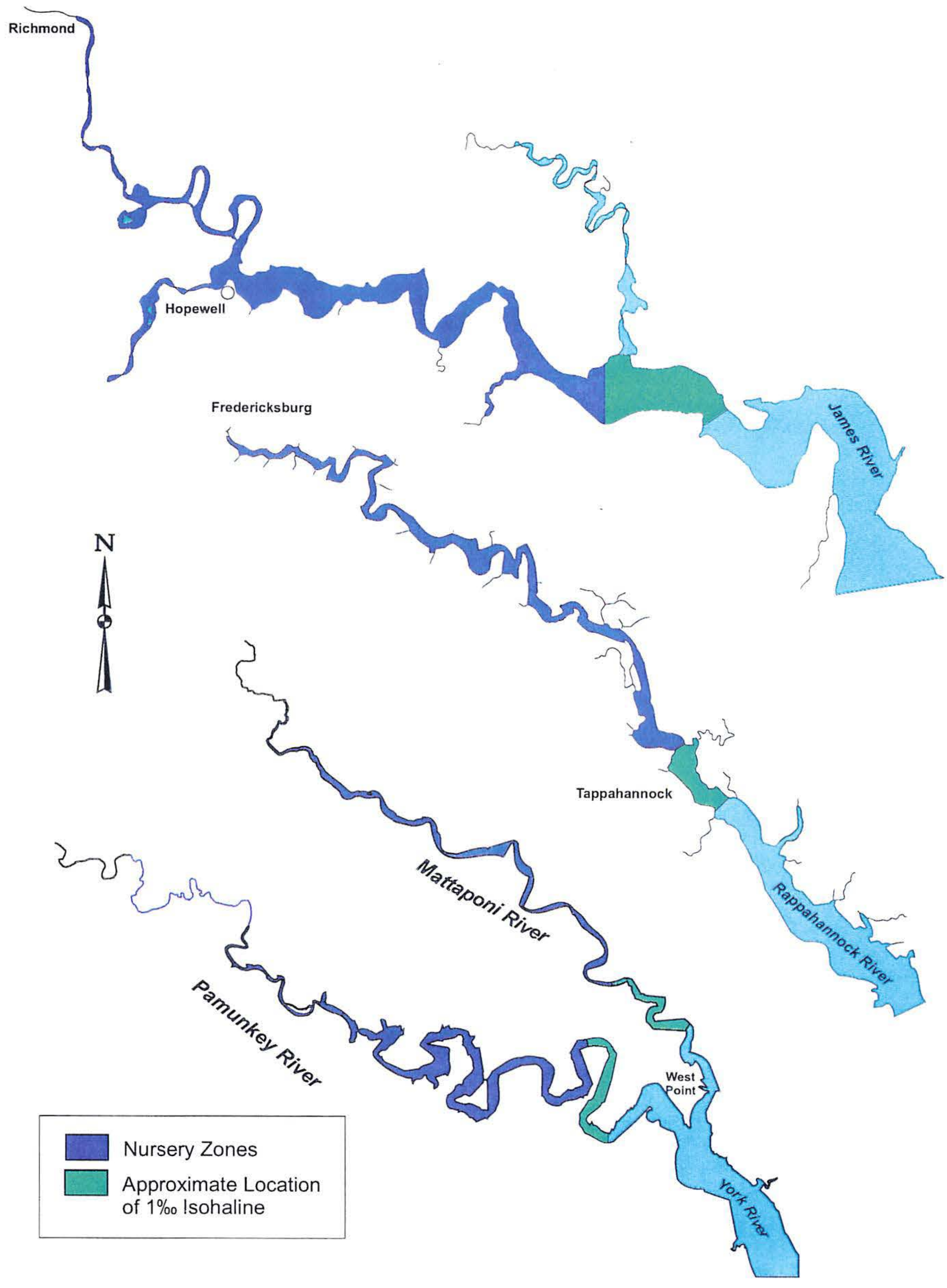


Figure 4a. 1995 Juvenile Blueback Herring Catch Curve

Mattaponi and Pamunkey Rivers

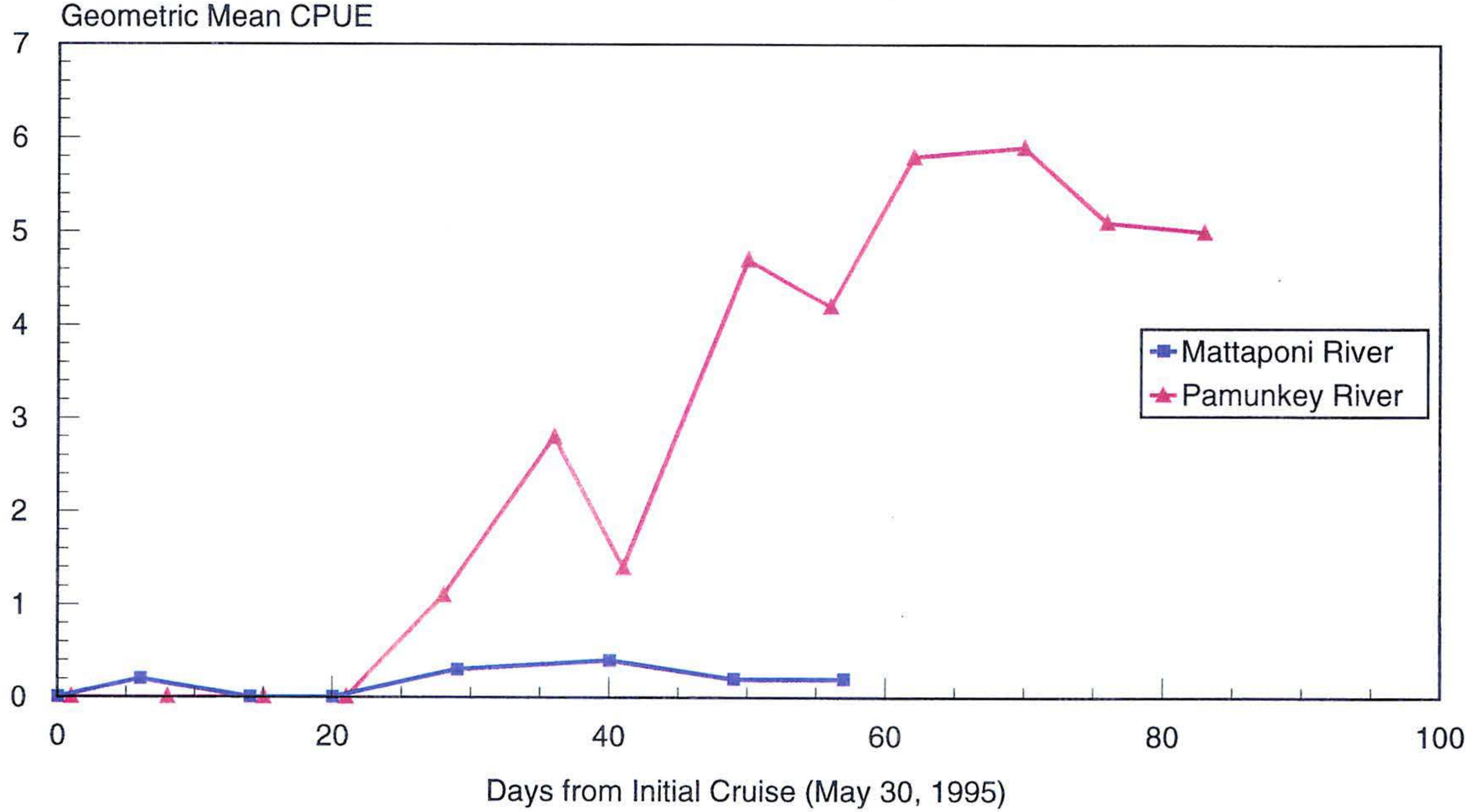


Figure 4b. 1996 Juvenile Blueback Herring Catch Curve

Mattaponi and Pamunkey Rivers

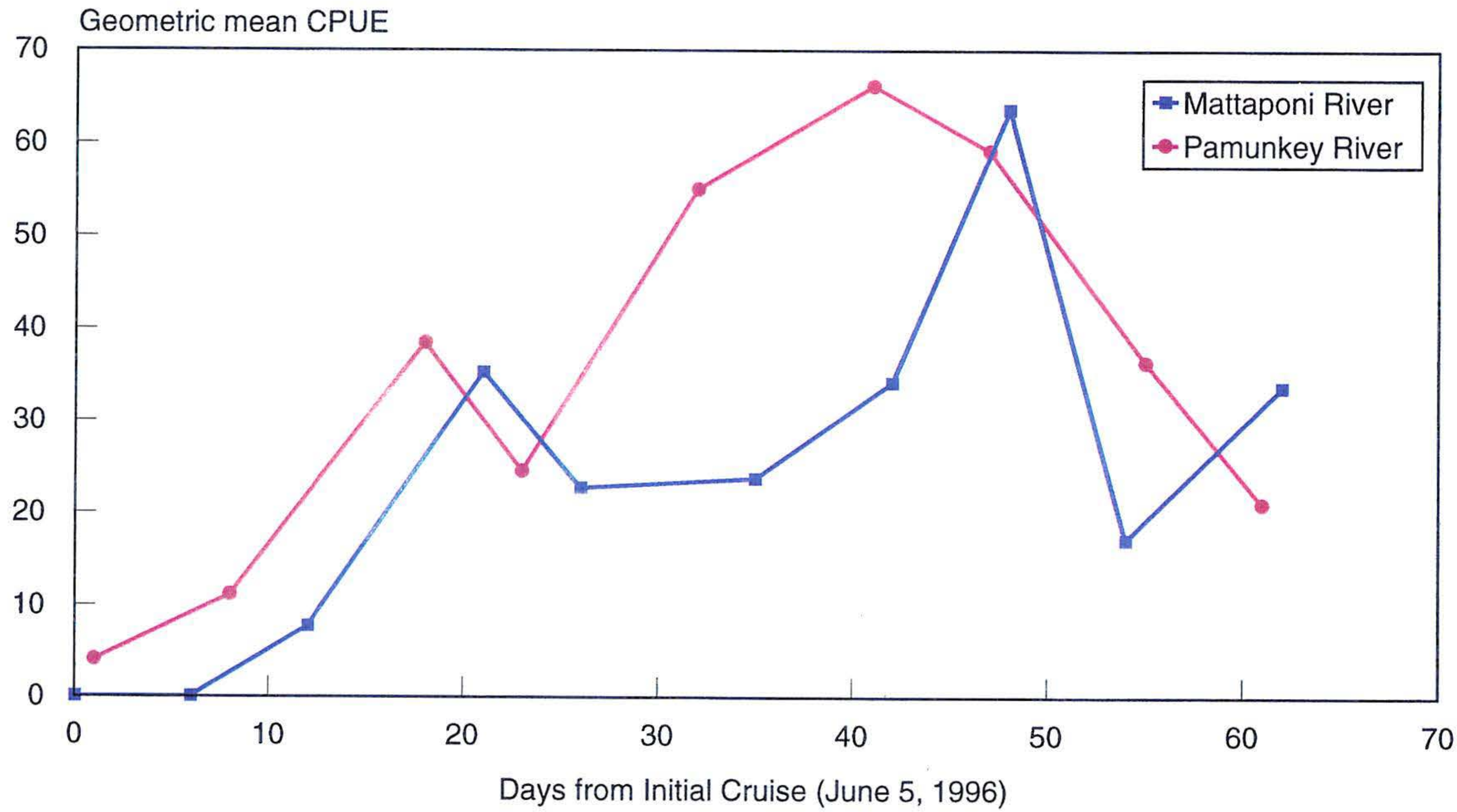


Figure 5a. 1995 Juvenile Alewife Catch Curve

Mattaponi and Pamunkey Rivers

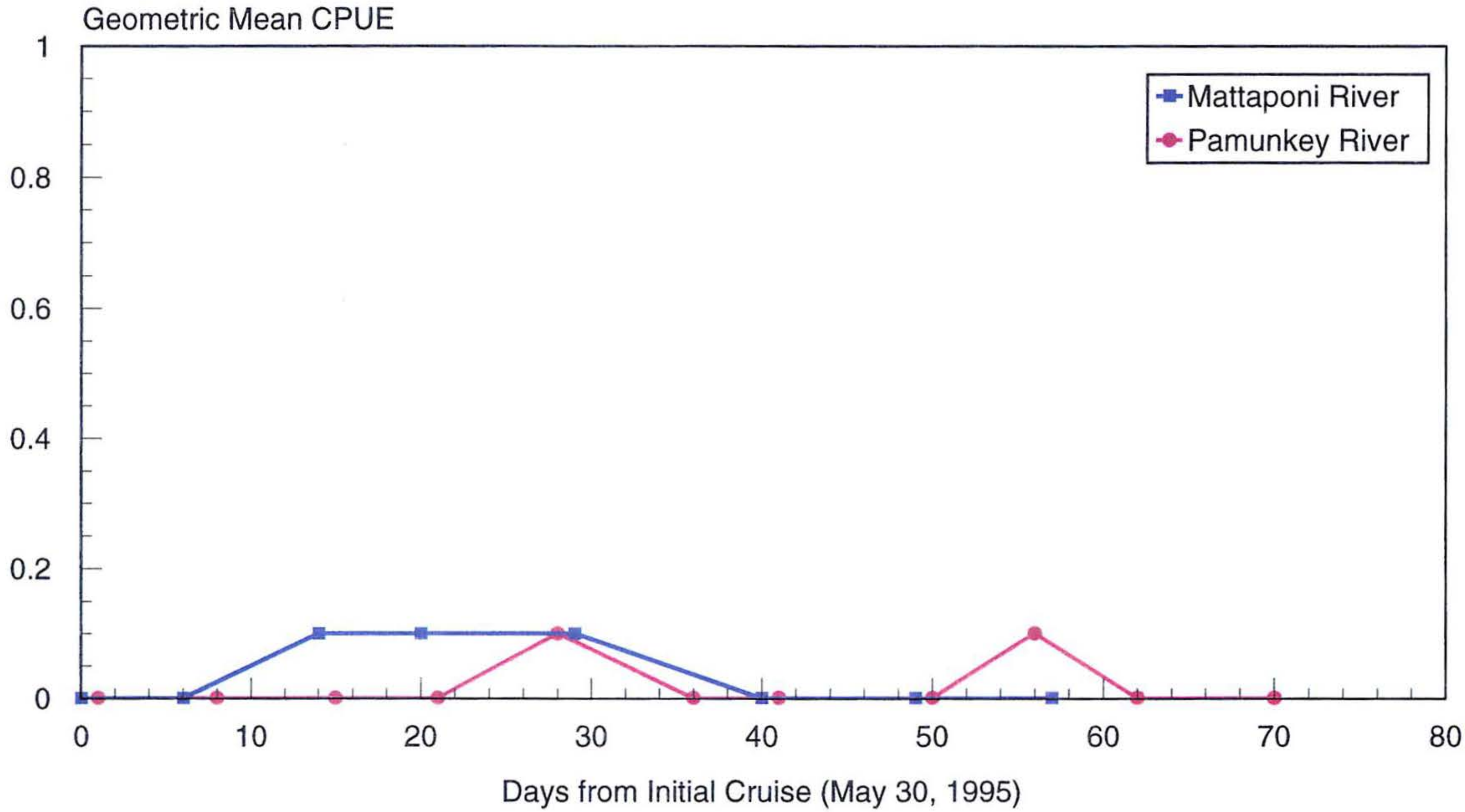


Figure 5b. 1996 Juvenile Alewife Catch Curve

Mattaponi and Pamunkey Rivers

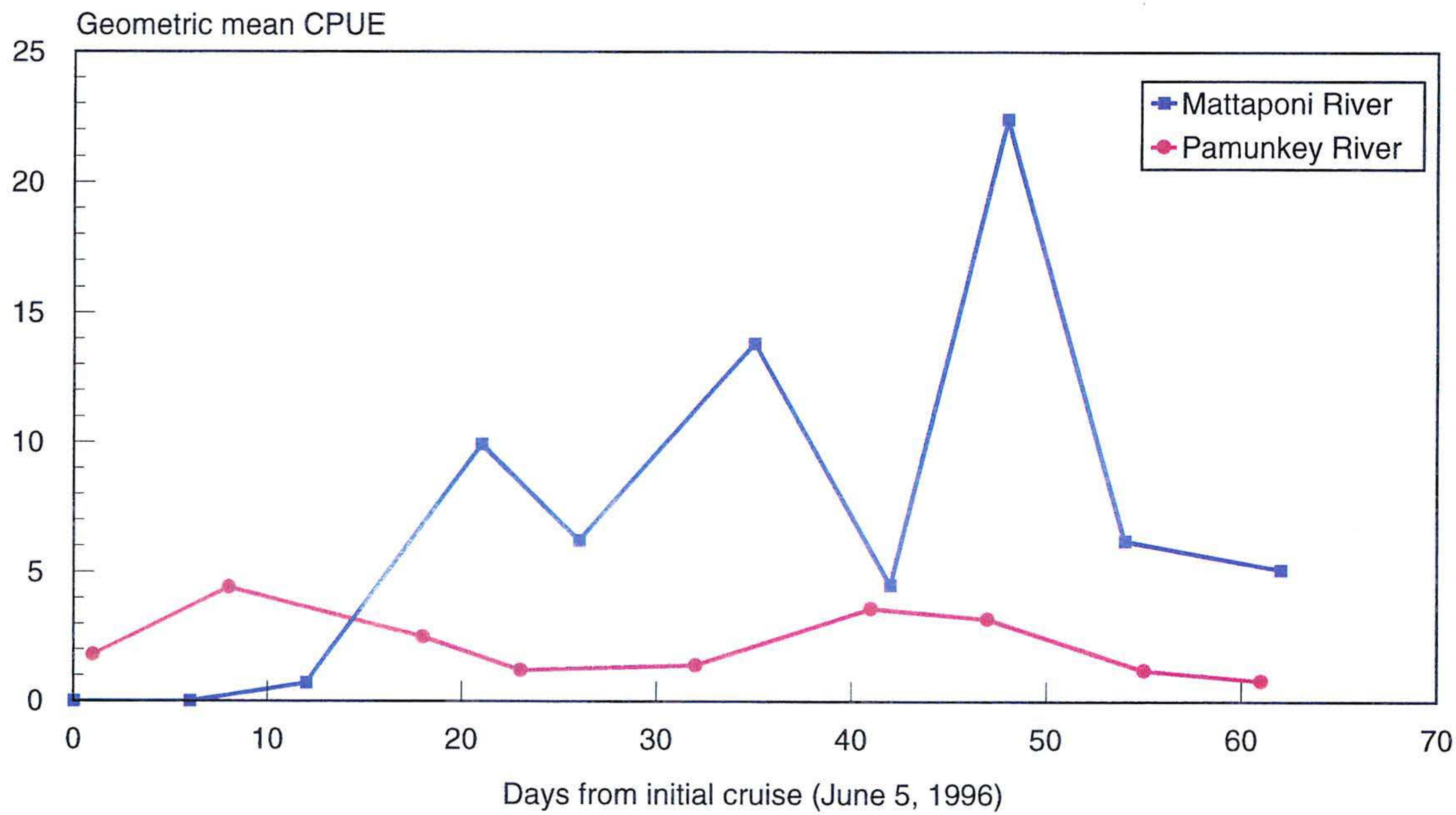


Figure 6a. 1995 Juvenile American Shad Catch Curve

Mattaponi and Pamunkey Rivers

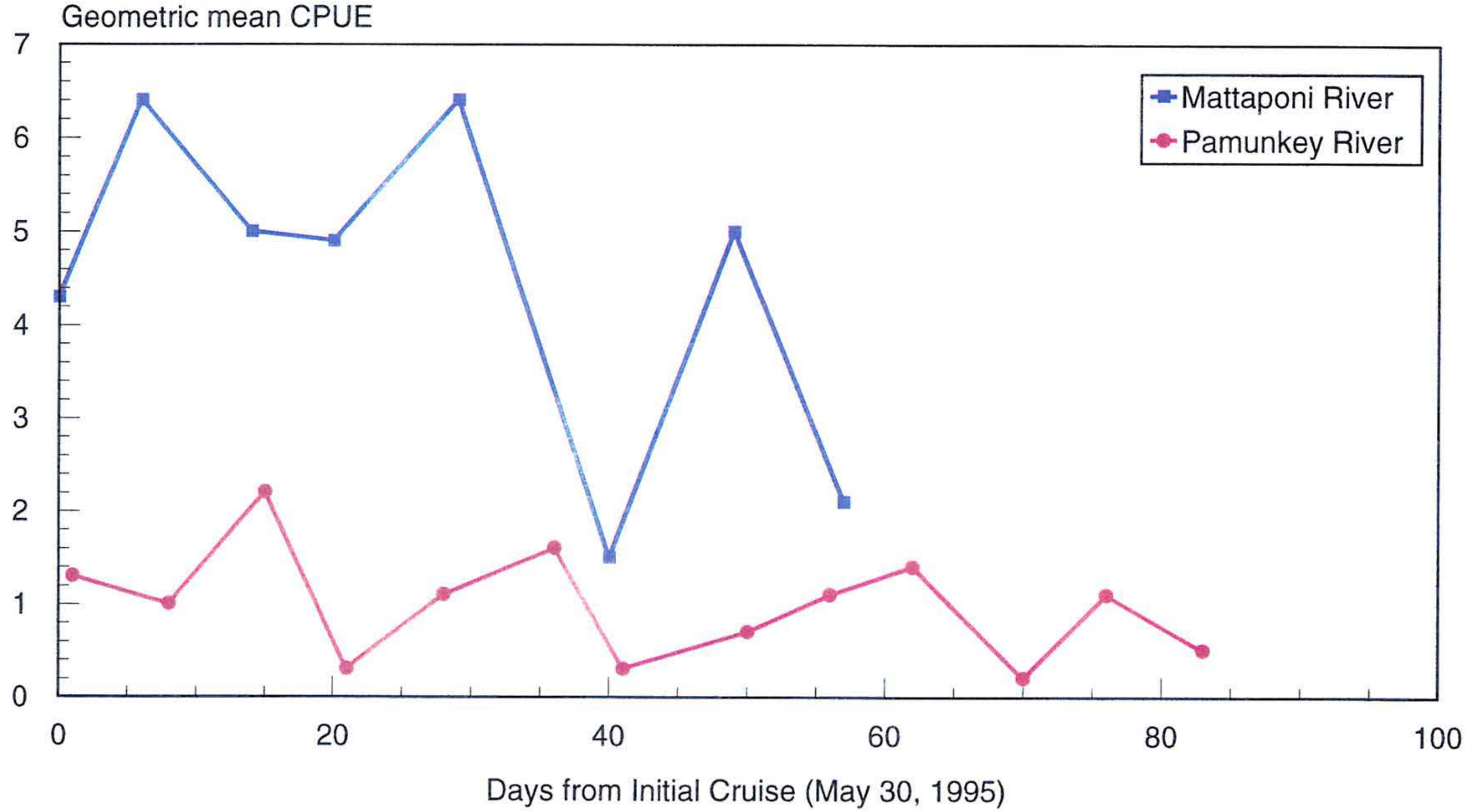


Figure 6b. 1996 Juvenile American Shad Catch Curve

Mattaponi and Pamunkey Rivers

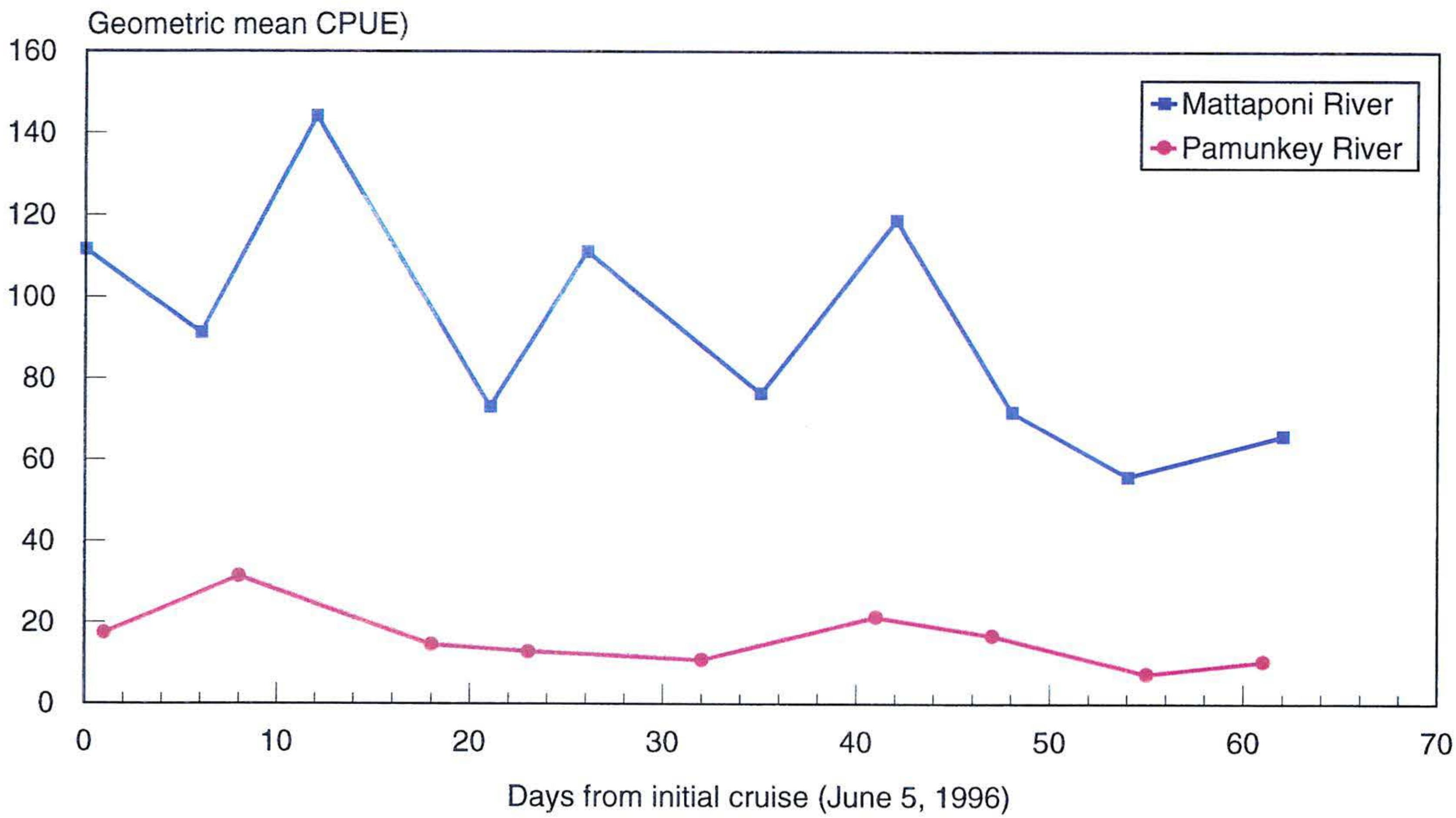
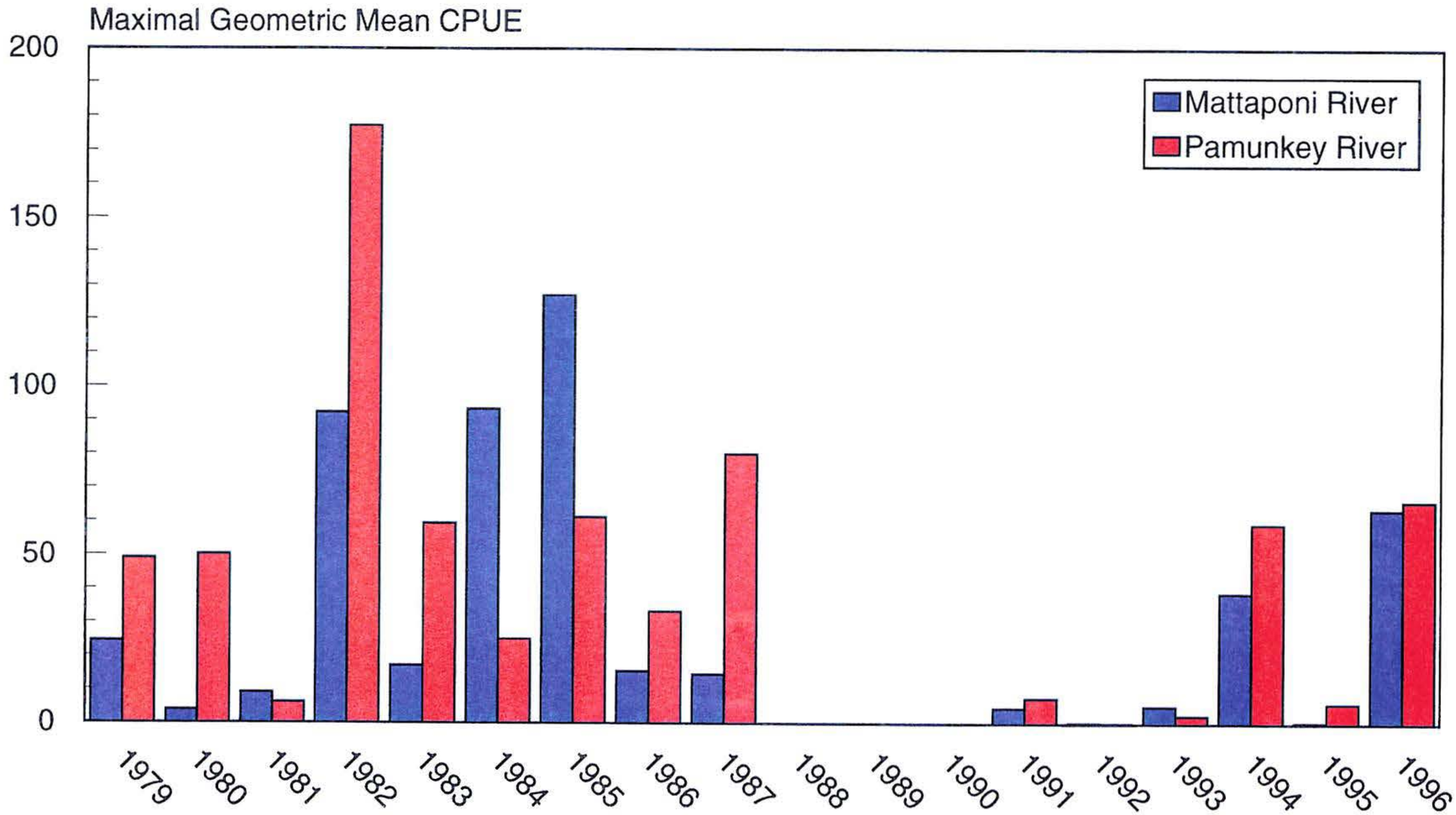


Figure 7. Juvenile Blueback Herring Index: 1979-1996

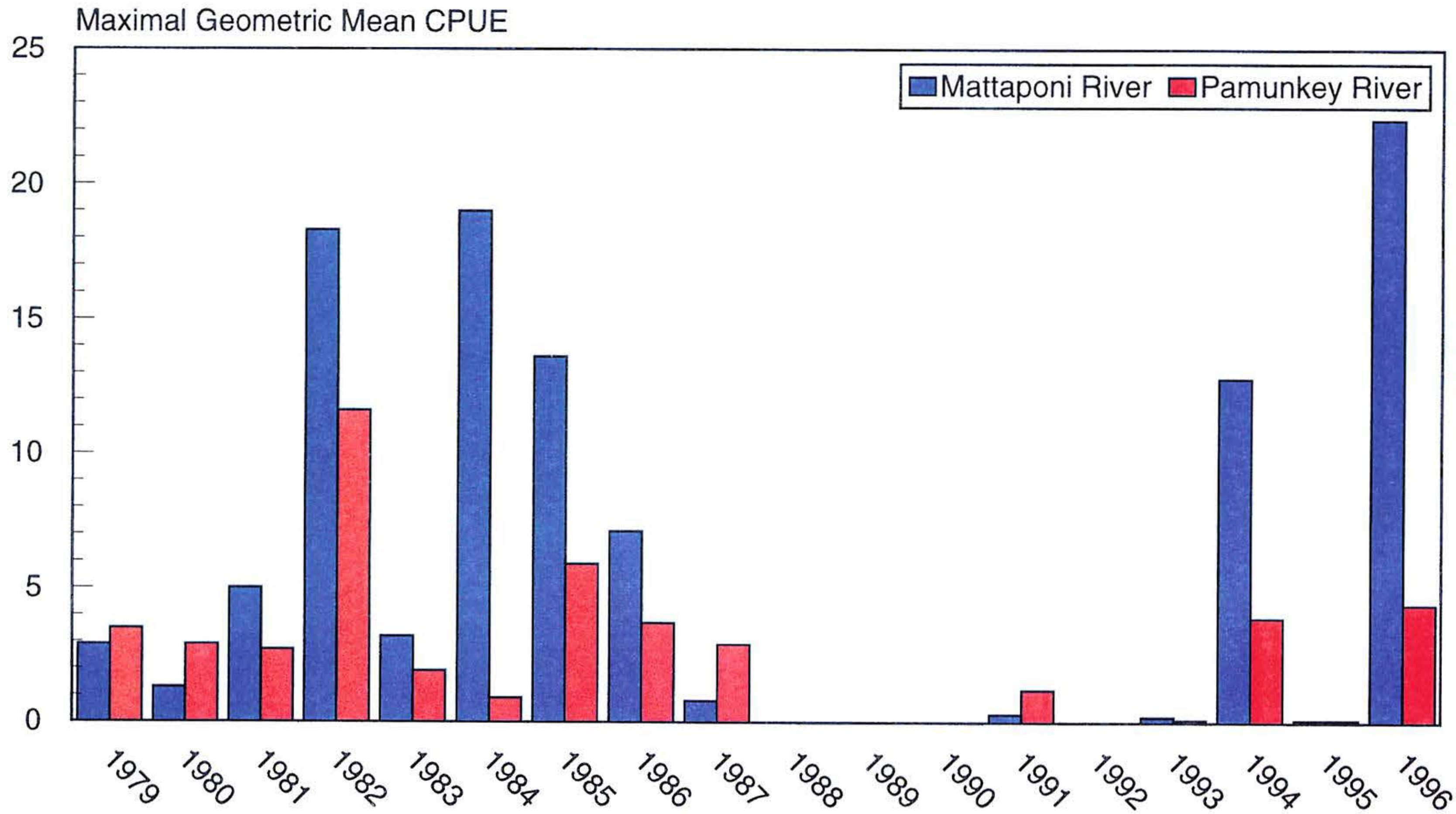
Mattaponi and Pamunkey Rivers



No sampling 1988-89; insufficient data 1990

Figure 8. Juvenile Alewife Index: 1979 -1996

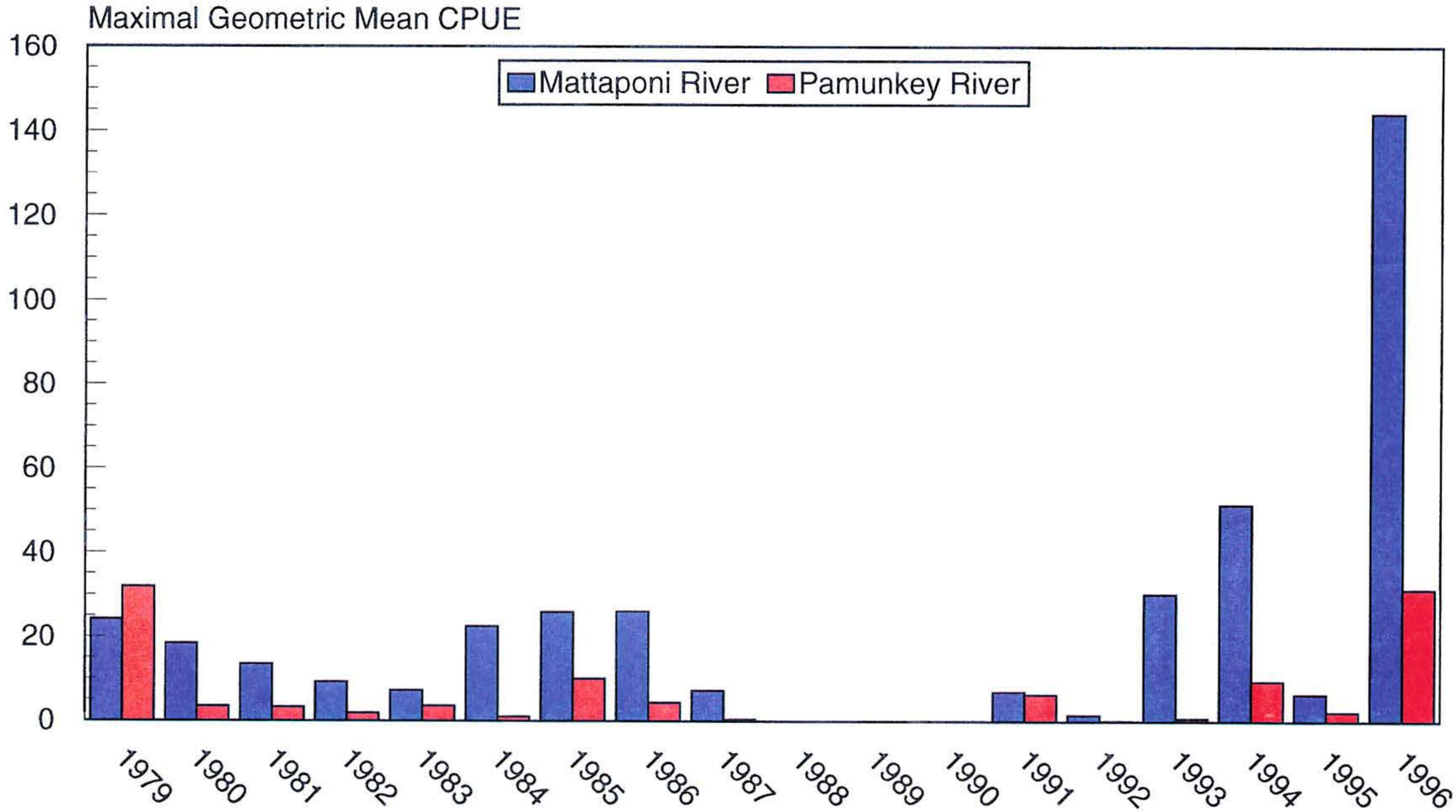
Mattaponi and Pamunkey Rivers



No sampling 1988-89; Insufficient data 1990

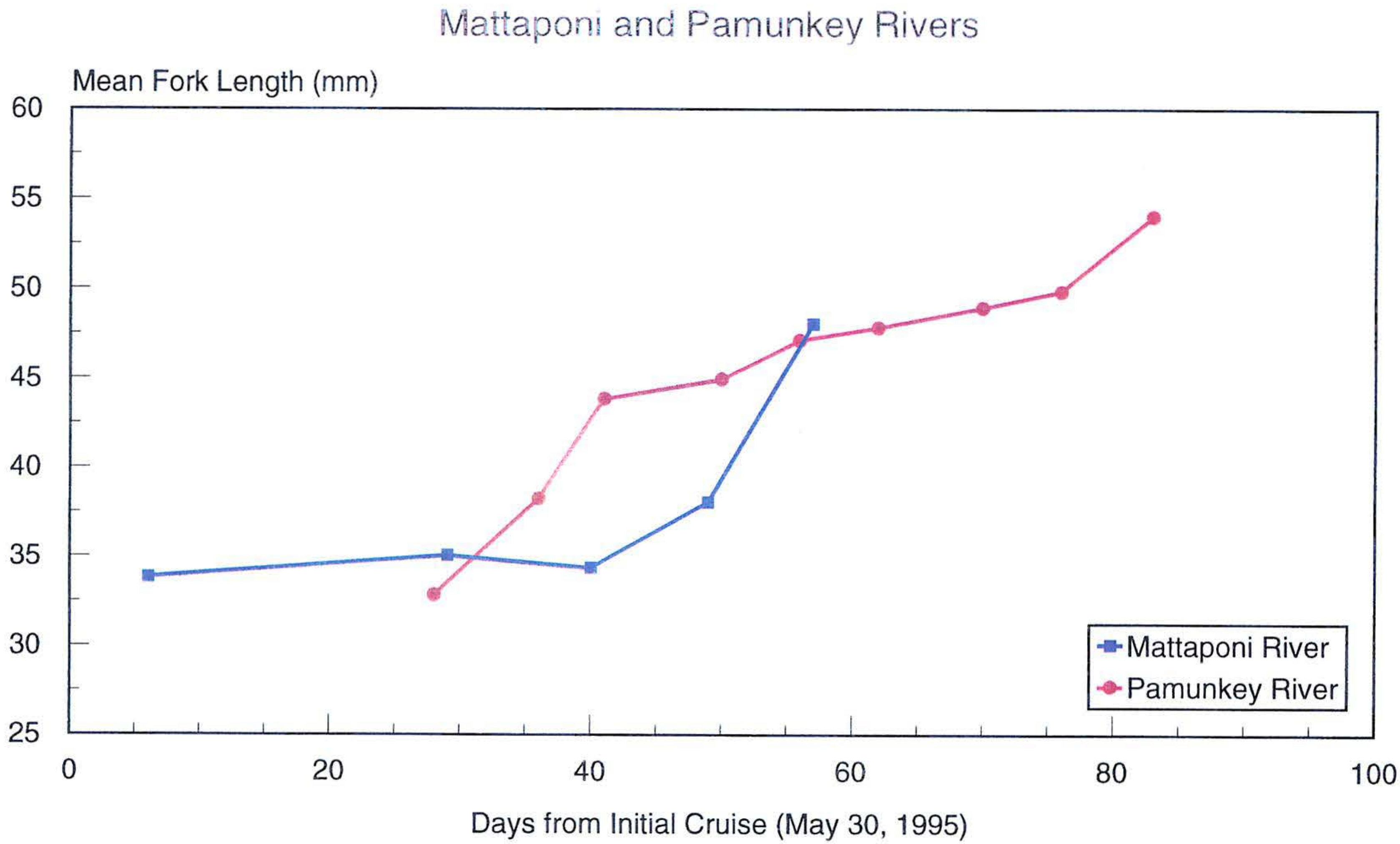
Figure 9. Juvenile American Shad Index: 1979-1996

Mattaponi and Pamunkey Rivers



No sampling 1988-89; insufficient data 1990.

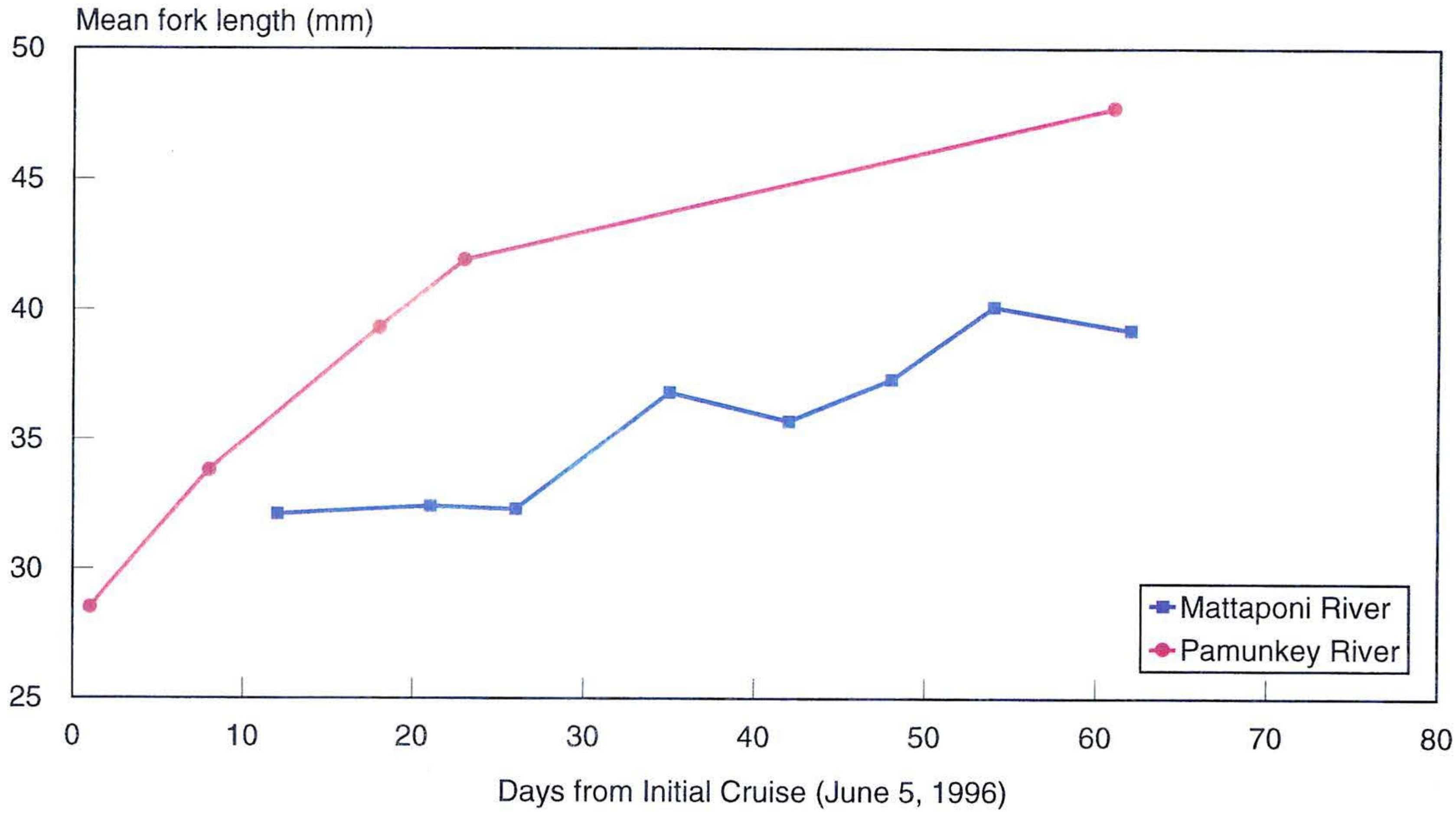
Figure 10a. Mean length of Juvenile Blueback Herring: 1995



Note: 27mm is gear minimum size

Figure 10b. Mean Length of Juvenile Blueback Herring: 1996

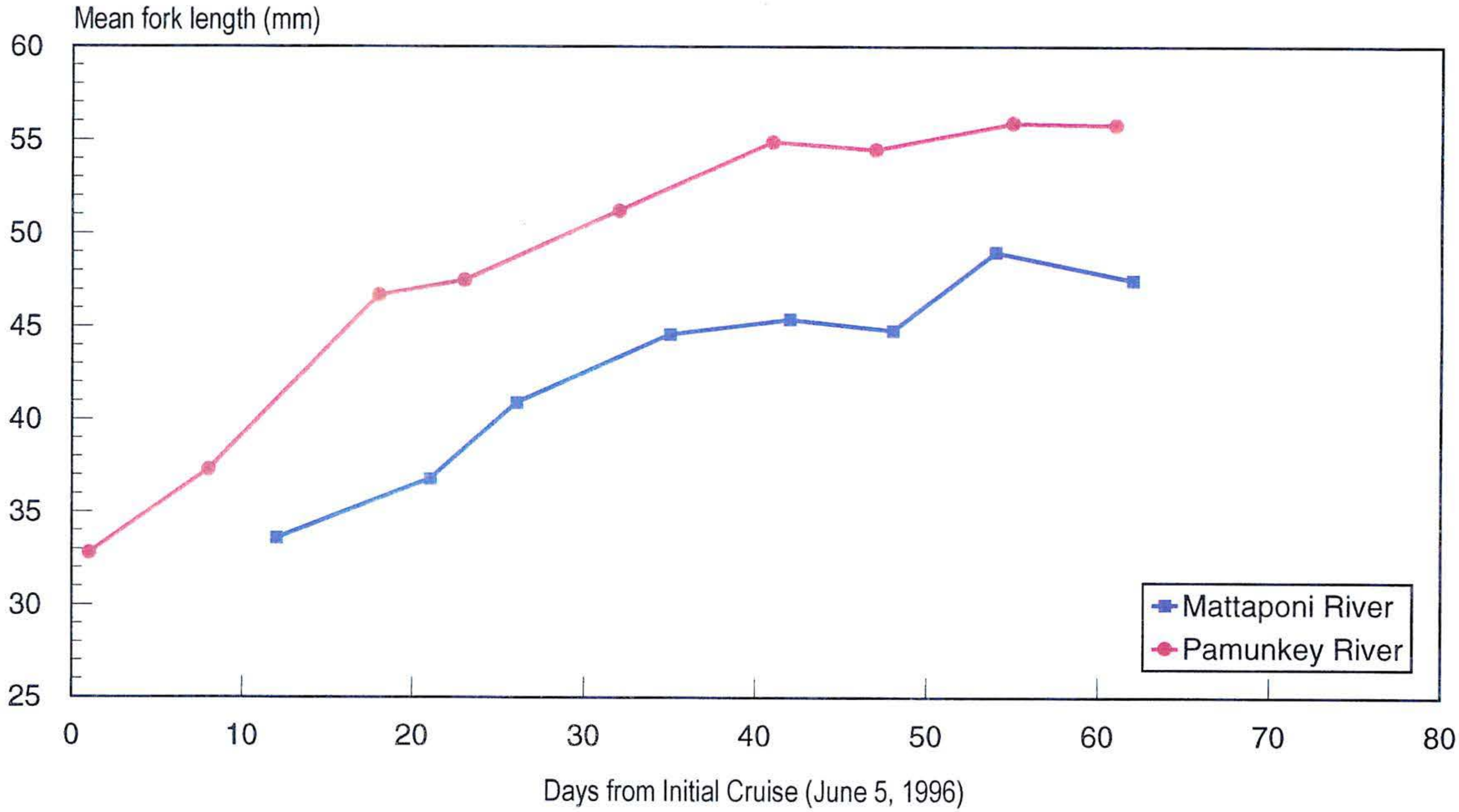
Mattaponi and Pamunkey Rivers



Note: 27mm is gear minimum size

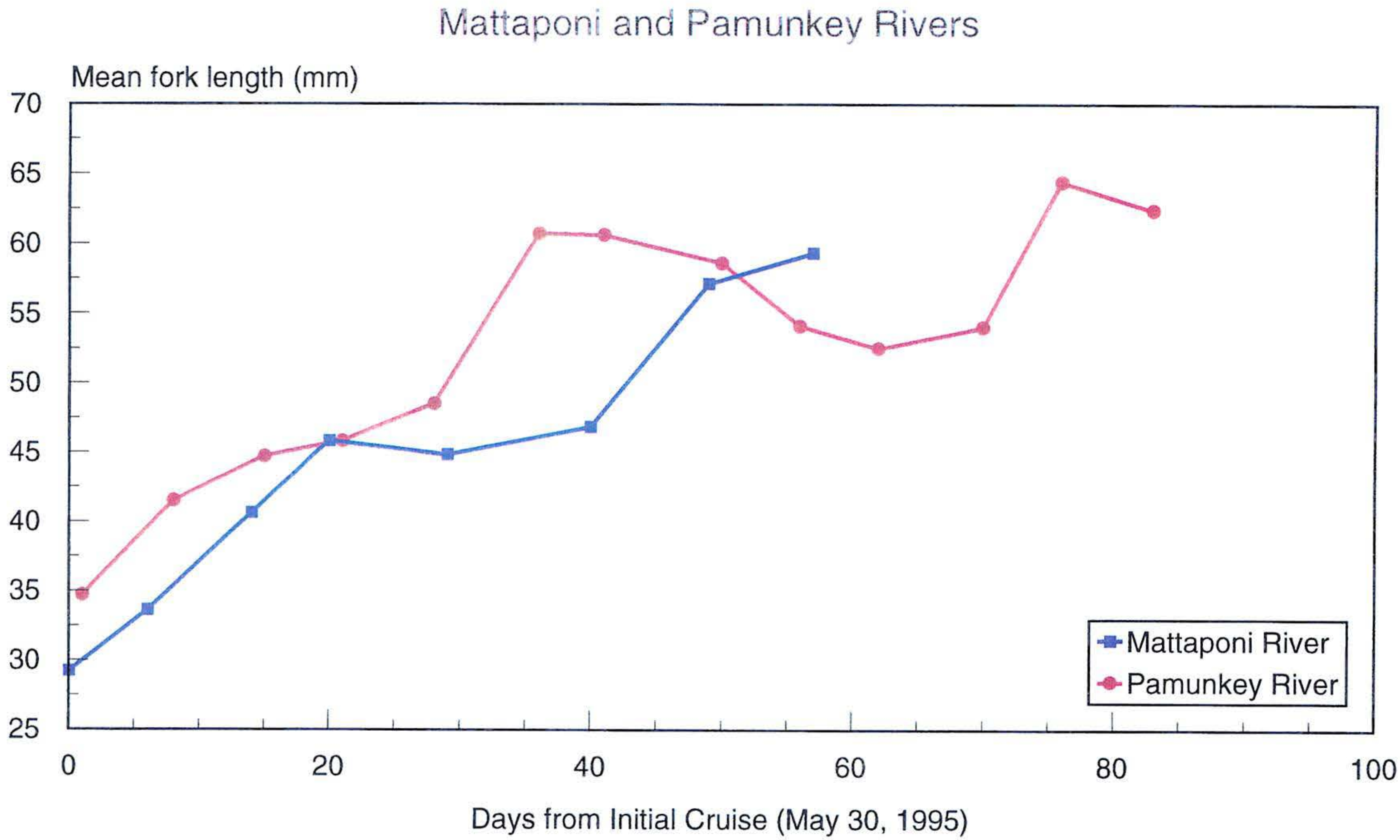
Figure 11. Mean Length of Juvenile Alewife: 1996

Mattaponi and Pamunkey Rivers



Note: 27mm is gear minimum size

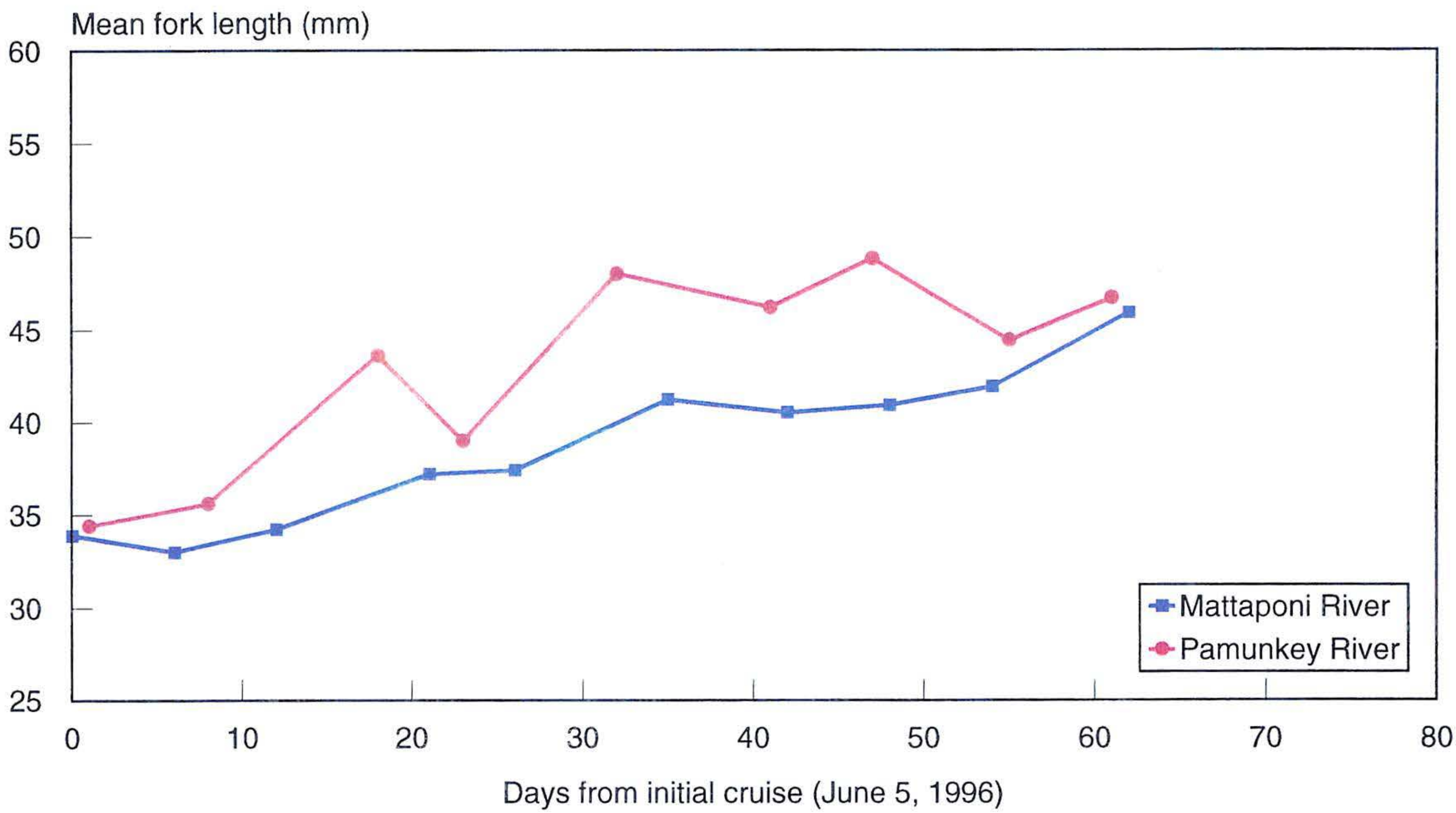
Figure 12a. Mean Length of Juvenile American Shad: 1995



Note: 27mm is gear minimum size

Figure 12b. Mean Length of Juvenile American Shad: 1996

Mattaponi and Pamunkey Rivers



Note: 27mm is gear minimum size