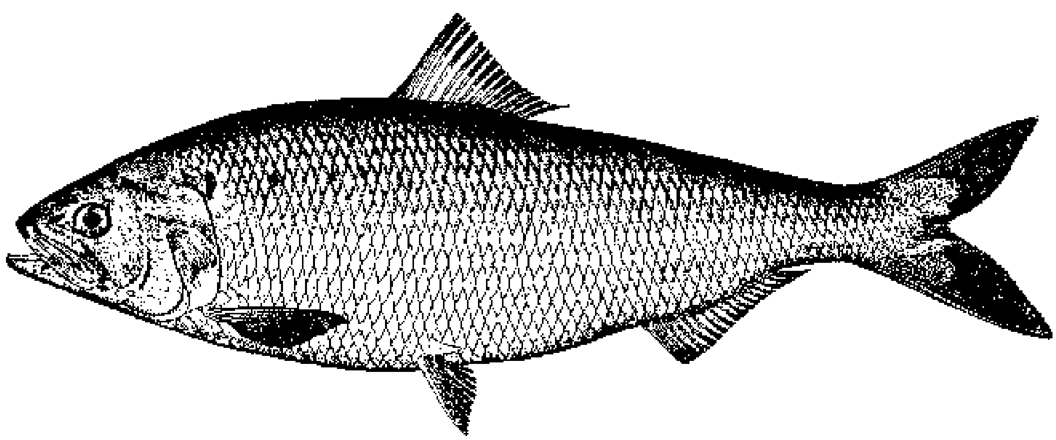
Atlantic States Marine Fisheries Commission

American Shad Stock Assessment

Peer Review Report



March 1998

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PREFACE

This is a report of the Atlantic States Marine Fisheries Commission pursuant to U.S. Department of Commerce, National Oceanic and Atmospheric Administration Award Nos. NA87 FGO 025 and NA97 FGO 0034.

OVERVIEW

The Stock Assessment Peer Review Process, adopted in May 1997 by the Atlantic States Marine Fisheries Commission, was developed to standardize the process of stock assessment reviews and validate the Commission's stock assessments. The purpose of the peer review process is to: 1) ensure that stock assessments for all species managed by the Commission periodically undergo a formal peer review; 2) improve the quality of Commission stock assessments; 3) improve the credibility of the scientific basis for management; and 4) improve public understanding of fisheries stock assessments. The definition of stock assessment adopted for this process includes model development, parameter development, and data review.

The Stock Assessment Peer Review Process report outlines four options for conducting a peer review of Commission managed species. These options are, in order of priority:

1) The Stock Assessment Workshop/Stock Assessment Review Committee (SAW/SARC) conducted by the National Marine Fisheries Service (NMFS), Northeast Fisheries Science Center (NEFSC).

2) A Commission stock assessment review panel composed of 3-4 stock assessment biologists (state, federal, university) will be formed for each review. The Commission review panel will include scientists from outside the range of the species to improve objectivity.

3) A formal review using the structure of existing organizations (i.e. American Fisheries Society (AFS), International Council for Exploration of the Sea (ICES), or the National Academy of Sciences).

4) An internal review of the stock assessment conducted through the Commission's existing structure (i.e. Technical Committee, Stock Assessment Committee).

Twice annually, the Commission's Interstate Fisheries Management Program (ISFMP) Policy Board prioritizes all Commission managed species based on species Management Board advice and other prioritization criteria. The species with highest priority are assigned to a review process to be conducted in a timely manner.

In October 1997, American shad and Atlantic sturgeon were prioritized for an external peer review to be conducted in early 1998. An external review panel was formed of four stock assessment biologists with expertise in anadromous species. Panel members included Dave Perkins, US Geological Service; Roger Rulifson, East Carolina University; Ray Schaffter, California Department of Fish and Game; and Saul Saila, University of Rhode Island (retired). Dr. Saila was unable to attend the review.

Terms of reference were developed for both species and were used to focus discussions during a three day meeting (March 17-19, 1998) to review stock assessments for American shad and Atlantic sturgeon. This Stock Assessment Peer Review Report includes all details of the stock assessment conducted for American shad, including data inputs, model parameters, assessment results, and management advice. A supplementary Terms of Reference and Advisory Report is also available, which provides the peer review panel comments and advice on each specific term of reference. If you are interested in obtaining copies of the Stock Assessment Peer Review Report for Atlantic sturgeon or either of the Terms of Reference and Advisory Reports, please contact Dr. Lisa L. Kline at (202) 289-6400 or lkline@asmfc.org.

The major portion of the Shad Stock Assessment Peer Review Report is the stock assessment report of American shad from selected Atlantic coast rivers, drafted by Victor Crecco, Chairman of the Commission's Shad and River Herring Stock Assessment Subcommittee. Several ancillary reports are also appended, including: 1) Stock Status and Definition of overfishing Rate for American Shad of the Hudson River Estuary, drafted by Kathryn Hattala and Andrew Kahnle; 2) Stock Contributions for American Shad Landings in Mixed Stock Fisheries Along the Atlantic Coast, drafted by K. Hattala, R. Allen, N. Lazar, and R. O'Reilly; and 3) Review of American Shad Petersen Population Estimates for the Upper Chesapeake Bay, 1980-1997, drafted by the Maryland Department of Natural Resources. We would also like to recognize the contributions of various Commission staff members who contributed a great deal of time and effort to the peer review meeting and completion of reports, including Tina Berger, Jeffrey Brust, John Field, Lisa Kline, Vanessa Jones, and Heidi Timer.

These reports were presented to the Commission's American Shad and River Herring Technical Committee and Management Board prior to submission to the Peer Review Panel. As of March 1998 the information contained in these reports was current. However, these committees have continued to update the data contained in these reports so as to maintain and improve the management of these species. As such, portions of these reports may have been updated since the peer review and more comprehensive analyses may have been conducted.

EXECUTIVE SUMMARY

Given the pronounced drop in coastwide shad landings and stock abundance from several Atlantic coast rivers after 1990, a revised stock assessment is clearly warranted to determine the root cause(s) of the recent shad declines along the Atlantic coast. In this report, the Shad Stock Assessment Subcommitee (SSAS) estimated an overfishing definition (F_{30}), stock trends, and current and historic coastal (F_c) and inriver (F_r) fishing mortality rates on American shad from 19 selected stocks or river systems located from Maine Rivers in the north to the Altamaha River, GA to the south. Trends in total mortality (Z), which include fishing and natural mortalities, were examined for the Pawcatuck River RI, Upper Chesapeake Bay MD and tributaries of Albemarle Sound NC. The SSAC also examined trends in commercial landings for Maine Rivers, as well as for North Carolina Rivers (Albemarle Sound, Neuse, Pamlico and Cape Fear Rivers) and South Carolina Rivers (Waccamaw - Pee Dee, Savannah, Edisto and Santee Rivers). The SSAS examined trends in relative adult stock abundance in the Merrimack River MA-NH based on fishway counts and for Virginia Rivers (James,York and Rappahannock Rivers) based on commercial catch-per-effort (CPUE). The Thompson-Bell yield-per-recruit (YPR) model was used to estimate the overfishing definition (F_{30}) for each shad stock.

Based on historic trends in commercial CPUE, fishway counts, and population estimates, there is evidence of recent (1992-96) and persistent stock declines in 2 of 12 rivers or systems (Hudson River NY and York River VA). Stock declines were evident in the Pawcatuck River RI from 1992 to 1994, but stock abundance has risen sharply in the Pawcatuck during 1995 and 1996. Similarly, although shad stock abundance in the Connecticut River had declined to low levels from 1992 to 1995, stock size has risen steadily in 1996 and 1997 to levels approaching the long-term average (800,000 fish). Inriver commercial landings in the Edisto River SC have declined since 1990, but shad stock abundance in the Edisto exhibited no apparent decline from 1989 to 1996. This strongly suggests that the drop in commercial landings in the Edisto River was largely due to a reduction in fishing effort and not stock abundance. There was no evidence of recent stock declines for seven additional stocks including the Merrimack River MA-NH, the Delaware River DE-NJ, Upper Chesapeake Bay tributaries MD, Rappahannock River VA, James River VA, Santee River SC and the Altamaha River GA. Presumed stock declines inferred solely from declining trends in inriver commercial landings were evident for seven additional stocks including the Neuse NC, Pamlico NC, Cape Fear NC, Waccamaw-Pee Dee SC and Savannah Rivers SC, for tributaries of Albemarle Sound NC, as well as for rivers in the state of Maine.

Recent (1992-96) coastal fishing mortality rates (F_c) on seven shad stocks (Connecticut, Hudson, Delaware, Upper Bay Edisto, Santee and Altamaha Rivers) were relatively low (F_c range: 0.02 to 0.24) and well below overfishing definitions (F_{30} range: 0.39 - 0.48). Average (1992-96) total fishing mortality rates (F_t), which include inriver and coastal fishing mortalities, were below overfishing definitions (F_{30}) for all seven shad stocks for which inriver (F_r) and coastal (F_c) fishing rates could be estimated. The recent (1994-97) average F_t level (F_t = 0.45) on Edisto River shad was only slightly below the overfishing definition (F_{30} = 0.48) for southern stocks, indicating that fishing mortality rates on Edisto shad should be monitored closely over the next few years. Based on the analysis of seven shad stocks (Connecticut, Hudson, Delaware, Upper Bay Edisto Santee and Altamaha Rivers), there is no evidence thus far that the coastal intercept fishery has had an adverse impact on shad stock abundance along the Atlantic coast.

There are no direct fishing mortality estimates (F) on the Pawcatuck River stock. However, total mortality rates (Z) declined by about 50% in the Pawcatuck River between 1989 and 1992. Fishing mortality rates have apparently not increased on the Pawcatuck shad stock since Z estimates have not risen recently. This suggests that the recent (1992-94) stock decline in the Pawcatuck was not due to overfishing. The ability to rule out overfishing for the Pawcatuck River stock is tempered somewhat by the fact that no stock origin studies have ever been conducted on the coastal Rhode Island shad landings which, in theory, could easily have overharvested the small (stock size: 1000 to 2000 fish) Pawcatuck stock. Moreover, total mortality (Z) estimates are not available for the Pawcatuck stock after 1992. In order to address potential overfishing in the Pawcatuck, it would be beneficial to estimate fishing mortality (F) directly and to conduct a tagging study on the Rhode Island coastal fishery to determine stock origin.

Relative exploitation rates (u_{rel}) from the coastal intercept fishery on the York, Rappahannock and James Rivers VA exhibited no apparent trends from 1980 to 1993. This suggests that the coastal intercept harvest was not related to the shad stock declines in the York and Rappahannock Rivers. The ability to directly link the coastal intercept fishery to stock declines for these rivers is somewhat limited by the lack of CPUE data in 1994, 1995 and 1996, and by the fact that relative exploitation rates cannot be directly compared to the overfishing definition (F_{30}). In addition, it is difficult to assess recent trends in relative exploitation on the Rappahannock or James River origin shad because shad fishing effort declined markedly in these rivers by as compared to the 1980-85 period.

There are no direct estimates of current fishing mortality (F) for seven rivers that have exhibited a recent decline in shad landings. These include shad stocks from Maine Rivers, Albemarle Sound NC, Neuse River NC, Pamlico River NC, Cape Fear River NC, Waccamaw-Pee Dee River SC, and the Savannah River SC. Given the limitations in using landings trends to infer stock trends, there is no way to adequately link inriver and coastal fisheries with presumed stock declines in these rivers. Total mortality estimates (Z) have been estimated for shad tributaries of Albemarle Sound between 1980 and 1995. Since these Z estimates have varied without trend, there is no indication that a rise in fishing mortality was related to the decline in commercial shad landings in Albemarle Sound.

Shad stock sizes in the Hudson River have declined rather steadily from 1988 to 1996, although current average F (mean F = 0.33) was still below the estimated overfishing definition (F_{30} = 0.39). As a result, the Hudson River stock is considered to be fully exploited. Shad stock abundance in the Merrimack River, Santee River SC, Altamaha River GA, Delaware River and Upper Bay Rivers MD have either recently risen to high levels (i.e. Santee, Altamaha and Upper Bay stocks) or have remained stable (i.e. Delaware and Merrimack stocks). Current (mean 1992-96) fishing mortality rates (F_t) on these stocks have either approached the overfishing definition

(F_{30} level) (i.e. as in the case of the Altamaha and Edisto stocks), or were far below the estimated F_{30} level (i.e. as in the case of the Upper Bay, Delaware and Santee River stocks). No fishing mortality estimates are available for the Merrimack River stock.

There is no evidence of recent (1990-96) recruitment failure for any of the eight shad stocks (Maine Rivers, Pawcatuck, Connecticut, Hudson, Delaware, Upper Bay Tributaries, Altamaha and Virginia Rivers) for which a continuous time series of juvenile indices could be examined.

This assessment estimated fishing mortality (F) rates for nine shad stocks and general trends in abundance for 13 American shad stocks. The total range of extant American shad populations includes additional populations in small river systems, as well as depleted populations in larger river systems that are actively being restored. Also, much historical and habitat is currently vacant and may be targeted for restoration in the future. For these stocks, individual states have targeted minimal fishing mortality to protect small stocks and rebuild others. This assessment cannot quantitatively address these systems because of limited biological data, as well as associated uncertainties in stock composition of small populations in these fisheries. Like all mixed stock fisheries, small stocks can be at risk under these conditions.

TERMS OF REFERENCE

1) Estimate natural mortality (M) for American shad stocks by major river system or geographic region (ME-CT, NY-VA, NC-FL)

2) Assess relative status of American shad stocks in the Merrimack, Pawcatuck, Connecticut, Hudson, Delaware, James, York, Rappahannock, Edisto, Santee, and Altamaha Rivers through analysis of fishway counts, mark/recapture techniques, hydro acoustic surveys, or commercial catch per unit effort data.

3) Review population estimates of American shad in the Upper Chesapeake Bay based on mark-recapture techniques.

4) Review biological reference points, coastal fishing mortality, and in-river fishing mortality (sexes combined) for the Connecticut, Hudson, Delaware, Upper Chesapeake Bay, Edisto, Santee, and Altamaha Rivers.

5) Evaluate the risk of mixed stock (ocean intercept) fisheries to depleted and hatchery-supplemented stocks, given the assumed stock contributions to ocean landings.

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INTRODUCTION

The American shad (*Alosa sapidissima*) is an anadromous clupeid that spawns mainly during spring in many Atlantic coast rivers from winter to summer (Walburg and Nichols 1967). Many of these spawning runs have been subjected to inriver commercial and recreational fisheries of varying magnitude. The reported inriver commercial landings currently (1996) account for about one-third of the total reported USA commercial landings of American shad (Hattala 1997). The total inriver commercial landing have declined steadily from over 3.2 million pounds in 1980 to less than 600,000 pounds in 1996 (Figure 1). American shad are also harvested primarily by gillnets from a coastal intercept commercial fishery that takes place during spring from Florida to Maine. These intercept landings rose steadily from 1980 to a peak of 2.0 million pounds in 1989, then declined thereafter to about a million pounds in 1996 (Figure 2). Moreover, shad population abundance in the Hudson, Connecticut and Pawcatuck Rivers recently has (1990 to 1995) declined to low levels (Hattala 1995; Crecco 1995; Powell 1995). The underlying cause(s) for the widespread decline in shad landings may differ regionally, and may be due to several factors including overfishing, enhanced striped bass predation, changes in abiotic conditions and a drop in commercial fishing effort.

The most recent shad assessment was conducted by the Commission (Gibson et al. 1988) in 1987 on 12 shad stocks located from Rhode Island to Florida. The results indicated that the average maximum sustainable harvest rate (u_{msy}), the previous overfishing definition, for 12 American shad stocks was about 0.50 (ie a 50% harvest rate, F_{msy} = 0.69). Except for the Susquehanna shad stock in the mid-1970's, the estimated annual fishing mortality rates (u) from the other 11 shad stocks during the mid-1980's were below the u_{msy} level of 0.50. The 1987 assessment also indicated that relative and absolute stock sizes from 10 shad stocks were either increasing or were stable from 1980 through 1986, whereas stock abundance from two southern shad stocks (Tar-Pamlico and Cape Fear stocks) had declined steadily from 1980 through 1986 under moderate fishing pressure. The major conclusions from the 1987 assessment were that overfishing was not occurring during the early to mid-1980's, and that stock sizes were generally stable along the Atlantic coast.

Given the persistent drop in coastwide shad landings and stock abundance from several Atlantic coast rivers after 1990, a revised stock assessment is clearly warranted. An assessment is needed to determine which shad stocks have exhibited the greatest declines, and determine the root cause(s) for these declines along the Atlantic coast (Rulifson 1994). In this report, an overfishing definition (F_{30}), relative and absolute stock trends and current and historic fishing mortality rates (F) were estimated on American shad from 19 selected stocks from Maine Rivers in the north to the Altamaha River, GA in the south (Table 1). Trends in total mortality (Z), which include fishing and natural mortalities, were examined for the Pawcatuck River RI and tributaries of Albemarle Sound NC. The SSAC also examined trends in commercial landings and juvenile shad abundance for rivers in the state of Maine. The SSAS examined trends in relative adult stock abundance in the Merrimack River MA-NH based on fishway counts and for the York, Rappahannock and James Rivers VA based on commercial catch-per-effort.

Because of potential overharvest associated from the coastal intercept fishery, an effort was made to estimate coastal (F_c) fishing mortality rates on each shad stock. The Shad Stock Assessment Subcommittee (SSAS) (Hattala et. al. 1997) separated the 1980-96 coastal landings (Table 2) by river system or by state (Tables 4 and 5) based on available tagging and recent mitochondrial DNA studies (mtDNA) (Brown and Epifanio 1994). This assessment by the SSAS was based on trends in population estimates, fishway counts, commercial landings catch-per-unit-effort (CPUE) and juvenile abundance indices. Direct inferences about overfishing were made on only those shad stocks (ie Pawcatuck, Connecticut, Hudson, Delaware, Upper Bay, James, York, Rappahannock, Edisto, Santee, Altamaha Rivers) for which estimated stock trends, total mortality (Z), relative exploitation and fishing mortality rates (F) were available. Trends in commercial landings data were used to evaluate stock conditions only for selected shad rivers in North Carolina (Albemarle Sound tributaries, Cape Fear River, Neuse River and Pamlico Rivers) and South Carolina (Savannah and Waccamah-Pee Dee Rivers). This was necessary because no CPUE and fishway counts data were made available on these stocks to the SSAS. The SSAS also examined trends in the spawning population in the Merrimack River MA-NH based on fishway counts, as well as changes in commercial CPE from the York, Rappahannock and James Rivers, Virginia. A particular stock was determined to be overfished if shad stock abundance declined recently (1992-1996) under total fishing mortality rates ($F_t = F_c + F_r$) that exceeded the overfishing definition (F_{30}).

METHODS

Abundance and Fishing Mortality Data

In this report, a combination of commercial landings, nominal fishing effort, catch per effort (CPUE), fishway counts, population estimates, juvenile abundance and age structure data were used to reconstruct population abundance and fishing mortality trends for each of the 19 shad stocks (Table 1, Appendix 1 to 11). The quality and quantity of shad data differed greatly among the 19 stocks (Table 1). Conclusions based solely on declining historic trends in shad landings can be very misleading without considering changes in the ratio of landings to fishing effort (i.e. CPUE). For this reason, an assessment of stock trends was based on changes in abundance derived from population estimates, fishway counts and commercial landings CPUE rather than solely from commercial landings data. If overharvest is an underlying cause for a stock decline in a particular river, the recent (1992-96) average total fishing mortality rates (F_t) generated by inriver and coastal commercial fisheries should exceed the overfishing definition (F_{30}).

Given the high level of uncertainty associated with commercial landings and in certain population estimates, a stock was considered depleted if commercial landings, stock abundance and/or CPUE displayed a qualitative decline from 1992 to 1996. No time series and regression analyses were performed to more rigorously determine a recent stock decline. Since a recent decline in shad commercial landings can be due to reduced fishing effort and/or to a decline in stock abundance, the assessment of stock condition based on landings trends was made (ie North Carolina Rivers and certain South Carolina Rivers) only when relative (CPUE) or absolute abundance data were lacking. Given below is a description of the data sets and methods used to estimate stock abundance, recruitment, nominal fishing effort and fishing mortality rates (F) for each shad stock.

Coastal Intercept Commercial Fisheries

Because coastal commercial intercept landings of American shad are composed of numerous shad stocks (Talbot and Sykes 1958; Harris and Rulifson 1989; Brown 1992), the contribution of each shad stock to the coastal intercept landings and its effect on total fishing mortality (F_t) on each stock needed to be estimated. The problem of separating the coastal landings by time (year) and space (stock) has been confounded by the limited number of tagging and mitochondrial DNA (mtDNA) studies on the shad intercept fishery since 1960. After considering the many limitations in the mtDNA and coastal tagging studies, the SSAS attempted to estimate the contribution of the 1980-96 coastal intercept shad landings by state or river system by combining the results of a recent mitochondrial DNA (mtDNA) study (Brown and Epifanio 1994) with various tagging studies from the coastal intercept fisheries (Hattala et. al. 1996, Parker 1992, Krantz et. al. 1992, Jesian et. al. 1992, McCord 1987 and Nichols 1958). Please refer to the document by Hattala et. al. (1997) for specific details on how the coastal intercept landings were decomposed into states and river systems from 1980 to 1996. The annual commercial intercept landings (pounds and numbers) (Tables 3 and 4) from each states or river system were estimated as the product of the average fractional contribution of the landings from each system based on coastal tagging and mtDNA studies (Hattala et. al. 1997 for details) and the reported coastal landings from each state (Table 2).

Maine

American shad juvenile indices (mean catch/ seine haul) of abundance have been monitored from five Maine river systems (Kennebec River, Androscoggin River, Merrymeeting Bay, Eastern River and Cathance River) from 1979 to 1995 (Squires 1995) (Appendix 1). An overall juvenile shad index for each year was derived as the arithmetic mean index for all five rivers combined (unweighted). Coastal commercial shad landings (lbs.) are also available from 1951 to 1995 (Figure 4). There are no fishing effort data or estimated fishing mortality rates (F) on shad for the state of Maine.

Merrimack River MA-NH

Fishlift data at the Essex Dam have been used to monitor relative shad population trends in the Merrimack River from 1980 through 1995 (Brady 1995). A more effective adult shad abundance index was derived as a ratio of shad numbers lifted annually and the number of days in which the Essex Dam lift had been operating from 1980 to 1995 (Appendix 2). There are no fishing effort data, commercial landings or estimated fishing mortality rates (F) on shad from the Merrimack River.

Pawcatuck River RI

Population estimates based annually on fishlift counts at the Potter Hill Fishladder on the Pawcatuck River were available from 1970 through 1996 (Gibson et al. 1988; Powell 1995). Juvenile indices (catch/seine haul) in the Pawcatuck River have been made annually in 1977-78 and from 1985 to 1996 (Appendix 3). Adult recruitment estimates (contribution of virgin adults) also have been derived for the 1974-1990 year-classes based on age composition and adult lift counts from 1970 to 1996 (Gibson et al. 1988). Total mortality rates (Z) among adult shad have been estimated annually from 1979 through 1992 based on the log survival ratio of repeat spawners in year t+1 to the total adult stock in year t (Gibson et al. 1988; Powell 1995). There are no commercial landings and fishing effort data in the Pawcatuck River. Since there have been no tagging studies conducted on the Rhode Island coastal shad landings, we were unable to determine the contribution of the Pawcatuck stock in these coastal landing

Connecticut River CT-MA

The state of Connecticut has monitored shad abundance (pounds and numbers), age structure and spawning history in the Connecticut River from 1966 through 1996. This has been done by population estimates based on mark-recapture studies combined with annual fishway counts and age subsampling at the Holyoke lift (Appendix 4) (Crecco and Savoy 1987; Crecco 1995). Juvenile production (mean catch/seine haul) in the Connecticut also has been monitored from 1966 through 1996 by annual beach seine surveys (Appendix 3). Adult recruitment to the spawning population from the 1966-1982 year-classes has been estimated in the Connecticut River based on the age structure of the shad populations from 1970 to 1988. The adult recruitment estimates from 1966 to 1982 were highly correlated ($r = 0.82$, $P<0.01$) to the juvenile indices which produced them, indicating that juvenile production estimates were a useful predictor of future stock size.

Inriver fishing mortality rates (F_r) have been estimated from 1970 to 1996 (Appendix 4) as a log ratio (seasonal fishery) of commercial landings (adjusted for 50% reporting rate and discard of male shad) in numbers (CL) plus the riverwide recreational harvest in numbers (RL) divided by stock size (N):

$$F_r = - \log 1 - (CL+RL/(N)). \qquad (1)$$

Crecco and Savoy (1986) found that inriver commercial shad landings (CL) had been under-reported or discarded to the State by between 35 and 67% from 1979 to 1983 based on the ratio of tag returns to the reported commercial landings.

The contribution of Connecticut River shad to the coastal intercept fishery between 1980 and 1996 (Tables 3 and 4) was based on the coastal landings from Virginia to Maine (Table 2) and the combined tagging and mtDNA results (Hattala et. al. 1997). More specifically, the coastal landings that were estimated from the Connecticut River shad stock was the sum of the VA-MD coastal harvest (times 0.064 and 0.03), the DE-NJ coastal landings (times 0.188), and the NY-NE coastal landings (times 0.50). Since landings underreporting and discard have been documented for the inriver commercial fishery, the coastal intercept landings in number (CCL) (assumed average weight = 5.0 lbs.) from the Connecticut River stock (Table 5) were also adjusted up to reflect a 50% reporting rate and discard rate of male shad. Given that the coastal landings were assumed to occur before the spawning stock enters the River, the coastal fishing mortality rates (F_c) on Connecticut River shad were also estimated by adding the coastal landings (CCL) (Table 4) to the population estimate (N) in equation 1:

$$F_c = - \log (1 - (CCL/(CCL+N))). \qquad (2)$$

The total fishing mortality rate (F_t) on Connecticut River shad was estimated between 1980 and 1995 by adding F_r and F_c.

Spawning stock biomass (SSB) for Connecticut River shad was estimated by firstly, converting stock size in numbers (N) and catch in numbers (N) to weight by multiplying these values by 5.0 lbs. and then subtracting the catch in weight from stock size in weight (Appendix 4).

Hudson River NY

The state of New York (NY DEC) has monitored shad relative abundance and age structure in the Hudson River from 1980 through 1995 based on commercial gillnet catch per effort (CPUE) and CPUE from spawning stock seine surveys (Appendix 5) (Hattala 1995). Juvenile shad recruitment in the Hudson also has been monitored from 1980 through 1994 by annual beach seine surveys (Appendix 5). In addition, postlarval relative abundance (catch/tow) from 1974 through 1992 has been monitored by Con. Ed. Utilities. Since there is a strong positive correlation ($r = 0.85$, $P<0.002$) between the NYDEC juvenile and utilities postlarval indices between 1980 and 1992, the postlarval indices were chosen as a recruitment index because the utilities indices represent a longer time series (Appendix 5).

There is a long time series (1980-96) of commercial shad landings and nominal fishing effort (either licensed gillnet yd.^{2} or licensed ft.) data, including the number of closed hrs./week, in the Hudson River (Hattala 1995) (Appendix 5). Klauda et al. (1976) generated catch/effort data (catch/gillnet yds.^{2}) for American shad from 1931-1975. Fishing effort in the Hudson from 1980 to 1995 was expressed as either licensed gillnet ft. or gillnet yds.^{2}. There is a significant positive regression between commercial fishing effort expressed as yds.^{2} and ft. from 1932 to 1964 ($r = 0.94$, regression: ft. = 4.43*yds.^{2}**0.70). Using this regression, fishing effort (E) expressed as gillnet yds.^{2} in certain years were then converted to licensed ft. and then multiplied by the season length from 1980 to 1995 (Appendix 5). Since fishing effort data on Hudson River shad are not yet available for 1996, the 1995 effort estimate (176.4 gillnet yds.^{2}) was used as an effort estimate in 1996.

Talbot (1954) estimated shad population size and harvest rates (u) in the Hudson River from 1940 to 1951 by estimating the catchability coefficient (q) from a single tag-recapture study in 1951. Talbot (1954) estimated shad stock size assuming that the estimated q in 1951 remained constant over time. Fredin (1954) estimated the size of the nearby Connecticut River shad population from 1940 to 1951 with the same methods as Talbot (1954) for the Hudson. The results showed that, on average, the Hudson shad stock was 2.9 times larger than the Connecticut River shad stock from 1940 to 1951 (Appendix 5). From these data, the scale of difference (i.e. 2.9) between the average size of the Connecticut and Hudson stock can be established (Appendix 5). However, as will be shown below, the magnitude of the population sizes in the Connecticut (Fredin 1954) and Hudson Rivers (Talbot 1954) was greatly underestimated.

Leggett (1976) studied shad in the Connecticut River and reported that the Petersen disc tags used in Talbot's (1954) and Fredin's (1954) tagging studies caused tagged shad to be more susceptible to the gillnets, resulting in an 45% overestimate of q in the Hudson and Connecticut Rivers. For this reason, the q estimate from Talbot (1954) ($q = 0.0035$) was reduced by 45% ($q = 0.0019$). Crecco and Savoy (1981) tagged shad in the Connecticut River from a pound net (nonselective gear) in 1980 and concluded that the catchability coefficient (q) used by Leggett (1976) based on gillnet sampling was overestimated by about 100%. This was because the gillnet mesh (5.5 in. mesh) used for tagging by Leggett (1976) selected for the larger female shad which resulted in too many recaptures from commercial gillnets and population estimates that were greatly underestimated. For this reason, the catchability coefficient (q) in the Hudson River was further reduced (q = from 0.0019 to 0.00093) (Appendix 5) to reflect the gillnet selectivity bias in Talbot (1954). Shad population size in lbs. (N) in the Hudson from 1980 to 1996 was estimated with commercial landings (C) adjusted for underreporting (50% reporting rate as per the Connecticut River), fishing effort (E = licensed ft.* open season) and the adjusted catchability coefficient (q = 0.00093):

$$N = C / (1 - \exp - (q * E)). \qquad (3)$$

The accuracy of equation 3 to estimate stock size (N) depends on the assumption that the catchability coefficient (q) is either constant over time, or is unrelated to stock size and fishing effort (E). Although Crecco and Savoy (1985) reported that q was inversely related to shad stock size in the Connecticut River, the degree of bias in stock reconstruction of the Connecticut stock with equation 3 was not sufficiently high to have altered historic trends from 1940 to 1973 (Leggett 1976).

Inriver fishing mortality rates (F_r) were estimated on Hudson River shad from 1980 to 1996 (Appendix 5) as a log ratio (seasonal fishery) of adjusted commercial landings in numbers (CL) divided by stock size (N):

$$F_r = - \log 1- (CL/(N)). \qquad (4)$$

In an effort to corroborate shad population abundance in the Hudson River based on Talbot (1954), the NYDEC has conducted tag-recapture studies on Hudson River shad from 1995 to 1997 (Kathy Hattala pers. comm.). The preliminary population estimate of adult shad in 1995 was 750,000 fish (Hattala 1997). Given the adjusted (i.e. for underreporting) inriver commercial shad landings in numbers of 79,583 fish in 1995, the inriver annual harvest rate (u) in 1995 was estimated to be 0.00062) as a ratio between the 1995 F (F_r=0.11) and the 1995 fishing effort (176.4 gillnet yds.[2]). This revised q estimate was then substituted into equation 3 to estimate an additional time series of stock sizes from 1980 to 1996. An additional time series of inriver fishing rates (F_r) were also generated with the new stock estimates (N) from the 1995 q estimate (q = 0.00062) and the adjusted commercial landings (equation 4).

Shad spawning biomass (SSB) in the Hudson between 1980 and 1996 was estimated by subtracting the adjusted commercial landings (C) from the population estimate (N) (Appendix 5). Assuming an average weight of 4.8 lbs. per fish, shad stock size in weight (N) was converted to numbers (N_t). Inriver fishing mortality (F_t) on Hudson River shad was estimated as a log ratio between landings (C) and stock size (N) (equation 1).

The coastal intercept landings in number (CCL) (assumed average weight = 4.8 lbs.) attributed to the Hudson River stock (Tables 3 and 4) were based on coastal tagging and mtDNA studies from NC to Maine (Hattala et. al. 1997) and the coastal landings from those states (Table 2). These coastal commercial landings were also adjusted up to reflect a 50% reporting rate and discard rate. Since the coastal landings were assumed to occur before the spawning stock enters the Hudson, the coastal fishing mortality rates (F_c) on Hudson River shad were estimated by adding the coastal landings (CCL) (Table 4) to the population estimate (N) in equation 2. The total fishing mortality rate (F_t) on Hudson River shad was estimated between 1980 and 1996 by adding F_r and F_c.

Shad adult recruitment from 1974 to 1994 was estimated by scaling the utility postlarval index (Appendix 5) to the magnitude of the adult stock size between 1974 and 1994, assuming a 50% average repeat spawning rate based on the observed spawning history data from 1984 to 1991 (Hattala 1995).

Delaware River DE-NJ

The states of New Jersey and Delaware together have monitored shad relative and absolute abundance in the Delaware River based on commercial gillnet CPUE from 1989 through 1996 (Shirey 1995) and Petersen tag-recapture studies during most years (no estimates in 1984,1985,1987,1988,1990,1991,1993 and 1994) from 1975 through 1992 (Allen 1996) (Appendix 6). The 1995 and 1996 shad population estimates were based on hydro-acoustic methods (Allen 1996). The state of New Jersey also has monitored juvenile relative abundance (catch/seine haul) in the Delaware from 1979 through 1996 (Lupine 1991; Allen 1996). A fisheries-dependent index of adult stock abundance (mean catch/seine haul) from 1960 to 1995 is also available in the Delaware River from the Lewis haul seine fishery (Allen 1995) (Appendix 6). Commercial landings data (lbs.), separated into coastal, Delaware Bay and Delaware River landings, are available from the state of New Jersey between 1960 and 1996 (Allen 1995,1996). A similar breakdown of commercial shad landings from the state of Delaware has been made from 1985 to 1996 (Shirey 1996). In an effort to estimate total shad landings from the Delaware River, the reported commercial landings were doubled in order to reflect underreporting (i.e. 50% as per the Connecticut River) and the addition of substantial (50 to 80% of the New Jersey commercial landings; Lupine (1991)) recreational landings (Appendix 6). Inriver landings in numbers were estimated from 1980 to 1996 by dividing the landings (lbs.) by 4.5 lbs., which was the long-term average weight of a shad from commercial nets (Chittenden 1974) (Appendix 6).

The contribution of Delaware River shad to the coastal intercept fishery and in Delaware Bay between 1980 and 1996 (Tables 3 and 4) was based on the coastal landings (Table 2) from SC to RI and the tagging and mtDNA results. Coastal commercial landings (CCL) that were attributed to the Delaware River stock (Tables 3 and 4) were doubled to reflect catch underreporting and discard. Coastal landings from the Delaware in numbers were estimated from 1980 to 1996 by dividing the coastal landings (lbs.) by 4.5 lbs., which was the long-term average weight of a shad from commercial nets (Chittenden 1974) (Appendix 6).

To estimate shad population sizes in the Delaware River during years (1984,1985,1987,1988,1990,1991,1993 and 1994) when no population estimates were made, the SSAS opted to use the average of the nearest two population estimates that bracket those years when no tag-recapture estimates were generated. For example, the population estimates (N) for the years 1984 and 1985 (422,500 fish) were based on the average of population estimates derived in 1983 (250,000 fish) and 1986 (595,000 fish). Similarly, the 1987 and 1988 population estimates (713,500 fish) were based on the average of the 1986 and 1989 (832,000 fish) population estimates.

Inriver fishing mortality (F_r) on Delaware River shad between 1980 and 1996 was estimated as a log ratio between inriver commercial landings in numbers (C) and stock size (N) (equation 1). Since the coastal harvest of Delaware River shad is assumed to have occurred before the spawning stock enters the River, coastal fishing mortality (F_c) on Delaware River shad was estimated from 1980 to 1996 as a log ratio (equation 2) between the coastal landings in number (CCL) (assumed average weight = 4.5 lbs.) from the Delaware, and the population size (N) plus the coastal harvest (CCL). Total fishing mortality (F_t) on Delaware River shad between 1980 and 1996 was estimated by adding F_c and F_r.

Annual recruitment (Appendix 6) to the Delaware River stock from the 1979- 1996 year-classes has been estimated based on juvenile indices (Appendix 6). Spawning stock biomass (SSB) from the Delaware was estimated from 1979 to 1996 by subtracting the inriver commercial landings in weight each year from the population estimate in weight (assuming 4.5 lbs. per fish).

Upper Bay MD

The state of Maryland has monitored shad absolute abundance (mark-recapture) and age structure from Upper Chesapeake Bay (mainly the Susquehanna River) from 1984 through 1996 (Weinrich 1995) (Appendix 7). Weinrich (1995) also estimated total annual mortality rates for adult shad in the Nanticoke River and Upper Bay from 1985 to 1994 (Appendix 7). Coastal commercial shad landings, fishing effort (yds. of gillnet) and CPUE data have been monitored by the state of Maryland from 1983 to 1995 (Weinrich 1995) (Appendix 7). Since a moratorium had been imposed on commercial shad fishing in Maryland's portion of the Bay since 1980, there are no reported Bay commercial landings within Maryland from 1980 to 1996 (Appendix 7).

The U. S. Fish and Wildlife Service (USFWS) has monitored the proportion of hatchery and wild American shad that were passed over the Conowingo Dam on the Susquehanna River from 1989 to 1996 (Dick St. Pierre USFWS pers. comm., see Appendix 7). In addition, the proportion of hatchery and wild shad from the entire Upper Bay stock has been monitored from 1993 to 1996 (Carol Markham MDDNR pers. comm., see Appendix 7). Since there is a significant ($r = 0.96$, $P<0.01$) inverse linear relationship between the proportion of wild fish from the Conowingo Dam and from the Upper Bay from 1993 to 1996 (Appendix 7), this regression was used to estimate the fraction of wild shad from the Upper Bay stock from 1989 to 1992. Since there are no data on the fraction of wild fish from the Conowingo Dam before 1989, the average fraction of wild fish from the Upper Bay stock from 1993 to 1996 (mean = 0.52) also was used to estimate the number of wild shad from the Upper Bay stock between 1980 and 1988. To determine whether or not the hatchery component of the Upper Bay stock was largely responsible for the upward trend in stock size, we examined the trend in the stock abundance of wild and hatchery-reared shad from the Upper Bay stock between 1980 and 1996.

The contribution of Upper Bay shad to the coastal intercept fishery between 1980 and 1996 (Tables 3 and 4) was based on coastal landings from SC to NY (Table 2) and the combined tagging and mtDNA results (Hattala et. al. 1997). The estimated coastal landings from the Upper Bay in weight (Table 3) and number (Table 4) (assumed average weight = 4.0 lbs.) were adjusted upward to reflect an assumed 50% reporting rate for commercial landings. Bay fishing mortality (F_r) on American shad between 1960 and 1965 was estimated as a log ratio between inriver commercial landings in numbers (C) and stock size (N) (equation 1) (Appendix 7), assuming a 50% reporting rate. Since the coastal harvest of Upper Bay shad is assumed to have occurred before the spawning stock enters the Upper Bay, coastal fishing mortality (F_c) from the Upper Bay shad was estimated , as for other shad stocks, from 1980 to 1996 as a log ratio (equation 2) between the coastal landings in number (CCL) (adjusted up to reflect an assumed 50% reporting rate) from the Upper Bay (Tables 3 and 4), and the population size (N) from the Upper Bay plus the coastal harvest (CCL). Total fishing mortality (F_t) on Upper Bay shad between 1980 and 1996 was estimated by adding F_c and F_r. Since total mortality rates (Z) were estimated from the Upper Bay from 1985 to 1995, natural mortality rates (M) for adult shad were estimated for those years by subtraction (i.e. $M = Z - F_t$).

Juvenile recruitment has been estimated Bay-wide for the 1980-1995 year-classes based on annual beach seine surveys (Weinrich 1995). Spawning stock biomass (SSB) from the Upper Bay was estimated from 1980 to 1996 by subtracting the commercial landings in weight each year from the population estimate in weight (assuming 4.0 lbs. per fish).

Virginia Rivers

The Virginia Marine Resources Commission (VMRC) has monitored commercial shad landings in the James, York, and Rappahannock Rivers from 1973 to 1993 (O'Reilly 1995). Commercial shad landings (lbs.) have been separated by inriver and coastal landings from 1973 to 1996 (Appendix 8). Since mandatory reporting of commercial landings began in Virginia during 1993, the assumption was made here that the pre-1993 landings data reported to Virginia had constituted 70% of the post-1992 landings. As a result, the pre-1993 landings data have been increased by 30% to reflect a 70% reporting rate (Rob O'Reilly pers. comm.).

The contribution of Virginia shad to the coastal intercept fishery between 1980 and 1996 (Tables 3 and 4) was based on coastal landings from SC to NY (Table 2) and the VA/MD mtDNA analysis (Brown and Epifanio 1994) of Rudee, Wachapreague and Ocean City data from 1980-88. The 1989-96 composition was based on mtDNA from Wachapreague (1992/93) and Ocean City (1992) collections (Hattala et al. 1997). The estimated coastal landings emanating from Virginia Rivers in weight (Table 3) and number (Table 4) (assumed average weight = 3.7 lbs.) were then estimated. To estimate the contribution of coastal intercept landings from the James, Rappahannock and York Rivers from 1980 to 1993, the total coastal landings estimated from Virginia Rivers were separated into the York (0.433*coastal landings), Rappahannock (0.049* coastal landings) and James (0.518*coastal landings) Rivers based on the average contribution of inriver commercial shad landings by river system from 1973 to 1993 (Appendix 8).

Although there are no directed inriver fishing effort data by river system, nominal fishing effort data, expressed as total length (M) of stake gillnets used each year, are available based on inriver commercial logbooks compiled by fishermen for the Virginia Institute of Marine Sciences (VIMS) from 1980 to 1993 from the York, Rappahannock and James Rivers (Appendix 8). No inriver landings and effort data were available from 1994 to 1996 due to the moratorium on shad commercial fishing in 1994. Relative shad abundance based on the inriver commercial fisheries from each river was monitored from 1980 to 1993 in the York, James and Rappahannock Rivers by CPUE (sexes combined) (i.e. inriver commercial landings/length of net from gillnet).

To determine the potential impact from the coastal intercept fishery on Virginia shad stocks, relative exploitation (relu) on the James, Rappahannock and York River stocks between 1980 and 1993 was estimated as a ratio between the estimated coastal landings in numbers (Cst) from each river (Table 4) and inriver CPUE from each of the three stocks (James, Rappahannock and York Rivers):

$$u_{rel} = Cst / CPUE. \qquad (4)$$

If a rise in relative exploitation (u_{rel}) was coupled with a decline in stock size (ie CPUE), then this would represent presumptive evidence that the coastal intercept fishery was adversely affecting shad stock abundance.

Juvenile abundance indices were also conducted from the Mattaponi and Pamunkey Rivers (tributaries of the York River) for most years between 1979 and 1996 (Appendix 8) (Dixon et. al 1995).

North Carolina Rivers

The state of North Carolina has monitored commercial shad landings from Albemarle Sound, Cape Fear River, Neuse River, Pamlico River and Atlantic Ocean from 1972 to 1996 (Winslow 1995). Total mortality (Z) estimates have been made on adult shad from Albemarle Sound tributaries between 1972 and 1993 based on the linear regression of repeat spawners (Gibson et. al. 1988) (Appendix 9). There are no fishing effort data reported to the SSAS from specific NC river systems. Coastal intercept shad landings emanating from North Carolina rivers between 1980 and 1995 (Tables 3 and 4) were estimated from coastal intercept landings between SC and NY (Table 2) and from the combined tagging and mtDNA results (Hattala et. al. 1997).

Juvenile abundance indices based on bag seine surveys have been estimated from tributaries of Albemarle Sound from 1972 through 1995 (Appendix 9). Except for 1985, juvenile shad indices have approached zero (mean index < 0.4 fish/haul) in Albemarle sound, even during years (1982-1988) of high shad landings (Appendix 9). Given that no juvenile shad have been taken in this survey between 1989 and 1994 (i.e. index was 0.1 fish/haul in 1995 and 1996), this survey probably does not capture enough fish to provide a meaningful relative index of juvenile abundance.

South Carolina Rivers

The state of South Carolina has monitored commercial shad landings (lbs.) and a subsample of fishing effort (gillnet 100 yds.*hrs.) for the gillnet fishery from certain reaches of the Savannah, Edisto, Santee, and Waccamaw- Pee Dee Rivers from 1979 to 1995 (Appendix 10) (McCord 1995). The fishing effort data (100 yds.*hrs.), however, were not considered to be a random subsample from each river (Billy McCord SCDNR pers. comm.) and are therefore likely to be a biased estimate of relative fishing effort in these rivers. For this reason, the fishing effort data were not used in this assessment to estimate inriver fishing mortality rates from 1979 to 1995.

Inriver fishing mortality rates (F_r) recently have been (from 1989 to 1990 and from 1994 to 1997) estimated in the Edisto and Santee Rivers based on tag-recapture studies (McCord 1997, see Appendix 10). Although tag reporting was believed to be 100% in the Edisto River based on return rates between 50 dollar and 6 dollar reward tags (McCord 1991), SSAS believe it is unreasonable to assume 100% tag reporting. For this reason, the tag reporting rate in these studies (McCord 1995) was assumed to be 90% based on the results for the Santee River in 1991 and 1992 (Billy McCord SCDNR pers. comm.). We also assumed a 5% reduction in tags (M) due to the combined effects of tag loss and tag-induced mortality rate in the Edisto and Santee Rivers. This percentage (5%) was based on shad tagging studies in the Connecticut River (Leggett 1976; Crecco and Savoy 1987). As a result, 5% of the tagged fish (M) were removed before the annual fishing rates (u) were estimated:

$$u = R / M). \qquad (5)$$

In addition, since tag recoveries were reported from the coastal intercept fishery, we deducted these coastal recoveries from the original pool of inriver tags (M) for the Edisto and Santee stocks. Inriver fishing mortality rates (F_r) were estimated based on adjusted tags (M') and recoveries (R') for the Edisto stock in 1989-90 and from 1994-97 and for the Santee stock from 1991-92 by:

$$F_r = -\log (1-(R'/M')). \qquad (6)$$

The current average inriver fishing mortality rate (F_r) on Edisto River shad was based on the F_r estimates from 1994 to 1997.

Shad population size for the Santee River was estimated indirectly from 1990 to 1996 (Appendix 10) based on annual fishlift counts from the Santee-Cooper Rediversion Canal (McCord 1997). Since it was assumed that about 40% on average of the Santee shad run is passed annually at the fishlift from 1990 to 1996 (Billy McCord pers. comm.), total shad population size from 1990 to 1996 was estimated by dividing the annual lift counts by 0.4. It is clearly evident that annual harvest rates (u) on Santee River shad in 1991 ($U_{91} = 0.13$) and 1992 ($U_{92} = 0.17$) based directly on tagging (equation 5) were 4.24 times greater than harvest rates (u) generated by the ratio of reported inriver commercial landings in numbers (assumed average weight = 3.5 lbs.) to estimated stock size (Table 5). This disparity strongly suggests that reported commercial landings in the Santee River have been underreported by about 424%. For this reason, all inriver commercial landings from the Santee, Edisto, Savannah and Waccamaw-Pee Dee Rivers were adjusted upward by 424% to reflect underreporting. After harvest estimates (u) have been estimated on Edisto River shad in 1989, 1990, and from 1994 to 1997 based on equation 6, population size (N) for Edisto shad was estimated in those years as a ratio between the adjusted commercial harvest in numbers (C') and the annual harvest rate (u):

$$N = C' / u. \qquad (7)$$

The contribution of South Carolina shad in the coastal intercept harvest was based on coastal shad landings from SC to NJ (Table 2) and the tagging and mtDNA studies (Hattala et. al. 1997). Although a 424% underreporting rate was estimated for the inriver commercial landings in the Santee River, the coastal landings attributed to South Carolina Rivers were adjusted upward to reflect an assumed 50% reporting rate. McCord et al. (1987) reported that 68% of the coastal landings off Winyah Bay were recaptured in the Waccamaw-Pee Dee River, but this estimate is probably too high (Glen Ulrich pers. comm. SC DNR) because the fish were tagged near the mouth of the Waccamaw-Pee Dee River. The coastal landings from SC (Tables 3 and 4) were partitioned among the four rivers (5.3% for Edisto, 50.2% for Waccamaw-Pee Dee, 27.1% for Santee and 17.4% for Savannah Rivers) according to the long-term average percentage composition of the commercial landings from each river between 1979 and 1996 (Appendix 10). Since the coastal harvest of SC shad stocks is assumed to occur before the spawning stock enters their respective river, coastal fishing mortality rates (F_c) on Edisto and Santee River shad were estimated for selected years between 1989 and 1997 as a log ratio (equation 2) between adjusted coastal landings in number (CCL) ascribed to each river, and the population size (N) plus the coastal harvest (CCL) from each river system. Total fishing mortality (F_t) between 1980 and 1995 was estimated by adding F_c and F_r.

Juvenile abundance indices have not been estimated in any of these shad rivers.

Altamaha River GA

The state of Georgia has estimated the stock abundance of American shad in the Altamaha River from 1982 through 1996 by tag-recapture studies (Deener 1995) (Appendix 11). Inriver commercial landings from the Altamaha have been monitored since 1982 by a roving creel census (Michaels 1991). The data from 1982 to 1991 were used to develop a linear regression model (r^2= 0.80) between the reported and adjusted commercial landings. This model was used to adjust the 1992-96 reported commercial landings. The results of theses studies showed that commercial fishermen have underreported their landings on average by about 100% (i.e. they report on average one out of two shad from 1982 to 1996). Inriver fishing mortality rates (F_r) (sexes combined) from 1982-96 were estimated by converting the annual harvest rates (U_r) given in Deener (1995). Juvenile abundance indices also have been conducted in the Altamaha River from 1982 to 1991, but were discontinued thereafter because the index did not relate with subsequent recruitment to the adult stock (Ron Michaels pers. comm.).

The coastal intercept harvest attributed to all Georgia stocks were based on the coastal harvest from SC to MD (Table 2) and the tagging and mtDNA studies (Hattala et. al. 1997). According to McCord (1987), the Altamaha River comprised about 61% of the tag recoveries from Georgia rivers of fish originally tagged off SC. Hence, the coastal intercept landings from the

Altamaha (Appendix 11) were estimated by multiplying the coastal landings emanating from Georgia Rivers (Tables 3 and 4) from 1980 to 1995 by 0.61 and then by 2.0 to reflect an assumed 50% reporting rate. Given that the coastal harvest of Altamaha River shad occurs before the shad spawning stock has entered the river, coastal fishing mortality (F_c) was estimated from 1982 to 1996 as a log ratio (equation 2) between the coastal landings in number (CCL) from the Altamaha river (average weight = 3.1 lbs., Bert Deener pers. comm. GA DNR) and the population size (N) plus the coastal harvest (CCL). Total fishing mortality (F_t) between 1980 and 1996 was estimated by adding F_c and F_r.

Adult recruitment in numbers (R) to the Altamaha spawning population for the 1982-1990 year-classes has been estimated based as the number of virgin shad (ages 4 ,5 and 6) (Michaels 1995) in the adult shad population from 1983 to 1996. Spawning stock biomass (SSB) from the Altamaha was estimated from 1982 to 1996 by subtracting the commercial landings in weight each year from the population estimate in weight (assuming 3.1 lbs. per fish, Ron Michaels GA DNR pers. comm.).

Biological Reference Points

The Thompson-Bell yield-per-recruit (YPR) model (Appendix 12) was used to derive an overfishing definition for American shad based on a F_c biological reference point. The F_{30} level refers to the fishing mortality rate that generates 30% of maximum spawning potential for an unfished stock (F=0) as measured in the YPR model by biomass-per-recruit (B/R). In the last assessment (Gibson et. al 1988), F_{msy} was used as an overfishing definition for American shad. However, the magnitude of F_{msy} is very sensitive to the stock-recruitment properties of each shad stock. During our current assessment, the SSAS concluded that the relative precision of the stock-recruitment parameters for the Shepherd model was poorly estimated for most shad stocks, thereby reducing the usefulness of F_{msy} as an effective overfishing definition. For this reason, the F_{30} criterion was chosen by the SSAS to replace F_{msy}.

The F_{30} level for each stock was estimated based on the growth rates, natural mortality rates (M), maturation schedule, partial recruitment vector (PR) and a range of fishing mortality rates (F = 0 to 1.5 by 0.01) (Table 6). Since there are currently no minimum size limits imposed on any stocks of American shad, the YPR model was run with no minimum size limits. Given that the Shad Stock Assessment Subcommittee (SSAS) agreed earlier (Gibson et al. 1988) that changes in egg-per-recruit are directly proportional to changes in biomass-per-recruit (B/R), the female B/R values from the YPR model were used to express relative changes in reproductive effort for American shad following a reduction in fishing mortality. The model runs were made at 0.01 increments of F (F range: 0.0 to 1.3) assuming a range of natural mortality rates (M = 0.6 to 2.5) for adult female shad (ages 4-12) depending on latitudinal distribution.

Leggett and Carscaddan (1978) were among the first to document latitudinal differences in shad life history traits such as size-at-age, percentage of repeat spawning and fecundity per unit weight. For all model runs, natural mortality (M) among subadult shad (ages 1-4) was assumed to be constant at 0.3 (Table 6) based on size-based theory (Boudreau and Dickie 1987) and on stage-specific mortality estimates for American shad in the Connecticut River (Crecco and Savoy 1989).

The natural mortality rate (M) for adult (ages 4+) shad among northern stocks (Pawcatuck River RI to Upper Bay MD, exception for the Hudson River) was assumed to be constant at 1.50 based on the differences between total mortality (Z) and fishing mortality rates (F) in the Connecticut River (Leggett 1976; Crecco and Savoy 1987). Because of the relatively high (>40%) percentage of repeat spawners among Hudson River shad (Hattala 1995), M for adult shad in the Hudson was assumed to be 0.60. Given that the incidence of repeat spawning approaches zero for southern stocks (Waccamaw-Pee Dee R. SC to Altamaha R. GA), M was assumed to be constant at 2.5 among adult shad in these river systems (Table 6).

Gillnet studies on Connecticut River shad (Crecco and Savoy 1987) indicated that age 4 and age 5 female shad were partially (PR = 45% for age 4 and 90% for age 5) recruited to commercial gilllnet fisheries (Table 6), whereas all other exploitable age groups (ages 6+) were assumed to be fully (PR = 100%) recruited to commercial fisheries. In the absence of any documented landings data on age 1 to 3 shad, a PR vector of 0.0% was used for age 1 to 3 American shad. In all model runs, the PR vector was assumed to be constant (Table 6) for all YPR model runs. Biomass-per-recruit (B/R) levels were derived in the YPR model by the following expression:

$$B/R = \sum_{i = Y_i}^{Y_n} R*S*W_i*frac_i \qquad (6)$$

where R = one female recruit entering the exploitable stock;

W_i = age-specific weight (lbs);

$frac_i$ = the fraction of shad of age i that is sexually mature;

S = survival rate between ages i-1 and i;

Y_i = earliest age of adult spawning;
Y_n = latest age of adult spawning (12 years).

Yield-per-recruit (Y/R) levels were also derived in the YPR model by the following general expression:

$$Y/R = \sum_{i = Y_i}^{Y_n} R*F*W_i*PR \qquad (7)$$

Where R = one female recruit entering the exploitable stock;
W_i = age-specific weight (lbs);
F = the instantaneous fishing mortality rate occurring in the natal river;
PR = the partial recruitment vector of each age group to the commercial fisheries;
Y_i = earliest age entering the natal exploited stock (age 4);
Y_n = oldest age in the population (12 years).

Age-specific length (L_i) and weight (W_i) increments for shad were expressed by the von Bertalanffy growth equation estimated for each stock based on age-length data:

$$L_i = L \quad *(l\text{-}exp\text{-}K(t\text{-}t_o)), \quad (8)$$
$$W_i = W \quad *(1\text{-}exp\text{-}K(t\text{-}t_o))^{3.0} \qquad (9)$$

Where: L and W are the theoretical maximum length (inches) and weight (lbs), respectively;

K = rate at which L_i approaches L;

t_o = theoretical age at 0 length;

t = age in years.

The parameter estimates of K and t_0 were derived from back calculated age- length data in the Connecticut River and the Upper Bay MD based on nonlinear least squares regression (Table 6). Since size-at-age is much larger for northern than for southern shad stocks (Leggett and Carscaddan 1978), W was assumed to be constant at 10 lbs. for northern stocks, 13 lbs. for the Hudson River based on recent age data (Hattala 1995) and 7 lbs. for southern shad stocks.

The age-specific maturity schedule ($frac_i$) for female shad was estimated indirectly based on the maturity-age ogives reported in the literature (ASMFC 1985).

RESULTS AND DISCUSSION

Maine

The trend in relative juvenile production for Maine shad rivers showed no apparent decline from 1979 to 1995 (Figure 3). Dominant shad year-classes were evident in 1981, 1985 and 1990, although recent year-class (1994-95) production has been below average. Commercial shad landings from the coastal Maine commercial fisheries were relatively stable from 1979 to 1989, but have declined to very low levels thereafter (Figure 4). No inriver commercial landings have been reported from Maine Rivers, and there are neither fishing mortality estimates (F), fishing effort data, nor tagging studies for Maine shad rivers to determine the stock origin of coastal landings. As a result, we cannot determine whether the decline in Maine coastal shad landings (Figure 4) indicates a stock decline or a reduction in coastal fishing effort.

Merrimack River

The state of Massachusetts has monitored American shad relative abundance (shad lifted/day) at the Essex Dam fishlift on the Merrimack River from 1983 through 1995 (Brady 1995). Since shad relative abundance based on annual fishway counts has varied without trend from 1985 through 1995 (Figure 5), there is no evidence of a shad stock decline in the Merrimack River.

Pawcatuck River

Although shad population size (lbs.) in the Pawcatuck River has varied greatly from 1980 through 1996 , there is a steady decline in shad from 1992 (950,000 pounds) through 1994 (120,000 pounds), followed by a sharp resurgence in stock abundance in 1995 (330,000 pounds) and 1996 (750,000 pounds) (Figure 6). An increase in adult stock abundance in 1996 was fully expected based on the production of dominant year-classes in 1992 and 1993 (Figure 7). Although shad stock abundance in the Pawcatuck River has exhibited a decline from 1985 to 1996 (Figure 6), overall stock size has remained fairly stable from 1992 to 1996.

Total mortality rates (Z) of Pawcatuck River shad have exceeded 1.5 in most years between 1981 and 1989 (Figure 8), but have declined below 1.20 from 1990 to 1992. No total mortality estimates (Z) have been made in the Pawcatuck after 1992. There is neither a significant statistical ($P<0.05$) relationship between Z and the coastal commercial shad landings from Rhode Island between 1981 and 1992 "r" = 0.42. $P<0.18$) nor between stock size and the Rhode Island coastal landings (Appendix 3). Hence, overfishing is probably not the major cause for the recent and temporary (1992-94) shad decline in the Pawcatuck River. Our conclusions are tempered somewhat by the fact that no stock origin studies have ever been conducted on the coastal Rhode Island shad landings which, in theory, could easily have overharvested the small Pawcatuck stock. Before we can rule out overfishing, it would be beneficial to estimate fishing mortality (F) directly and to conduct a tagging study on the Rhode Island coastal fishery to determine stock origin.

Juvenile production (mean catch/seine haul) for the 1992, 1993 and 1994 year-classes was the highest since 1985, although the 1996 year-class appears to be weak (Figure 7). Assuming a qualitative relationship between juvenile production in year t and subsequent adult recruitment in year t+4 and t+5, adult stock size in the Pawcatuck River should continue to rise between 1997 and 1999 due to the strength of the 1992, 1993 and 1994 year-classes.

Connecticut River

Shad population size for the Connecticut River has varied greatly from 1975 through 1996 (Figure 9), but a recent decline (1993-95) in shad stock abundance was evident from 1.6 million fish in 1992 to a low of about 305,000 fish in 1995. Shad population abundance has risen recently in 1996 (667,100 fish) and 1997 (725,000 fish) to levels approaching the long-term (1966-95) average (800,000 fish) (Figure 9). Inriver fishing mortality rates (F_r) on Connecticut River shad have remained low but highly variable (F_r = 0.09 to 0.35) between 1975 and 1996 (Figure 10). Recent (1992-96) F_r levels have averaged 0.13 (Table 7). Coastal fishing mortality rates (F_c) on Connecticut River shad have also varied without trend from about 0.15 to 0 15 between 1980 and 1996 (Figure 11). Total fishing mortality rates (F_t) have also remained fairly stable from 1980 to 1996 (Figure 12). Since the current (1992-96) average total fishing mortality rate (F_t = 0.22)) on Connecticut River shad is well below the overfishing definition (F_c level of 0.43) (Table 7), there is no evidence that overfishing was the primary cause for the recent stock decline.

The pattern of adult stock decline in the Connecticut River (Figure 9) is very similar to that on the nearby Pawcatuck River, Rhode Island (Figure 6) located some 30 miles to the east from 1990 to 1995 "r" = 0.96, P < 0.001). In addition, juvenile shad production on the Connecticut River was persistently high from 1989 to 1994 (Figure 13), which should have resulted in a significant rise in adult stock size from 1993 to 1995, yet stock size actually dropped by about 300% (Figure 9). Savoy and Crecco (1995) reported based on recent juvenile production, that in order for overfishing to have caused the recent stock decline in the Connecticut, total fishing mortality (F_t) after 1989 would have to exceed 1.50, resulting in commercial landings that should have approached 3.0 million lbs. annually.

Strong year-class production in the Connecticut (Figure 13) has followed a pattern that was very similar to that observed in the nearby Pawcatuck River (Figure 7). These similarities in stock trends and juvenile production strongly suggest that the proximal cause for the Connecticut stock decline also has been operating on Pawcatuck shad. Since nearly all the evidence for the recent shad decline in the Connecticut pointed directly to enhanced striped bass predation from below the Holyoke Dam (Savoy and Crecco 1995), it is very likely that the recent shad decline in the Connecticut and nearby Pawcatuck River is directly related to striped bass predation and not overfishing.

Hudson River

Shad population size in the Hudson River based on Talbot's (1954) estimate of q has varied greatly from 1980 to 1996 (Figure 14), but has generally declined from about 2.3 million fish in 1980 to a low 404,000 fish in 1996. Inriver commercial landings declined from about 2.6 million lbs. in 1980 to less than 250,000 lbs. in 1996 (Figure 15). Inriver fishing mortality rates (F_r) (Figure 16) have generally declined from a high of 0.44 in 1984 to less than 0.19 after 1990. By contrast, coastal fishing mortality rates (F_c) on Hudson River shad have risen since the mid-1980's from about 0.08 to 0.19 in 1996 (Figure 17). Total fishing mortality rates (F_t) on Hudson shad have remained stable and independent of the stock decline from 1980 to 1996 (Figures 18 and 14). Moreover, the current (1992-96) average total fishing mortality rate ($F_t = 0.33$) on Hudson River shad (Table 7) was below the overfishing definition (F_c level of 0.39) for the Hudson stock. Based on these data, current fishing mortality ($F_t = 0.33$) indicates that the Hudson shad stock is fully exploited, allowing for about 35% of maximum spawning potential (%MSP) under steady-state conditions. Although there is ample evidence of a shad stock decline in the Hudson, there is no evidence that overfishing was the primary cause for this decline.

Shad population size in the Hudson River based on the 1995 tag-recapture estimate (Hattala 1997) of q were on average about 33% greater (Figure 19) than those derived by Talbot (1954) (Figure 14). Shad population abundance in the Hudson varied greatly from 1980 to 1996 (Figure 19), but has generally declined form about 3.3 million fish in 1980 to a low 536,000 fish in 1996. Inriver fishing mortality rates (F_r) (Figure 20) based on the 1995 population estimate (Hattala 1997) were about 33 % lower than those based on Talbot (1954) (Figure 16), and have generally declined form a high of 0.30 in 1984 to less that 0.13 thereafter. By contrast, coastal fishing mortality rates (F_c) on Hudson River shad have risen during the mid-1980's from abut 0.05 to 0.14 in 1996 (Figure 21). Total fishing mortality rates (F_t) on Hudson shad have remained stable and independent of the stock decline form 1980 to 1996 (Figures 22 and 19). Moreover, current (1992-96) average total fishing mortality rate ($F_t = 0.24$) on Hudson River shad (Table 7) was well below the overfishing definition (F_c level of 0.39) for the Hudson stock, which is consistent with results based on current F estimates from Talbot (1954) (Table 7). Based on fishing mortality rates derived from the 1995 tag-recapture (Hattala 1997), current magnitude of fishing mortality $F_t = 0.24$) indicates that the Hudson shad stock is partially exploited, allowing for about 47% of maximum spawning potential (%MSP) under steady-state conditions.

Year-class production in the Hudson has been high and relatively stable from 1981 to 1994 (Figure 23), so there is no evidence of recruitment failure. Juvenile production in the Hudson was generally highest from 1986 to 1990 (Figure 23), yet adult stock size during the mid-1990's continued to decline to historic low levels (Figures 14 and 19). Assuming a positive relationship between juvenile production in year t and subsequent adult recruitment in year t+4 and t+5 for the Hudson spawning stock, the recently observed decline in the Hudson River shad stock would be impossible to predict based on the relatively modest inriver and coastal landings (Appendix 5). Moreover, the magnitude of the stock decline would be difficult to relate to overfishing unless fishing mortality rates (F_t) from 1988 to 1995 had risen by at least 300% (i.e. from about 0.30 to 0.90). For these reasons, it is likely that some other biotic factors (possibly striped bass predation) other than overfishing, or perhaps some abiotic factors have caused the recent decline in the Hudson River shad stock.

Delaware River

Total shad population abundance (river population plus coastal landings) in the Delaware River has fluctuated greatly from 1980 to 1996 (Figure 24) from a low of 228,000 fish in 1980 to a high of nearly 1.1 million adult shad in 1990. Although shad population abundance in the Delaware River declined from 1992 to 1995 (Figure 24), the 1996 population size (899,930 fish) was the fifth highest in the time series (1980-1996). Juvenile production in the Delaware has remained relatively stable from 1980 through 1996, with dominant year-classes occurring in 1983, 1990, 1993 and 1996 (Figure 25). There is clearly no evidence that the Delaware River shad stock has undergone recruitment failure or has experienced a sharp population decline since 1992.

Inriver fishing mortality rates (F_r) on Delaware River shad have been very low (F_r less than 0.14) since 1980 (Figure 26). The F_r estimates have varied without trend from a low of 0.004 in 1981 to a high of 0.029 in 1990. The recent (1992-96) average F_r rate of 0.02 (Table 7) is well below the overfishing definition ($F_c = 0.43$) for this stock. Coastal fishing mortality rates (F_c) on Delaware River shad have been much higher (5 to 10 times greater in most years) than inriver fishing rate (F_r), but have remained relatively stable from 1980 to 1996 (Figure 27), from a low of 0.12 in 1981 to a high of 0.30 in 1983. The recent (1992-96) average F_c rate on Delaware River shad was 0.15. Total fishing mortality rates (F_t) have varied without trend from 1980 to 1996 (Figure 28). The recent (1992-96) average total fishing mortality rate (F_t) on Delaware River shad of 0.17 (Table 7) was well below the overfishing definition ($F_{30} = 0.43$) for this stock (Table 8). Hence, there is no evidence that the Delaware River shad stock has been overfished since 1980.

Upper Bay

Total shad population abundance (inriver stock size plus coastal landings from Upper Bay) from the Upper Bay (Weinrich 1995) increased steadily from a low of about 14,000 fish in 1980 to a high of 342,000 fish in 1995; the 1996 population size dropped to 213,000 fish in 1996 (Figure 29). When the estimated hatchery component of the adult shad stock was removed, the trend in adult stock abundance of wild fish was nearly identical to the total stock trend (Figure 30), indicating that the recent rise in the total Upper Bay stock was not driven solely by the recent rise in hatchery-reared fish. The overall trend in shad recruitment, based on juvenile abundance, to the Upper Bay stock (Figure 31) has generally increased from 1984 through 1995. Dominant year-classes were evident in 1989 and 1995 (Figure 31). There is no evidence that the shad stocks from the Upper Bay have experienced recruitment failure or a recent adult stock decline.

Inriver fishing mortality rates (F_r) on Upper Bay shad have been zero from 1980 to 1996 due to the moratorium. Coastal fishing mortality rates (F_c) have declined since 1980 from a high of 0.77 in 1984 to a low of 0.02 in 1995 (Figure 32). Since coastal landings have completely dominated the total shad commercial landings from the Upper Bay since 1980, the trend in total fishing mortality (F_t) is the same as the trend in coastal fishing mortality (F_c) (Figure 32). The recent (1992-96) average F_t rate on Upper Bay shad of 0.11 (Table 7) was considerably below the overfishing definition (F_{30} = 0.43) for the Upper Bay stock (Table 7). Natural mortality (M) of adult shad was estimated by subtracting F_t from the total mortality (Z) estimates from 1986 to 1995 (Figure 33). The average natural mortality rate (M) based on the 1986 to 1996 estimates for the Upper Bay stock was 1.89 (SE = 0.13), which was slightly higher than the assumed M of 1.5 for adult shad used in the Thompson-Bell Model (Table 6).

Virginia Rivers

The trends in inriver shad commercial landings from the James, York and Rappahannock Rivers have declined steadily from 1973 through 1987 (Appendix 8); thereafter landings remained low and have varied without trend. Shad commercial catch-per-effort (female CPUE) based on inriver landings in the Rappahannock River generally rose from 1980 to 1989, but CPUE declined steadily thereafter (Figure 34). Shad CPUE for the York River has declined steadily from a high in 1980 to the lowest level in 1993 (Figure 35). By contrast, CPUE for the James River has varied without trend from 1980 to 1993 (Figure 36). These data strongly suggest that shad stock abundance in the Rappahannock and York Rivers has recently declined to low levels at least since 1993.

Relative exploitation rates (u_{rel}) from the coastal fishery on the Rappahannock River stock have varied without trend from 1980 to 1993 (Figure 37). The u_{rel} levels from the coastal intercept fishery on the York River stock rose steadily from 1980 to a high in 1988 after which u_{rel} levels dropped abruptly to 1985 to 1987 levels (Figure 38), suggesting that the coastal intercept fishery has not had an adverse impact on the York River shad stock after 1987. Although relative exploitation rates on James River shad were highest in 1986 and 1987, there is no apparent trend in u_{rel} from the coastal intercept fishery on the James River stock from 1980 to 1992 (Figure 39). Since relative exploitation rates from the coastal fishery have not exhibited a clear rise for any of the three stocks from 1980 to 1993 (Figures 37-39), there is no evidence that the coastal commercial shad fishery has had an adverse effect on relative stock abundance in the James, Rappahannock and York Rivers since 1993. Since coastal landings from Virginia Rivers have continued to decline from 1993 to 1996 (Figure 40), there is no reason to believe that the coastal fishing mortality rates (F_c) have risen on the James, York and Rappahannock River stocks since 1993. The apparent shad stock declines in the York and Rappahannock Rivers based on CPUE (Figures 34 and 35) do not appear to be related to overharvest by the coastal intercept fishery.

Juvenile abundance indices in the Mattaponi River have varied without trend from 1980 through 1994; the 1996 index is clearly the strongest of the time series (Figure 41). The juvenile indices from the Pamunkey were very low in 1992 and 1993, but the two highest juvenile index in the time series occurred in 1994 and 1996 (Figure 42). There is no clear evidence of recent recruitment failure in the Pamunkey and Mattaponi Rivers (Figures 35 and 36).

Albemarle Sound NC

Shad landings data from Albemarle Sound were relatively stable from 1982 through 1990, but declined steadily thereafter (Figure 43). The recent (since 1991) downward trend in shad landings strongly suggests a serious decline in overall abundance of Albemarle Sound shad. By contrast, coastal shad landings attributed to North Carolina rivers have remained stable from 1984 to 1996 (Figure 44). Moreover, since total mortality rates (Z) on Albemarle Sound shad have also remained stable from 1982 through 1993 (Figure 45), it is unlikely that overfishing is the proximal cause of the apparent shad decline in Albemarle Sound.

Pamlico, Neuse and Cape Fear Rivers NC

Inriver commercial shad landings data from the Pamlico, Neuse and Cape Fear Rivers have declined to low levels from about 1987 to 1996 (Figures 46-48). There are neither fishing mortality estimates (F), fishing effort data, nor tagging studies for these three stocks. As a result, we cannot determine whether or not the decline in inriver commercial landings (Figures 43 and 46 to 48) indicates a stock decline or a reduction in inriver fishing effort. Since fishing mortality rates have not been estimated directly for North Carolina Rivers, there is clearly a need to estimate fishing mortality (F) and stock size based on tag-recapture studies.

Waccamaw-Pee Dee, Santee, Edisto and Savannah Rivers SC

Inriver commercial shad landings data from the Waccamaw-Pee Dee, Edisto and Savannah Rivers have either declined to low levels since 1989 or have remained low since 1985 (Figures 49-51). Since there are no recent fishing mortality (F) estimates for the Waccamaw-Pee Dee and Savannah Rivers, we cannot determine whether or not the decline in inriver commercial landings in these systems (Figures 43 and 45) indicates a stock decline or a recent reduction in inriver fishing effort. By contrast, inriver shad landings in the Santee River have risen exponentially from 1994 to 1996 (Figure 52) which is consistent with the recent dramatic increase in population abundance in the Santee based on fishway counts (Figure 53). Shad population size from the Edisto River in 1989 and 1990 and from 1994 to 1996 (Figure 54) based on tag-recapture studies (McCord 1997) has displayed only a modest decline, suggesting the recent drop in inriver commercial landings for the Edisto is largely due to a reduction in inriver commercial fishing effort.

Inriver (F_r) and coastal (F_c) fishing mortality rates are available for the Edisto River shad in 1989, 1990, and from 1994 to 1997 (Table 8). Similar F estimates are also available for the Santee River stock from 1990 to 1996 (Table 8). Inriver fishing mortality rates (F_r) for the Edisto River stock have declined steadily from a high of 0.67 in 1989 to a low of 0.13 in 1996 (Table 8). The recent average (1994 to 1997) inriver fishing rate (F_r) of 0.21 in the Edisto (Tables 7) was far below the overfishing definition (F_c = 0.43) for southern rivers. When the coastal average (1994 to 1997) fishing rates (mean F_c= 0.24) were added to F_r, the total current average F (F_{total}= 0.45) on Edisto shad (Table 7) was slightly below the overfishing definition of F_c = 0.48. As a result, the Edisto shad stock is considered to be fully exploited but not overfished. Since the recent (1994-97) average F_t level of 0.45 is only slightly below the overfishing definition (F_c = 0.48), both inriver and coastal fishing rates on Edisto River shad should be monitored closely during the next few years.

Inriver fishing mortality rates (F_r) for the Santee River has generally risen from 1990 to 1996 from a low of 0.06 in 1990 to a high of 0.33 in 1996 (Table 8). The current average F_r

(1992-96) of 0.17 was well below the overfishing definition (F_c = 0.48) for southern stocks (Tables 7). The coastal fishing mortality rates (F_c) on the Santee stock have declined steadily from 0.22 in 1990 to 0.02 in 1996 (Table 8). The recent (1992-95) average total fishing rate (F_{total}) was 0.19 (Table 7), which is still far below the F_c level of 0.48. As a result, since the current average F (F_{total} = 0.19) for Santee River shad is less than half of the overfishing definition (F_c = 0.48) (Table 7), the Santee River shad stock is considered partially exploited and not overfished. This conclusion is consistent with the observed rapid rise in shad stock abundance from 1990 to 1996 (Figure 53).

Altamaha River

Population abundance (inriver stock plus coastal landings) in the Altamaha River has varied greatly from 1980 to 1996 (Figure 54), although stock abundance has risen recently from about 80,000 fish in 1990 to a time series high of 285,000 fish in 1996. Inriver commercial landings in the Altamaha River have generally increased from 1991 to 1996 (Figure 55), whereas coastal commercial landings have declined to low levels by 1996 (Figure 56). Inriver fishing mortality rates (F_r) have generally exceeded 0.5 from 1980 to 1992 (Figure 57), but F_r levels have declined thereafter to about 0.30 to 0.45 from 1993 to 1996. Coastal fishing mortality rates (F_c) are much lower (F_c range: 0.01 to 0.09) than the inriver fishing rates and have declined steadily from 1990 to 1996 (Figure 58). Adult recruitment from the 1986 to 1991 year-classes has risen steadily in the Altamaha from 1990 to 1996 (Figure 59).

The recent average (1992-96) total fishing mortality rate (F_t= 0.39) on Altamaha River shad (Table 7) is below the F_c level of 0.48 for southern stocks. A current F_t level of 0.41 is equivalent to about 36% of maximum spawning potential (MSP). Since stock abundance has recently risen under moderately fishing mortality rates, the SSAS has concluded that the Altamaha River stock is fully exploited but not overfished. Since inriver fishing mortality rates (F_r) have exceeded the overfishing definition (F_c = 0.48) as recently as 1991 (Figure 57), inriver fishing mortality rates should be monitored closely in the Altamaha during the next few years.

Other Rivers

This assessment estimated fishing mortality (F) rates for nine shad stocks and general trends in abundance for 13 American shad stocks (Table 1). The total range of extant American shad populations includes additional populations in small river systems, as well as depleted populations in larger river systems that are actively being restored. Also, much historical and habitat is currently vacant and may be targeted for restoration in the future. For these stocks, individual states have targeted minimal fishing mortality to protect small stocks and rebuild others. This assessment cannot quantitatively address these systems because of limited biological data, as well as associated uncertainties in stock composition of small populations in fisheries. Like all mixed stock fisheries, small stocks can be at risk under these conditions.

The problem of managing small shad stocks is clearly illustrated by the Pawcatuck River stock. For this population, stock assessment results suggested that overfishing was not the major cause of recent stock declines in the Pawcatuck. However, these results should be weighed against the fact that no stock origin studies have ever been conducted on the Rhode Island coastal shad landings. From the magnitude of these landings, it is possible that the Pawcatuck population could be overharvested (ie, mixed stock landings biomass often exceeds biomass of the entire Pawcatuck River stock). Thus, for these smaller populations, it is important to estimate fishing mortality mortality directly and to conduct stock identification studies to determine stock composition in the mixed stock fishery. These data are needed to make fully informed management decisions.

LITERATURE CITED

Allen, R. L. 1995. New Jersey stock status report for American shad. Report to the Shad and River Herring Technical Committee, Sept. 6, 1995, 11 p.

Allen, R. L. 1996. New Jersey stock status report for American shad. Report to the Shad and River Herring Technical Committee.

ASMFC (Atlantic States Marine Fisheries Commission). 1985. Fishery management plan for the anadromous alosids stocks of eastern United States: American shad, hickory shad, alewife and blueback herring: Phase 2 in interstate planning for alosids of the Atlantic coast. Washington, DC.

Boudreau, P. R. and L. M. Dickie. 1989. Biological model of production based on physiological and ecological scaling of body size. Can. J. Fish. Aqua. Sci. 46:614-623.

Brady, D. 1995. Commonwealth of Massachusetts American shad stock status summary. Report to the Shad and River Herring Technical Committee, Sept. 6, 1995, 4 p.

Brown, B. L. 1992. Genetic analysis of American shad entering Chesapeake Bay. Ches. Bay Comm. Rep.

Brown, B. L. and J. M. Epifanio. 1994. Mixed-stock analysis of American shad in Virginia's and Maryland's coastal intercept fisheries. Report to Virginia Marine Resources Commission, Report # F-110-R, 115 pp.

Chittenden, M. E. 1974. Trends in the abundance of American shad in the Delaware River Basin. Ches. Sci. vol. 15:96-103.

Crecco, V. A. 1995. Status of American shad in the Connecticut River, 1970-95. Report to the Shad and River Herring Technical Committee, Sept. 1995, 17p.

Crecco, V. A. and T. F. Savoy. 1987. Fishery Management Plan for American shad in the Connecticut River. Connecticut Dept. Envir. Prot. Bureau of Fihseries, 136 p.

Crecco, V. A. and T. F. Savoy. 1986. Connecticut River shad study. 1986 Final Report. Connecticut Dept. Envir. Prot. AFC 16, 112 p.

Crecco, V. A. and T. F. Savoy. 1985. Density-dependent catchability and its potential causes and effects on Connecticut River American shad. Can. J. Fish. Aquat. Sci. 42:1649-1657.

Crecco, V. A. and T. F. Savoy. 1981. Connecticut River shad study. 1981 Final Report. Connecticut Dept. Envir. Prot. AFC 10, 107 p.

Deener, B. 1995. Status of American shad in the Altamaha River. Report to the Shad and River

Herring Technical Committee, 6p.

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. Completion Report NA46FU0393, 46p.

Fredin, R. A. 1954. Causes of fluctuations in abundance of Connecticut River shad. U. S. Fish and Wildlife Service Fishery Bulletin 54:247-259.

Gibson, M. R., V. A. Crecco and D. L. Stang. 1988. Stock assessment of American shad from selected Atlantic coast rivers. Atlantic States Marine Fisheries Commission. Special Report No. 15, 75p.

Harris, P.J. and R.A. Rulifson. 1989. Investigations of ocean landings for American shad and river herring from United States east coast waters. Completion report to the Atlantic States Marine Fisheries Commission, Washington, D.C. Contract 89-IPASRH, 92p.

Hattala, K. A., R. Allen and R. O'Reilly. 1997. Stock contribution for American shad landings in mixed stock fisheries along the Atlantic coast. Report to the Shad and River Herring Technical Committee, July 1997, 8 pp.

Hattala, K. A. 1997. Update on Hudson River American shad study. Memo to commercial shad fishermen on the 1995 American shad studies in the Hudson River. 2pp.

Hattala, K. A. 1995. American shad data from the Hudson River, 1930-95 used in the current stock assessment. Report to the Shad and River Herring Technical Committee, 24 p.

Hattala, K. A., R. V. Jesian and R. Allen. 1996. Summary of the 1995 tagging study of American shad along coastal New York. Report to the Shad and River Herring Technical Committee, 4p.

Jesian, R. V., S. K. Gaichas, J. E. Serafy and C. H. Hocutt. 1992. Stock composition of coastal Maryland and Virginia American shad fisheries: 1992 tagging study. U. S. Dept. Interior, Final Report F267-92-008, 24p.

Klauda, R. J., M. Nittel and K. P. Campbell. 1976. Commercial fishery for shad in the Hudson River: fish abundance and stock trends, pp 107-134. In Proceedings of a Workshop on American shad. U. S. National Marine Fisheries Service. 14-16 Dec 1976.

Krantz, A. K., J. P. Mowrer, A. A. Jarzynski, R. V. Jesian and D. R. Weinrich. 1992. Investigation of anadromous alosids in Chesapeake Bay. U. S. Dept. Interior, Report F-37-R, 18p.

Leggett, W. C. 1976. The American shad with special reference to its migration and population dynamics in the Connecticut River, pp 168-225. In D. Merriman and L. W. Thorpe, eds.

The Connecticut River Ecological Study: The impacts of a nuclear power plant. Amer. Fish. Soc. Monogr. I. 252p.

Leggett, W. C. and J. E. Carscadden. 1978. Latitudinal variation in reproductive characteristics of American shad: evidence for population specific life history strategies in fish. J. Fish. Res. Bd. Can. 35:1469-1478.

Lorda, E, and V. A. Crecco. 1987. Stock-recruitment relationship and compensatory mortality of American shad in the Connecticut River. Am. Fish. Soc. Sym. 1:469-482.

Lupine, A. J. 1991. Summary of activities to American shad and River Herring. Annual Report to the Shad and River Herring Scientific and Statistical Committee, ASMFC, Aug. 12, 1991, 6p.

McCord, B. 1997. The 1997 fishing mortality rates on shad in the Edisto and Santee Rivers based on tag-recapture studies. Report to the ASMFC Scientific and Statistical Committee, 6p.

McCord, B. 1995. Annual report to the Shad and River Herring Scientific and Statistical Committee, ASMFC, Sept. 6, 1995, 34p.

McCord, B. 1991. Monitoring and assessment of South Carolina's commercial shad fishery and incidental catch of sturgeon. Completion reports to National Marine Fisheries Service.

McCord, B., N. Jenkins, G. Ulrich. 1989. Monitoring and assessment of South Carolina's commercial shad fishery and incidental catch of sturgeons. Completion report to the NMFS. 45 pages.

Michaels, R. 1990. Population dynamics of the American shad in the Altamaha River. Interim Report 1985-90. Project No. G-3. Georgia Dept. Nat. Res. Game and Fish. 39 p.

Nichols, P. R. 1958. Effect of New Jersey-New York pound net catches on shad runs of Hudson and Connecticut Rivers. U. S. Dept. of the Interior, Fishery Bulletin 143, 58:491-500.

O'Reilly R. 1995. Commercial catch and effort data for American shad in Virginia Rivers. Report to the Shad and River Herring Technical Committee, 12p.

Parker, J. A. 1992. Migratory patterns and exploitation of American shad in the nearshore ocean waters of southeastern North Carolina. North Amer. J. Fish. Management. 12:752-739.

Powell, C. 1995. Annual report to Shad and River Herring Scientific and Statistical Committee, ASMFC. Report by the R. I. Div. Fish and Wildl. 10p.

Rulifson, R. A. 1994. Status of anadromous Alosa along the east coast of North America. Anadromous Alosa Symposium, 1994, pp. 134-158.

Savoy, T. and V. Crecco. 1995. Factors affecting the recent decline of blueback herring and American shad in the Connecticut River Report to the Atlantic States Marine Fisheries Commission, 46p.

Shirey, C. 1996. Status report for Delaware River shad through 1996. Report to the Shad and River Herring Technical Committee. 3p.

Shirey, C. 1995. Status report for Delaware River shad through 1995. Report to the Shad and River Herring Technical Committee, 2p.

Squires, T. 1995. Shad landings and juvenile indices from the state of Maine. Report to the Shad and River Herring Technical Committee, 4p.

Talbot, G. E. 1954. Factors associated with fluctuations in abundance of Hudson River shad. U. S. Fish and Wildlife Service Fish. Bull. 56:373-413.

Talbot, G. E. and J. E. Sykes. 1958. Atlantic coast migrations of American shad. U. S. Fish and Wildlife. Service Fish. Bull. 58(142):473-490.

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

Weinrich, D. R. 1995. Status of American shad in Maryland. Report to the Shad and River Herring Technical Committee, Sept. 1995, 18p.

Winslow, S. E. 1995. American shad stock status in North Carolina. Report to the Shad and River Herring Technical Committee, Sept. 1995, 20p.

Table 1. American shad rivers or systems and the respective time series of fisheries-dependent and fisheries-independent data used in the 1996 stock assessment.

Rivers	Juv Production	Landings	Pop Size[1/]	F[2/]
Maine R.	yes	*yes*[3/]	no	no
Merrimack R.	no	no	yes	no
Pawcatuck R.	yes	no	yes	yes
Connecticut R.	yes	yes	yes	yes
Hudson R.	yes	yes	yes	yes
Delaware R.	yes	yes	yes	yes
Upper Bay MD	yes	yes	yes	yes
James R.	no	yes	yes	yes
York R.	yes	yes	yes	yes
Rappahannock R.	no	yes	yes	yes
Albemarle Sound	yes	yes	no	yes
Neuse R.	no	yes	no	no
Pamlico R.	no	yes	no	no
Cape Fear R.	no	yes	no	no
Wacc-Pee Dee R.	no	yes	no	no
Edisto R.	no	yes	yes	yes
Santee R.	no	yes	yes	yes
Savannah R.	no	yes	no	no
Altamaha R.	yes	yes	yes	yes

1/ Either relative (CPUE) or absolute stock size;

2/ Either fishing (F), total mortality (Z) and/or relative exploition rates available.

3/ Only coastal shad landings are available for Maine.

Table 2. Landings (pounds *1000) adjusted based on percent reporting.

%>>	50%	50%	70%	50%	50%	50%	50%	50%	50%	50%	50%
Year	SC	NC	VA	MD	DE	NJ	NY	RI	MA	NH	ME
1980	310	8	137	0	180	239	227	4	17	14	56
1981	299	215	394	0	369	261	117	63	33	11	181
1982	490	128	396	0	655	560	147	159	59	5	52
1983	411	8	297	40	436	393	66	47	27	7	77
1984	786	27	920	38	412	418	67	73	59	10	67
1985	275	6	475	300	345	430	188	182	45	15	32
1986	451	126	508	252	424	314	146	105	120	34	46
1987	719	82	565	239	492	369	23	208	82	83	53
1988	517	100	613	529	582	467	31	244	101	92	64
1989	456	77	571	976	433	798	46	84	27	61	93
1990	323	74	465	567	950	899	11	46	11	76	24
1991	289	38	571	468	1021	769	53	56	1	38	4
1992	218	48	617	398	548	571	42	27	1	20	3
1993	130	56	487	156	592	640	15	81	1	13	0
1994	144	68	204	67	452	434	12	36	0	43	2
1995	265	206	146	100	382	560	29	56	0	61	0
1996	444	116	232	190	530	420	51	0	0	0	0

No adjustment for Virginia, data from mandatory reporting 1993-96, R. O'Reilly
The percent reporting used for all states needs resolving at TC level. KAH 8/19/97

Table 3. State stock(s) affected by mixed stock fisheries (pounds * 1000)

Year	FL	GA	SC	NC	VA	MD	Del. R.	Hud. R.	CT. R.	NECN
1980	5	23	205	147	24	14	202	163	246	162
1981	9	37	372	272	67	26	325	248	346	241
1982	10	45	429	312	67	38	581	443	464	260
1983	8	30	307	225	56	27	404	301	289	161
1984	18	59	668	498	159	44	476	325	356	274
1985	11	20	336	262	129	39	449	324	432	323
1986	13	42	493	370	127	37	409	294	410	315
1987	16	58	625	463	134	41	474	341	437	324
1988	18	44	605	462	190	54	596	420	536	412
1989	21	38	780	613	145	94	724	517	433	249
1990	14	29	543	424	97	84	932	684	462	171
1991	14	24	507	400	97	82	880	644	432	162
1992	13	19	466	371	95	68	611	437	287	123
1993	8	13	305	241	60	54	622	458	309	111
1994	5	15	201	152	26	31	420	316	221	74
1995	7	34	333	242	24	30	424	322	249	95
1996	10	40	438	323	39	38	463	341	215	66

Table 4. Conversion (of affected stocks) from pounds to numbers (* 1000) using average weight.

ave.wt>>	3.5	3.1	3.5	4	3.7	4	4.5	4.8	5	5
Year	FL	GA	SC	NC	VA	MD	Del. R.	Hud. R.	CT. R.	NECN
1980	1	7	59	37	7	3	45	34	49	32
1981	3	12	106	68	18	6	72	52	69	48
1982	3	14	123	78	18	9	129	92	93	52
1983	2	10	88	56	15	7	90	63	58	32
1984	5	19	191	125	43	11	106	68	71	55
1985	3	7	96	65	35	10	100	67	85	65
1986	4	13	141	92	34	9	91	61	83	63
1987	5	19	179	116	36	10	105	71	87	65
1988	5	14	173	116	51	14	132	88	107	82
1989	6	12	223	153	39	23	161	108	87	50
1990	4	9	155	106	26	21	207	143	92	34
1991	4	8	145	100	26	20	196	134	89	32
1992	4	6	133	93	26	17	136	91	57	25
1993	2	4	87	60	16	14	138	95	61	22
1994	1	5	57	38	7	8	93	66	44	15
1995	2	11	95	61	6	8	94	67	51	19
1996	3	13	125	81	11	10	103	71	43	13

Table 5. Method of estimating underreporting (424%) for the inriver commercial shad fishery in the Santee River SC based on the 1991 and 1992 data. The u is the annual inriver harvest for female shad based on inriver tagging (Appendix 10).

Year	Reported Landings #[1/]	u	Stock Size #[2/]
1991	13,280	0.13	440,250
1992	15,131	0.17	366,750

UNDERREPORTING

1991 433% = (0.13 / 0.030) * 100

1992 415% = (0.17 / 0.041) * 100

1/ Commercial landings in numbers were estimated by dividing reported landings in lbs. by 3.5 lbs.

2/Santee River stock size was estimated by assuming that 40% of the annual run was passed each year into the Rediversion canal (Billy McCord pers. comm.).

Table 6. Input parameters for the Thompson-Bell Yield-Per-Recruit Model (YPR) for each shad stock to estimate F_c. Northern rivers include the Pawcatuck RI to Upper Chesapeake Bay MD. Southern rivers include the Edisto SC, Santee SC and Altamaha GA.

Input Parameter	Estimates	River system
Stock -Recruitment	See Table 2	
Maturation Schedule (female shad)	Ages 1-3 0.0	all rivers
	Age 4 0.20	all rivers
	Age 5 0.60	all rivers
	Ages 6+ 1.00	all rivers
Natural Mortality (M)	Ages 1-3 0.30	all rivers
	Ages 4-10 1.50	Northern rivers
	Ages 4-10 0.60	Hudson River
	Ages 4-8 2.50	Southern rivers
Partial Rec. Vector	Age 4 0.45	all rivers
	Age 5 0.90	all rivers
	Ages 6-10 1.00	all rivers
Growth Parameters (VB)	K = 0.32	all rivers
	t_o = 0.26	all rivers
	W = 10.0 lbs.	Northern rivers
	W = 7.0 lbs.	Southern rivers
	W = 13.0 lbs.	Hudson River

Table 7. Mean (1992-96) inriver fishing mortality rates (F_r), mean (1992-96) coastal fishing mortality (F_c) and mean total (1992-96) fishing mortality (F_{total}) (sexes combined) as compared to the overfishing definition (F_c) for American shad from selected Atlantic coast rivers.

River	F_r	F_c	F_{total}	F_c
Connecticut R.	0.13	0.09	0.22	0.43
Hudson R.[1/]	0.17	0.16	0.33	0.39
Delaware R.	0.02	0.15	0.17	0.43
Upper Bay MD	0.01	0.11	0.12	0.43
Edisto R.[2/]	0.21	0.24	0.45	0.48
Santee R.	0.17	0.02	0.19	0.48
Altamaha R.	0.36	0.03	0.39	0.48

1/ 1995 population size (without coastal landings) = 526,000 based on 1951 tag-recapture study in the Hudson R. (Talbot 1954).

2/ Current fishing mortality rate (F) for Edisto R. based on the 1994-97 F estimates (Table 10).

Table 8. Estimates of inriver (F_r), coastal (F_c) and total (F_t) fishing mortality rates for shad (sexes combined) in the Edisto and Santee Rivers from 1989 to 1997 based on tagging (Appendix 10).

Year	Edisto			Santee		
	F_r	F_c	F_t	F_r	F_c	F_t
1989	0.67	0.34	1.01	-	-	-
1990	0.67	0.24	0.91	0.06	0.15	0.21
1991	-	-	-	0.14	0.06	0.20
1992	-	-	-	0.19	0.07	0.26
1993	-	-	-	0.11	0.06	0.17
1994	0.34	0.22	0.56	0.07	0.02	0.09
1995	0.21	0.28	0.49	0.12	0.01	0.13
1996	0.13	0.25	0.38	0.33	0.01	0.34
1997	0.16	0.19	0.35 [1/]	-	-	-

1/ Since commercial landings are not yet available in the Edisto for 1997 with which to estimate stock size, the 1997 coastal F estimates (F_c) was estimated indirectly as a direct proportion based on the average contribution of F_c in 1994, 1995 and 1996.

Figure 1. Reported Inriver Commercial Shad Landings (LBS. *1000) from the Atlantic Coast, 1980-1996

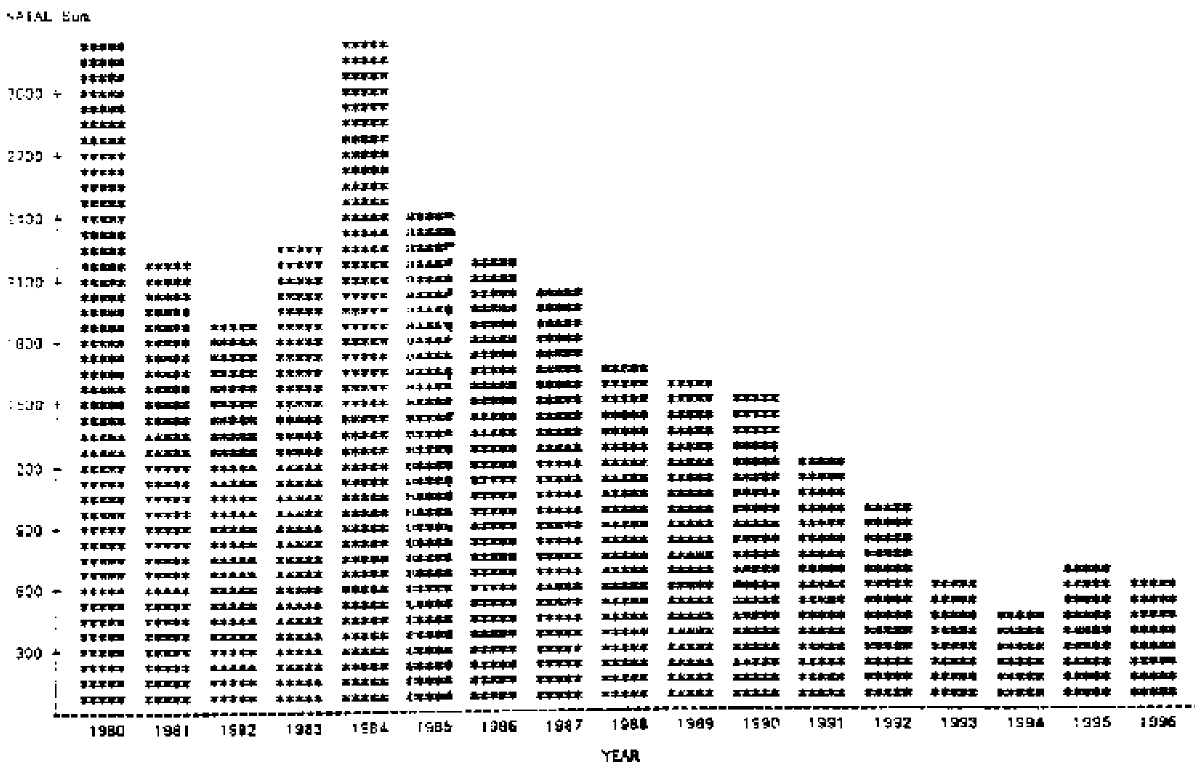


Figure 2. Reported Coastal Commercial Shad Landings (LBS. *1000) from the Atlantic Coast, 1980-1996

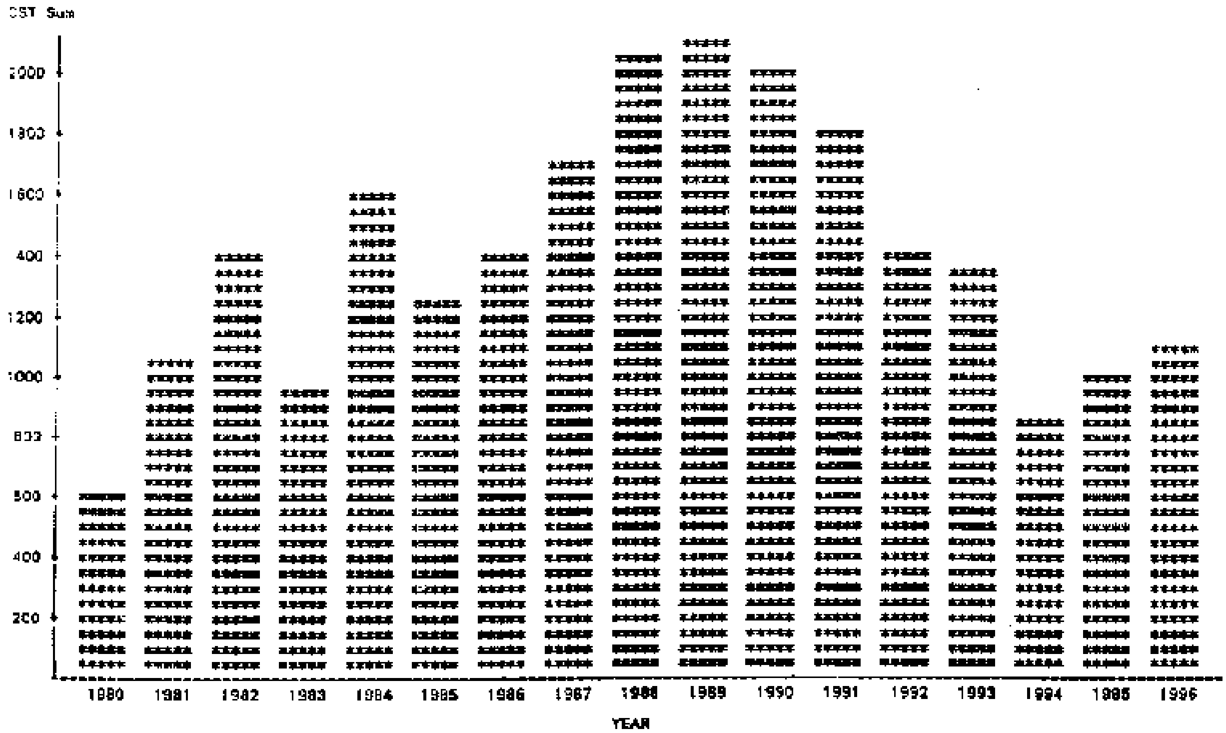


Figure 3. Overall Average Juvenile Shad Abundance Indices for Four Rivers in the State of Maine, 1979-1995

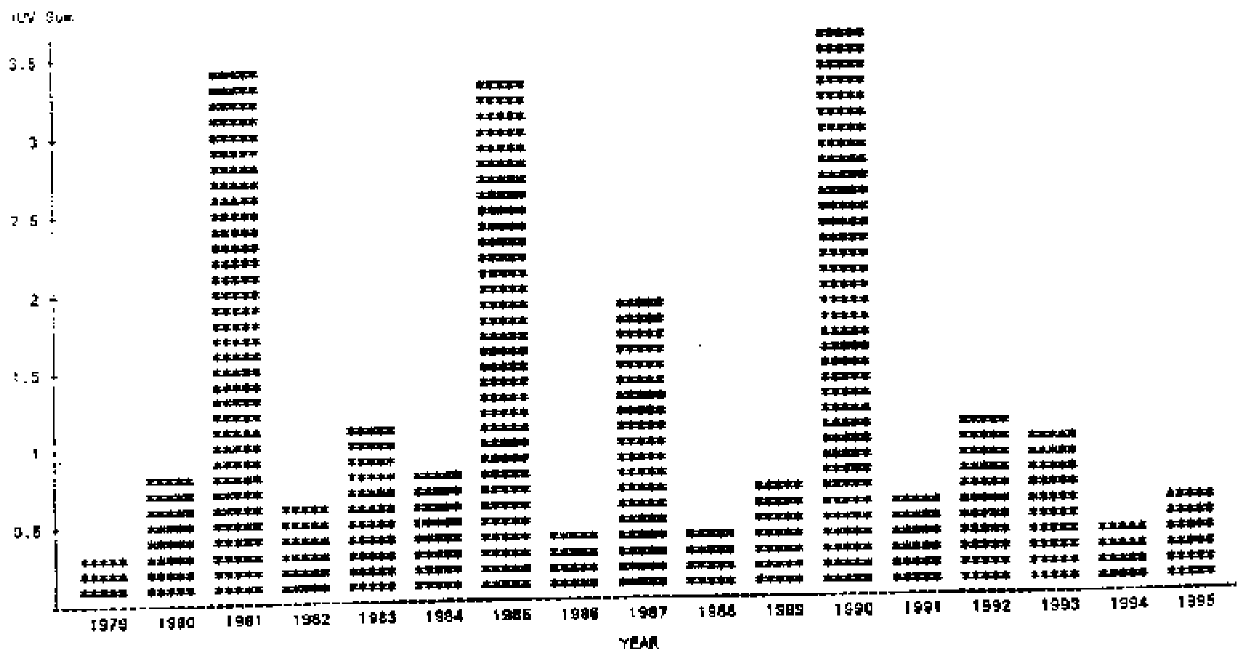


Figure 4. State-Wide Coastal Commercial Landings (LBS. *1000) of American Shad for the State of Maine, 1979-1992

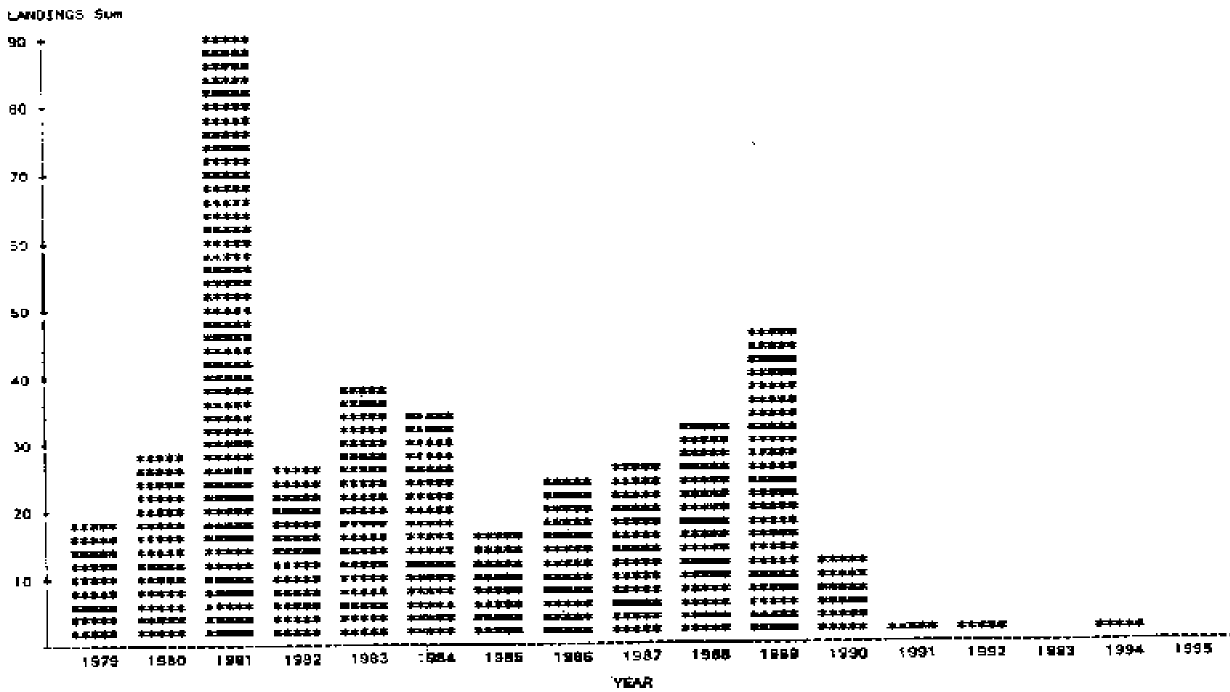


Figure 5. Relative Population Size (Mean Fish Lifted/Day) of American Shad in the Over the Essex Dam in the Merrimack R., 1983-1995

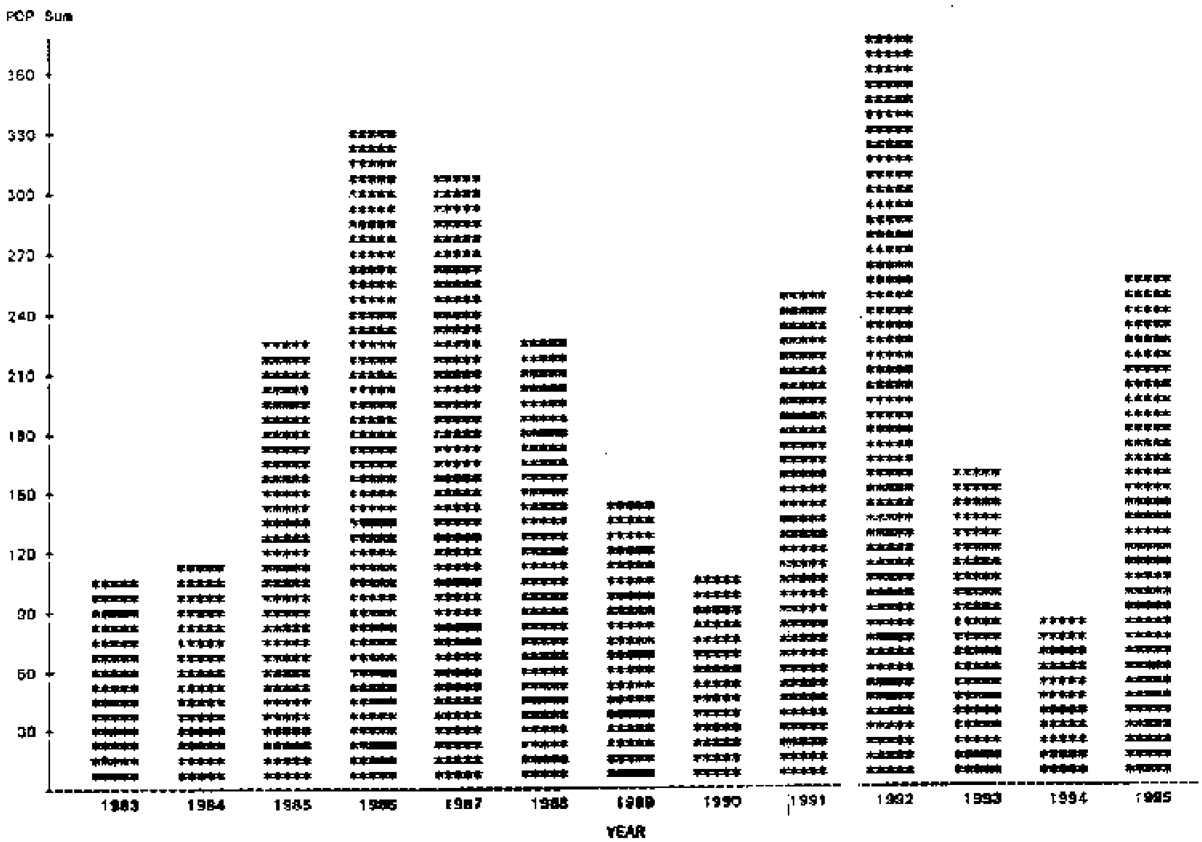


Figure 6. Population Size (LBS.) Entering the Pawcatuck River, 1974-1996

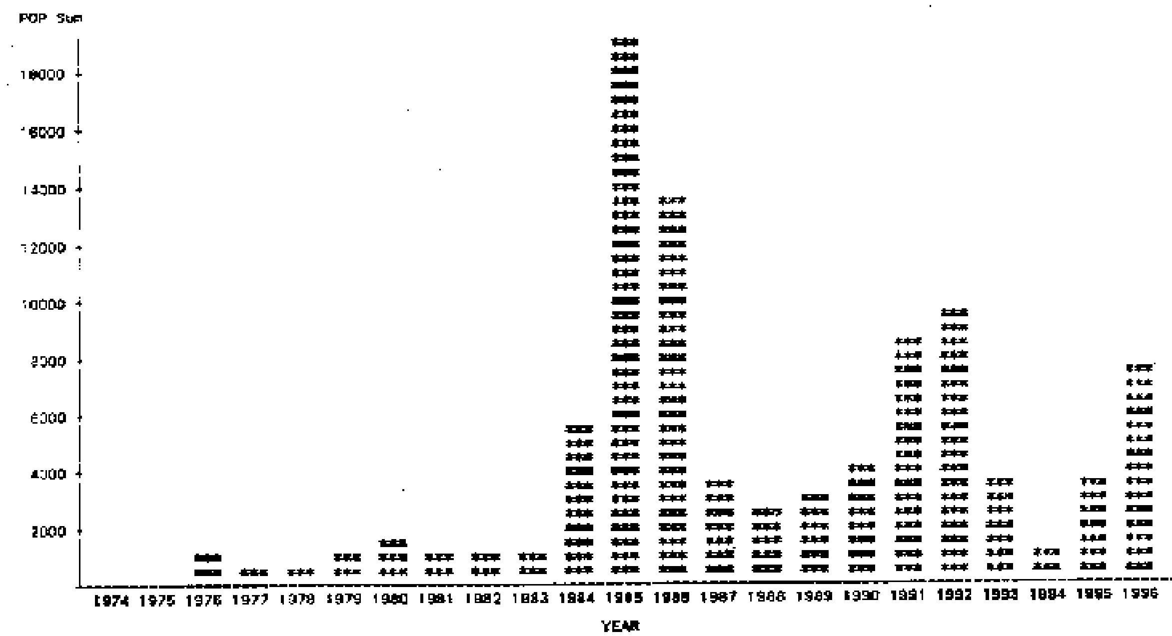


Figure 7. Juvenile Shad Indices of Abundance (Catch/Seine Haul) in the Pawcatuck River, 1977-1978 and from 1985-1996

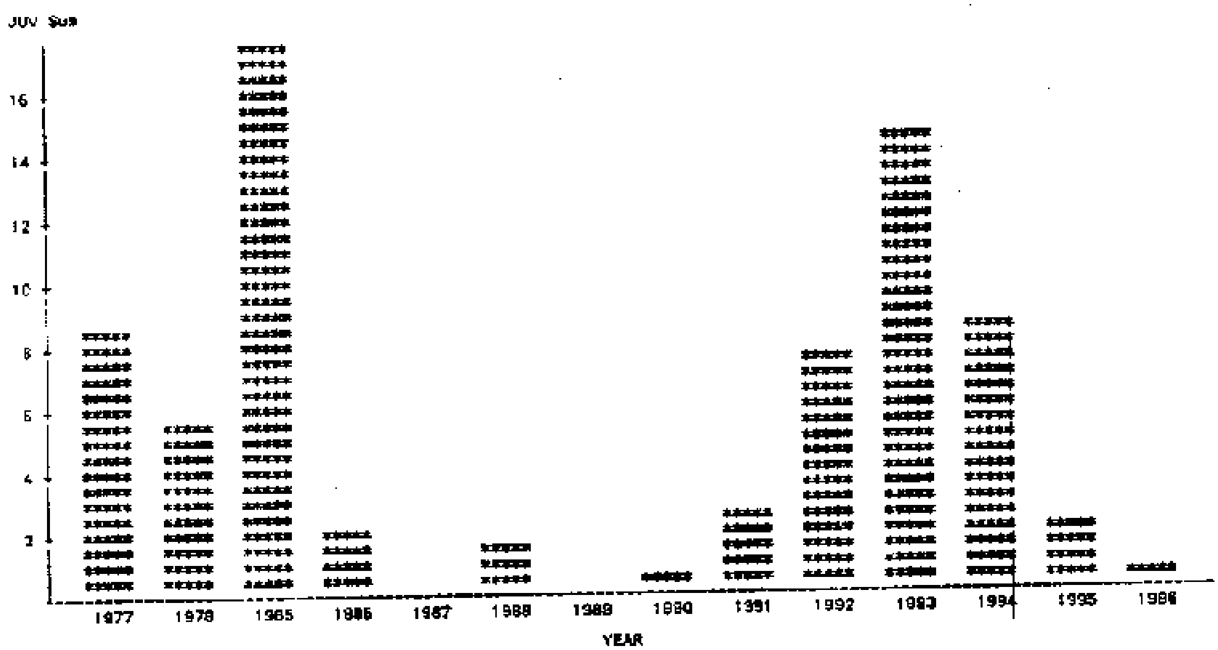


Figure 8. Total Mortality Estimates (Z) for American Shad in the Pawcatuck River, from 1981-1992

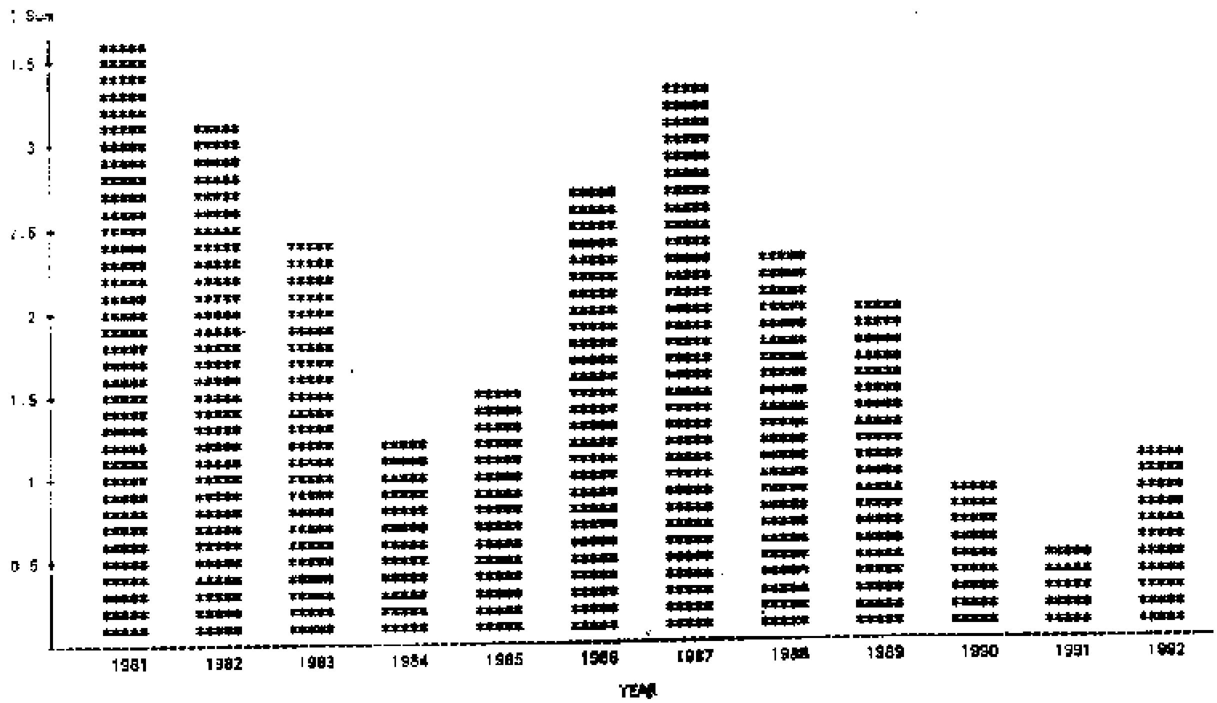


Figure 9. Population Size in Numbers (N *1000) of Connecticut River Shad, 1980-1997

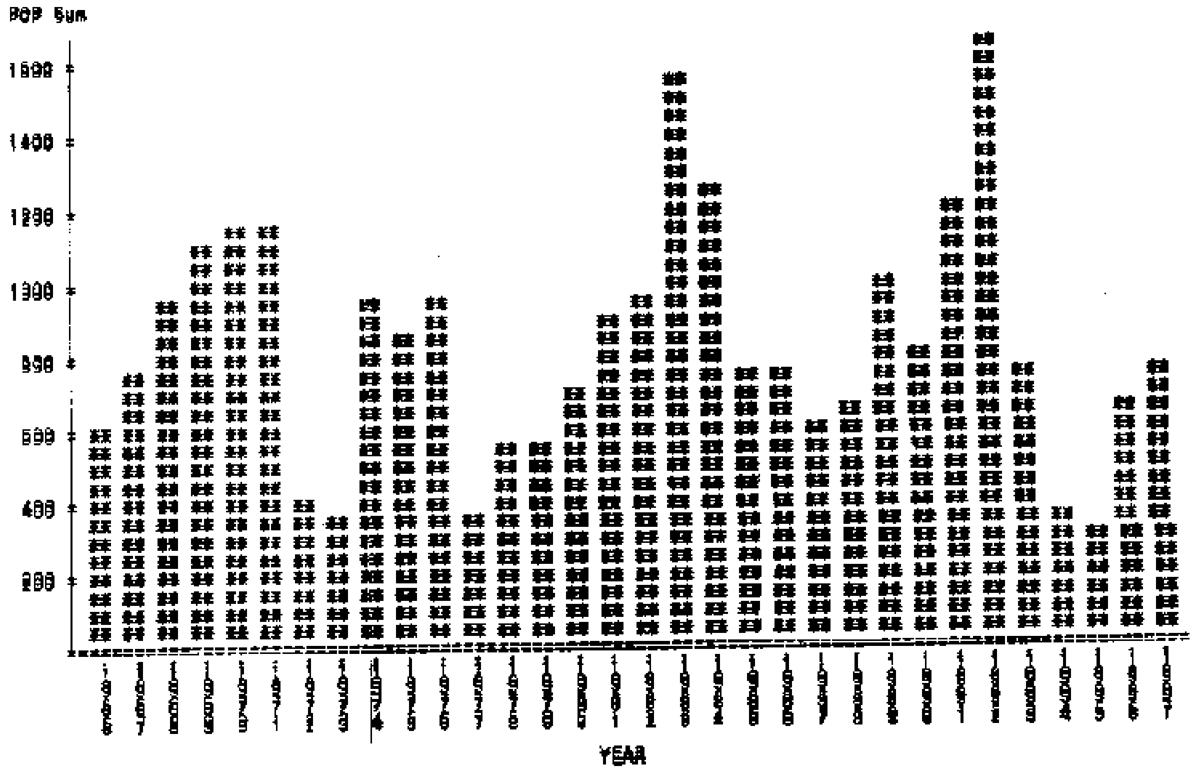


Figure 10. Fishing Mortality Rates from Commercial and Recreational Fishing on Connecticut River Shad, 1966-1996

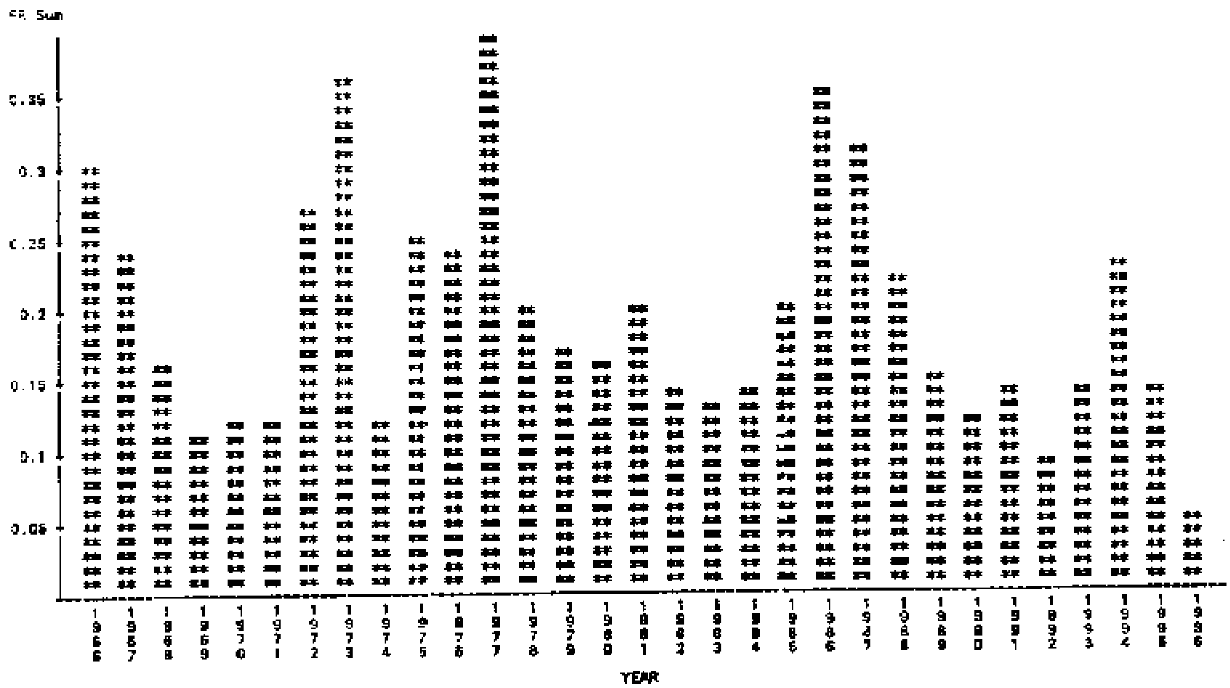


Figure 11. Fishing Mortality Rates (F) from the Coastal Commercial Fishery on Connecticut River Shad, 1980-1996

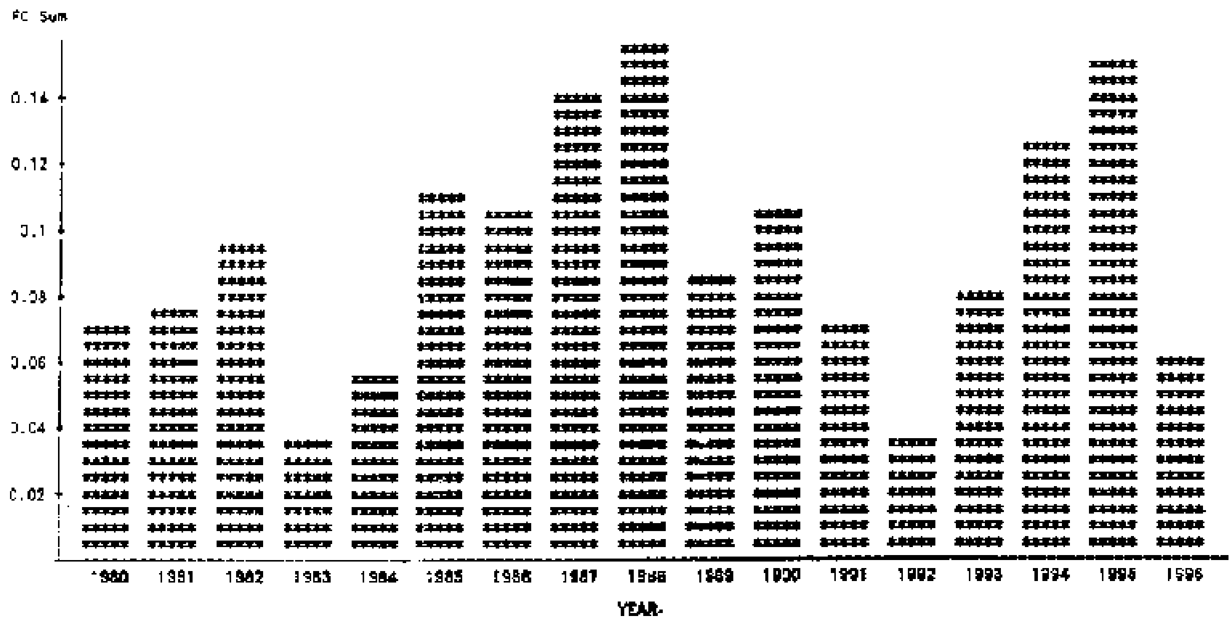


Figure 12. Total Fishing Mortality Rate from Commercial and Sport Fishing on Connecticut River Shad, 1980-1996

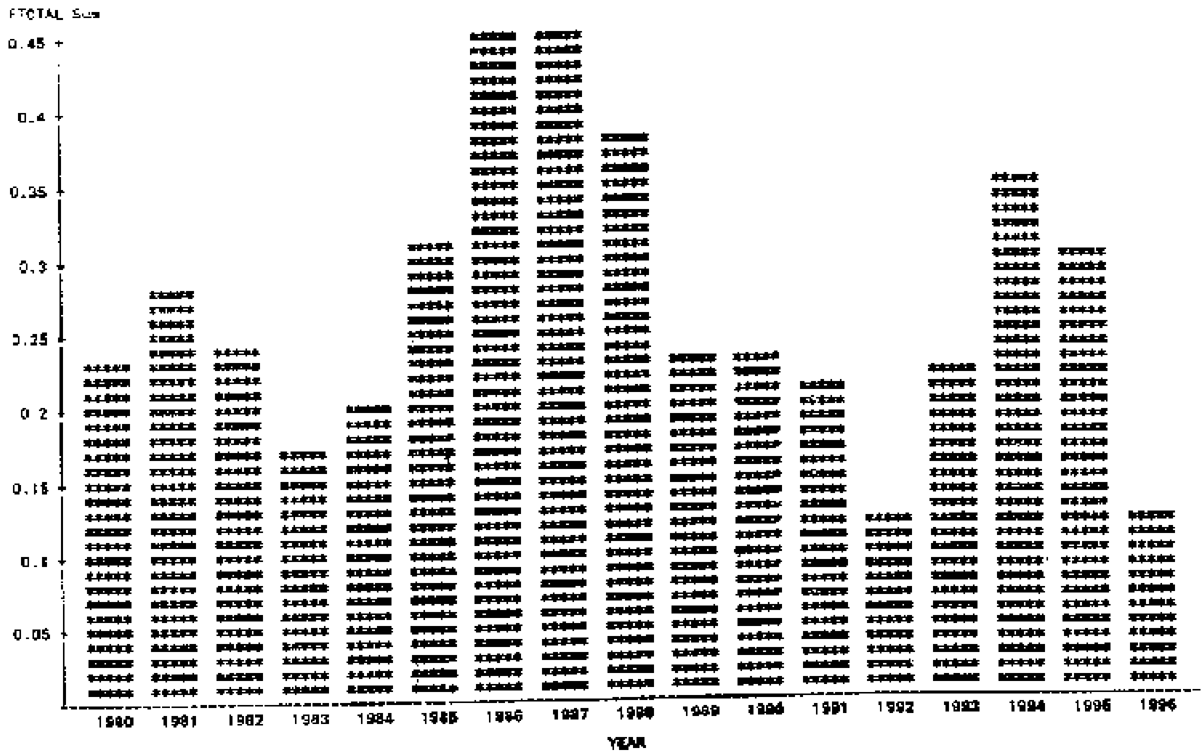


Figure 13. Recruitment Based on Scaled Juvenile Indices for Connecticut River Shad, 1966-1996

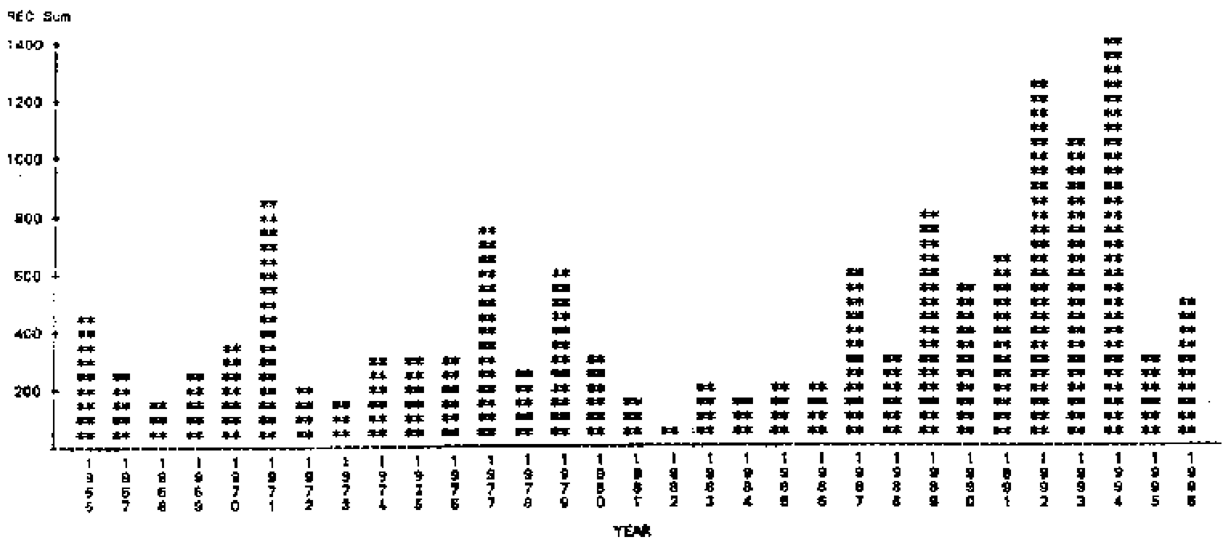


Figure 14. Population Size in Numbers of Hudson River Shad, 1980-1996, based on q estimate from Talbot, 1954

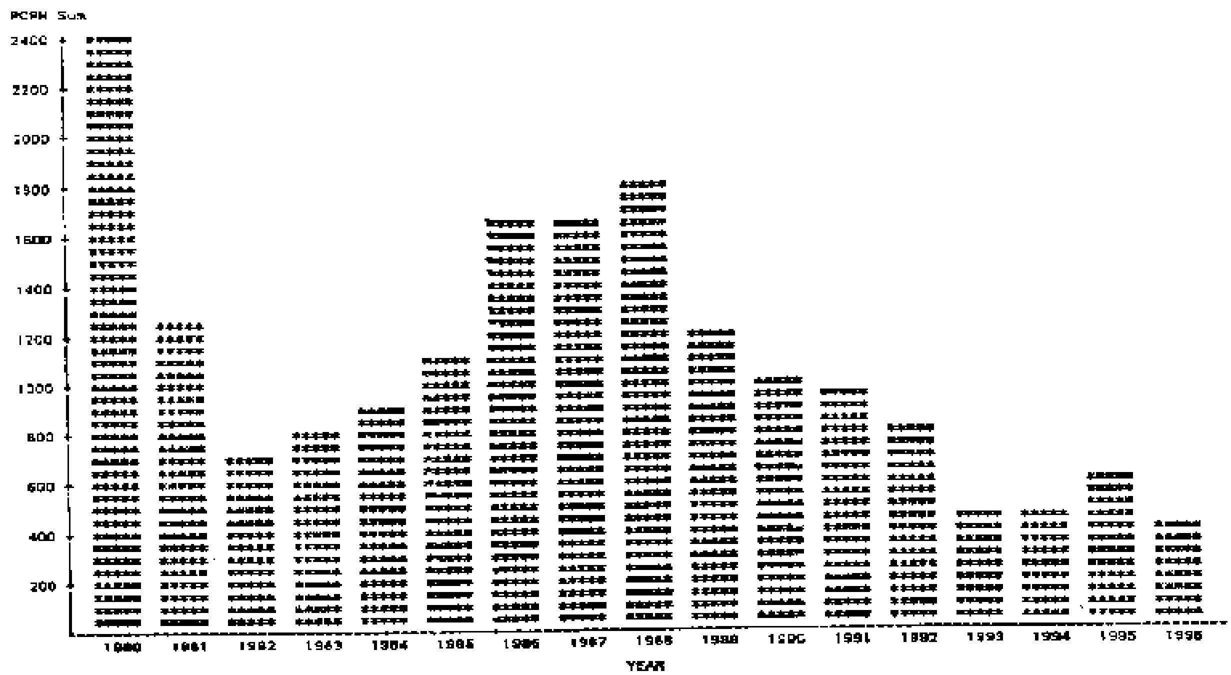


Figure 15. Commercial Shad Landings within the Hudson River, 1980-1996

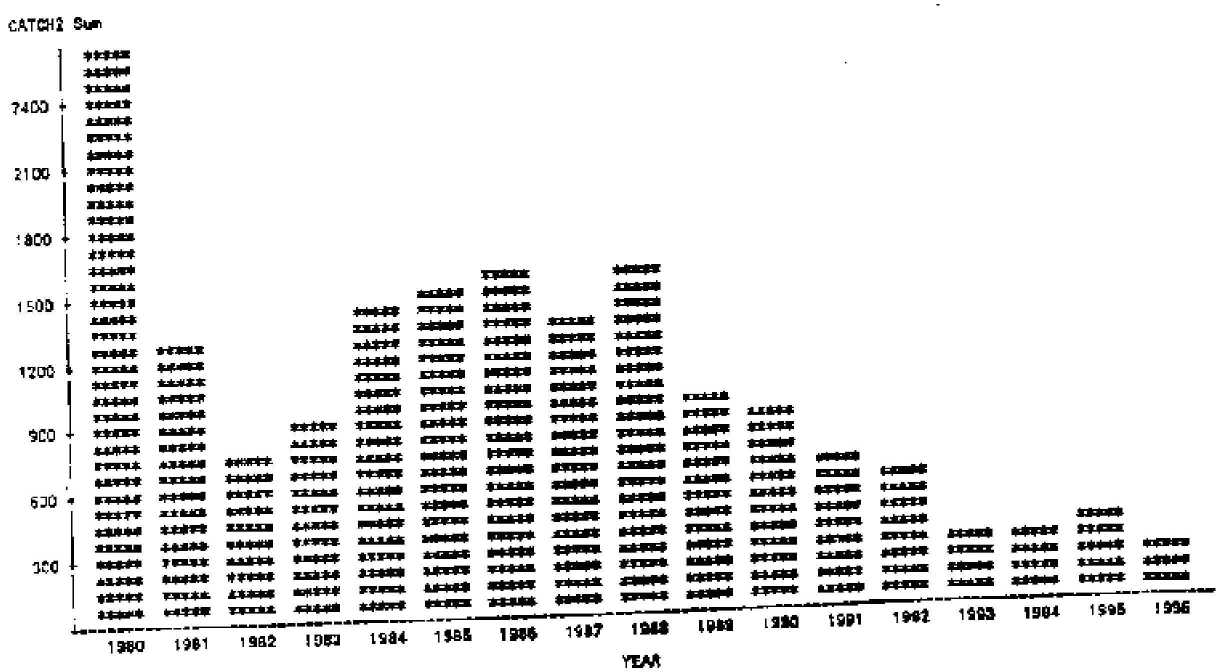


Figure 16. Fishing Mortality Rates from Inriver Commercial Fisheries on Hudson River Shad, 1980-1996, based on q estimate from Talbot, 1954

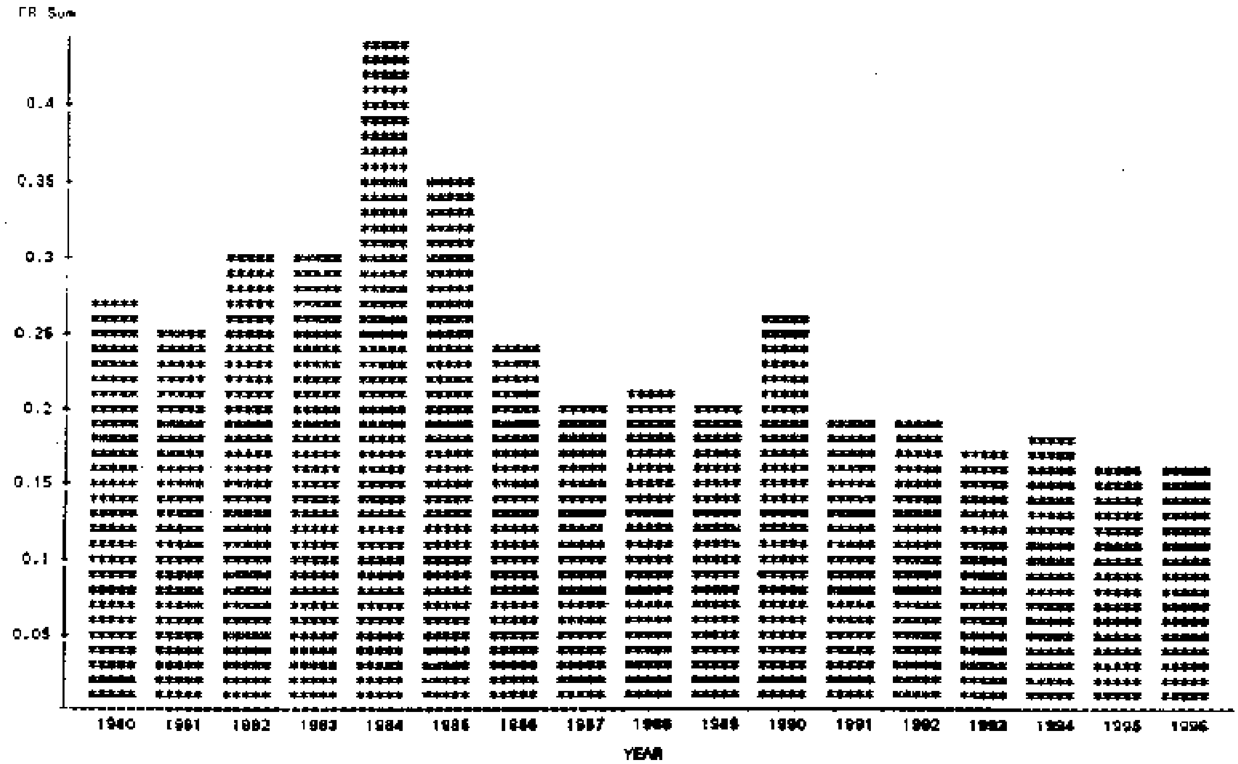


Figure 17. Fishing Mortality Rates from Coastal Commercial Fisheries on Hudson River Shad, 1980-1996, based on q estimate from Talbot, 1954

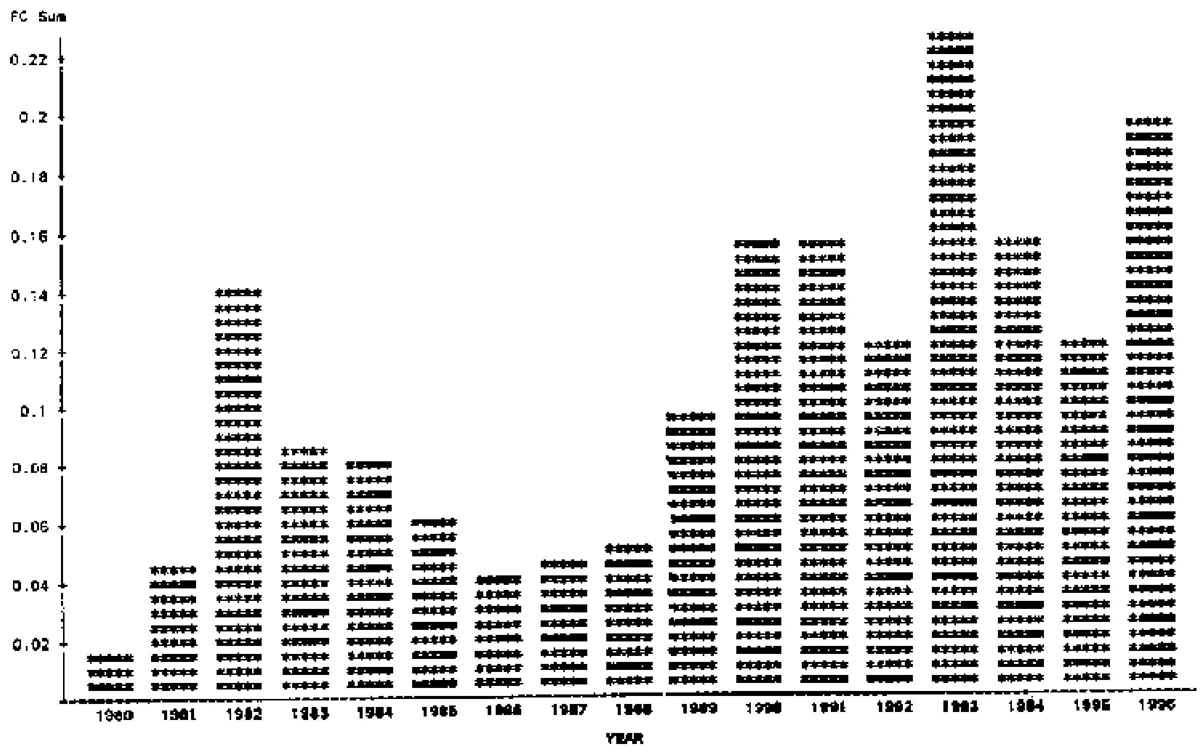
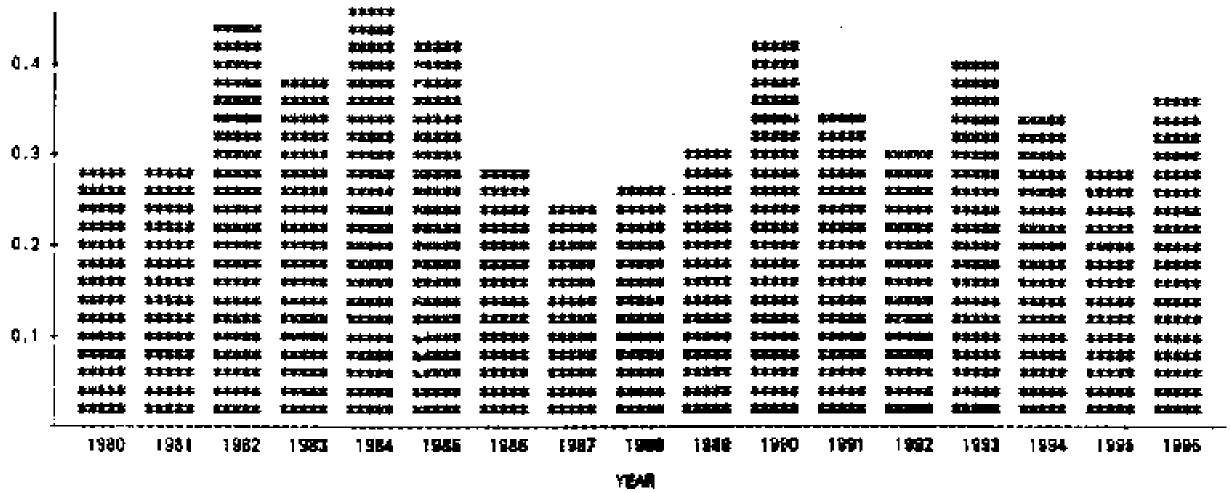


Figure 18. Total Fishing Mortality Rates on Hudson River Shad, 1980-1996, Based on q Estimate



from Talbot, 1954

Figure 19. Population Size in Numbers of Hudson River Shad, 1980-1996, Based on q Estimate from Hattala, 1997

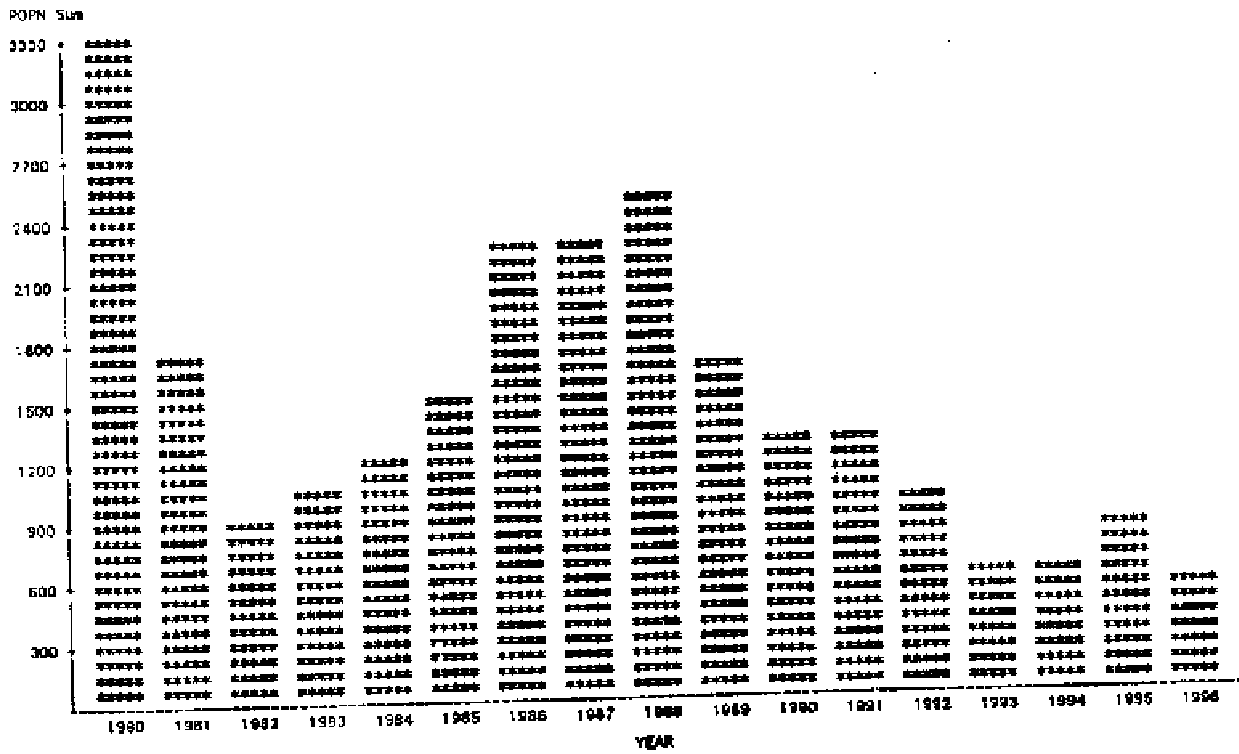


Figure 20. Fishing Mortality Rates from Inriver Commercial Fisheries on Hudson River Shad, 1980-1996, based on q estimate from Hattala, 1997

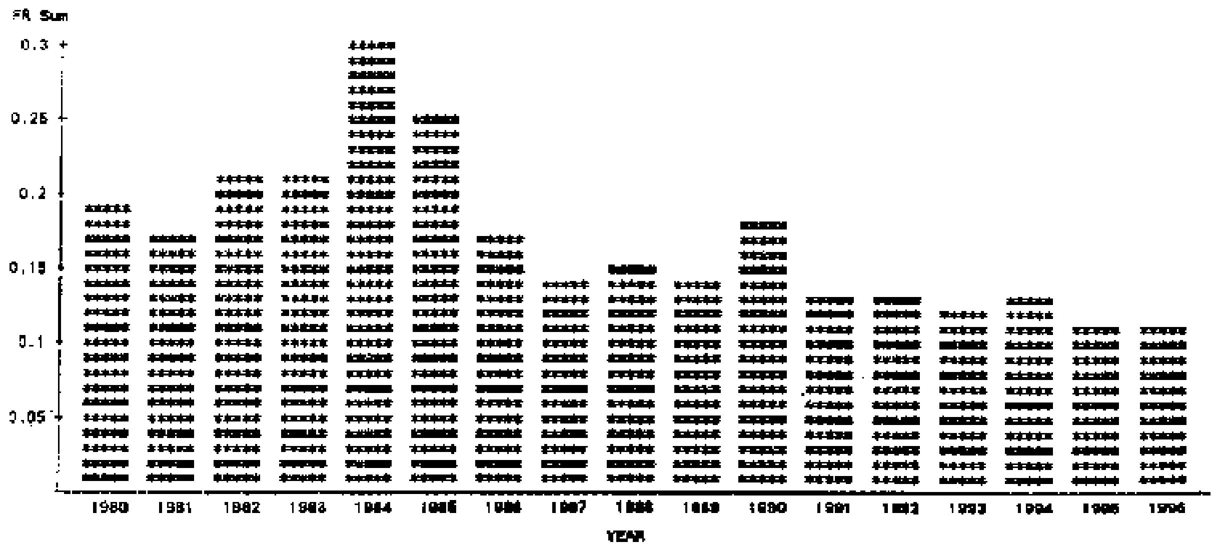


Figure 21. Fishing Mortality Rates from Coastal Commercial Fisheries on Hudson River Shad, 1980-1996, based on q estimate from Hattala, 1997

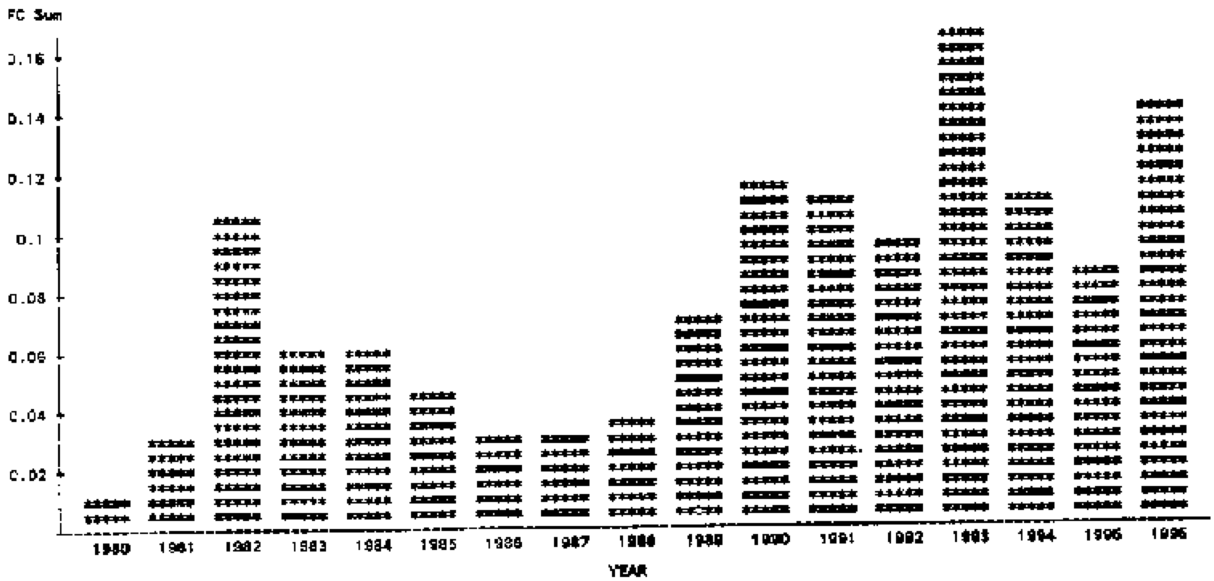


Figure 22. Total Fishing Mortality Rates from Coastal and Inriver Commercial Fisheries on Hudson River Shad, 1980-1996, based on q estimate from Hattala, 1997

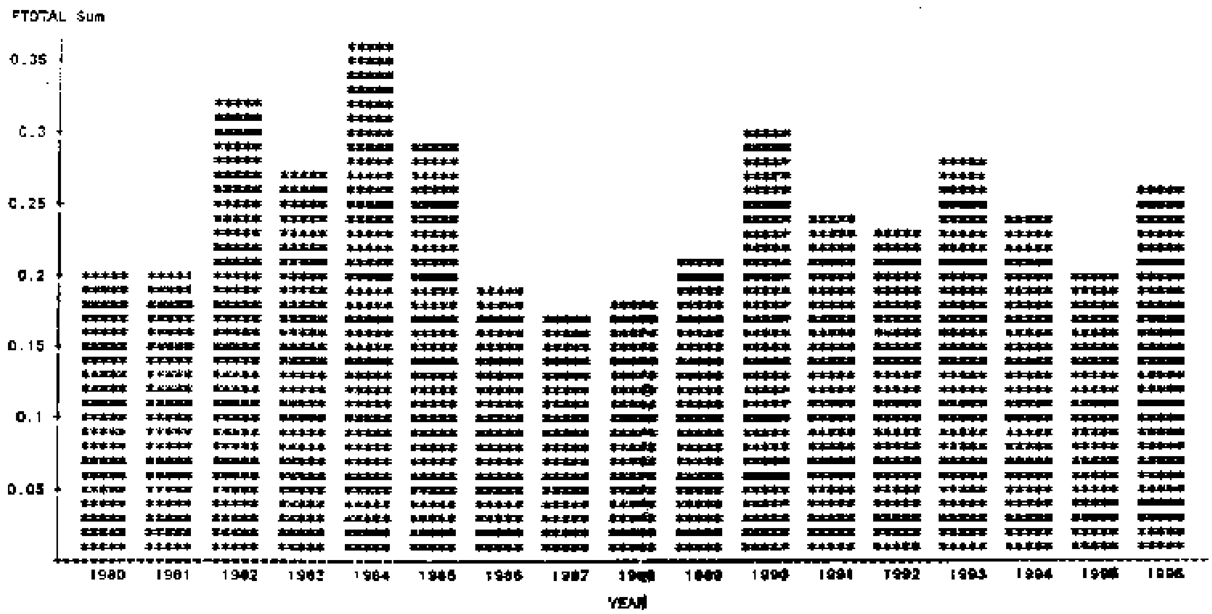


Figure 23. Postlarval Index of Recruitment (Catch/Tow) in the Hudson River, 1974-1994

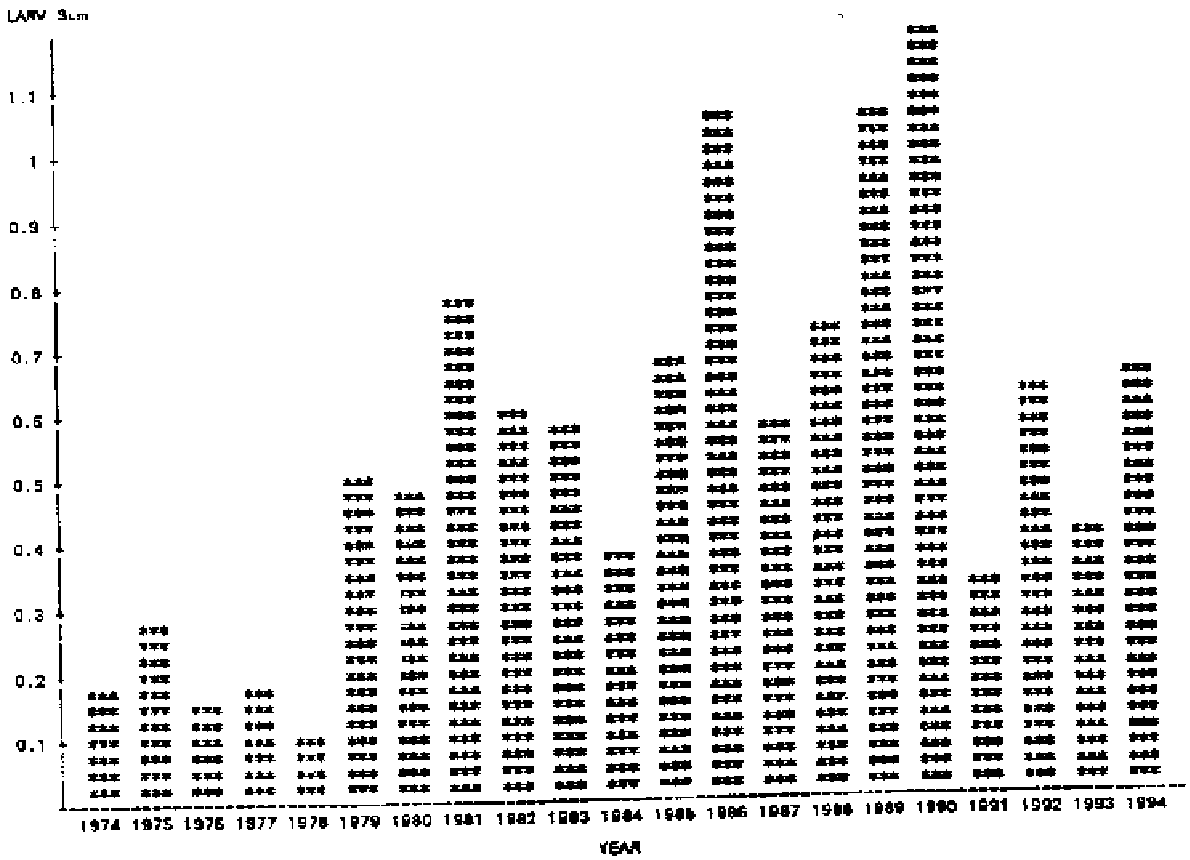


Figure 24. Population in Numbers for Delaware River Shad, 1980-1996

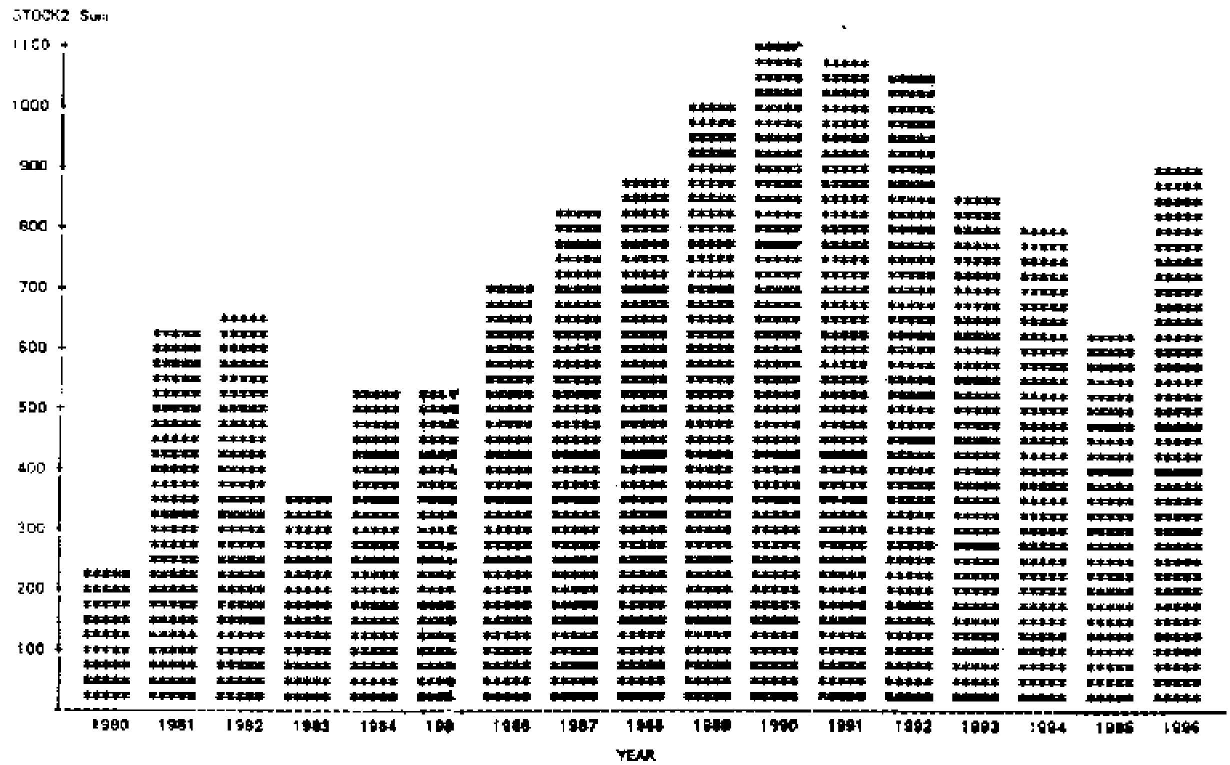


Figure 25. Recruitment Based on Scaled Juvenile Indices for Delaware River Shad, 1980-1996

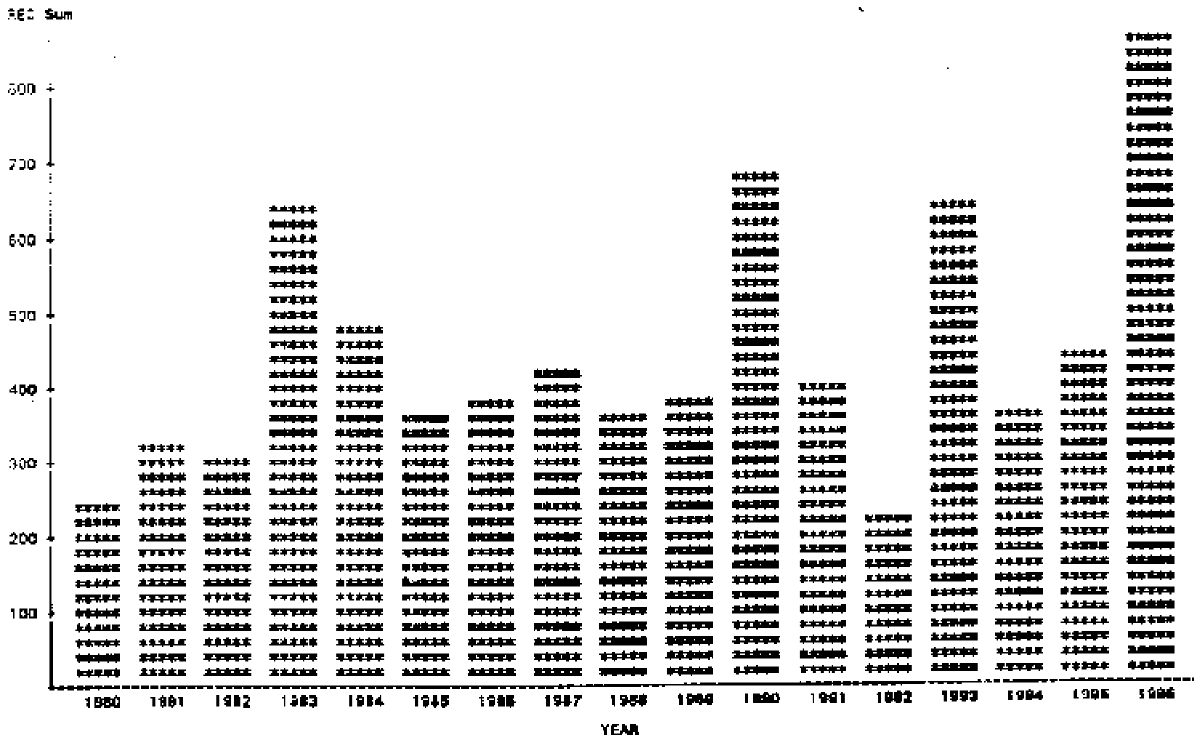


Figure 26. Inriver Fishing Mortality Rates (F) on Delaware River Shad, 1980-1996

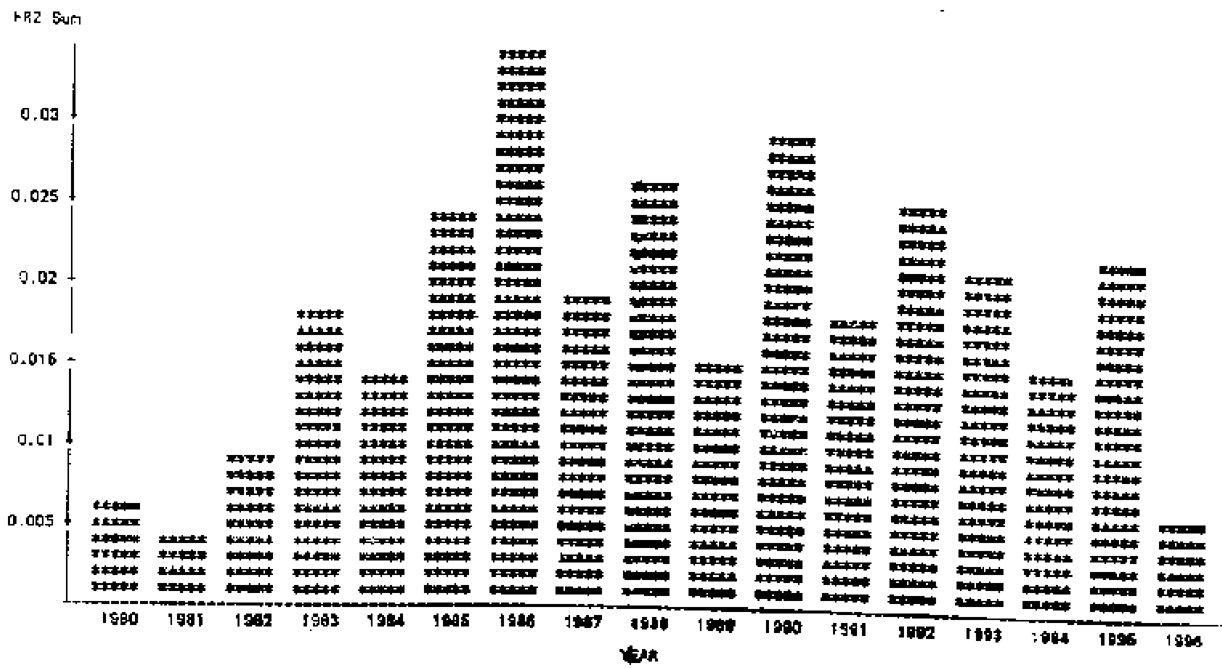


Figure 27. Coastal Fishing Mortality Rates (F) on Delaware River Shad, 1980-1996

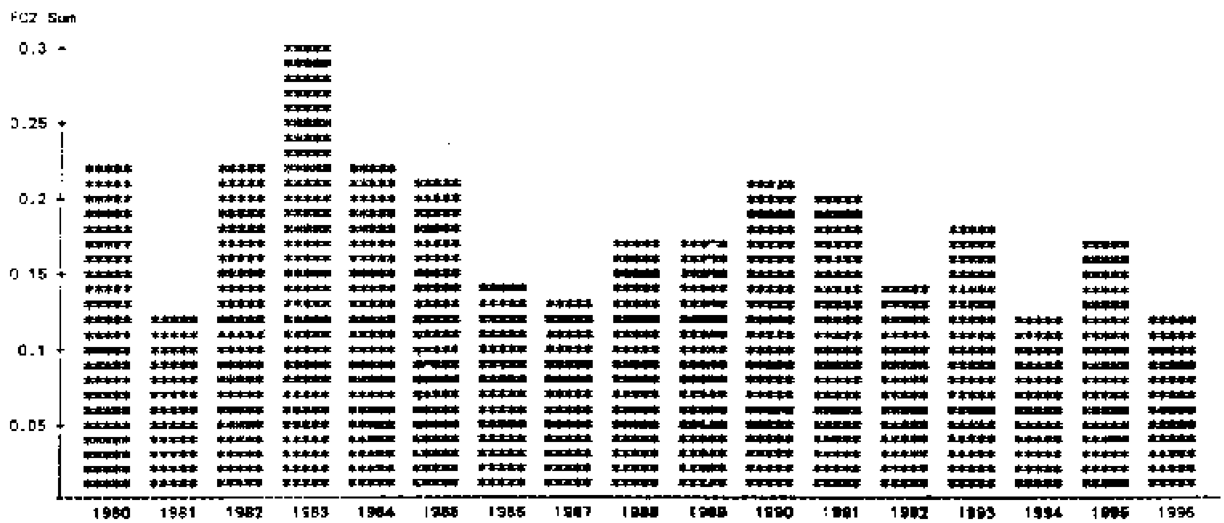


Figure 28. Total Fishing Mortality Rates (F) on Delaware River Shad, 1980-1996

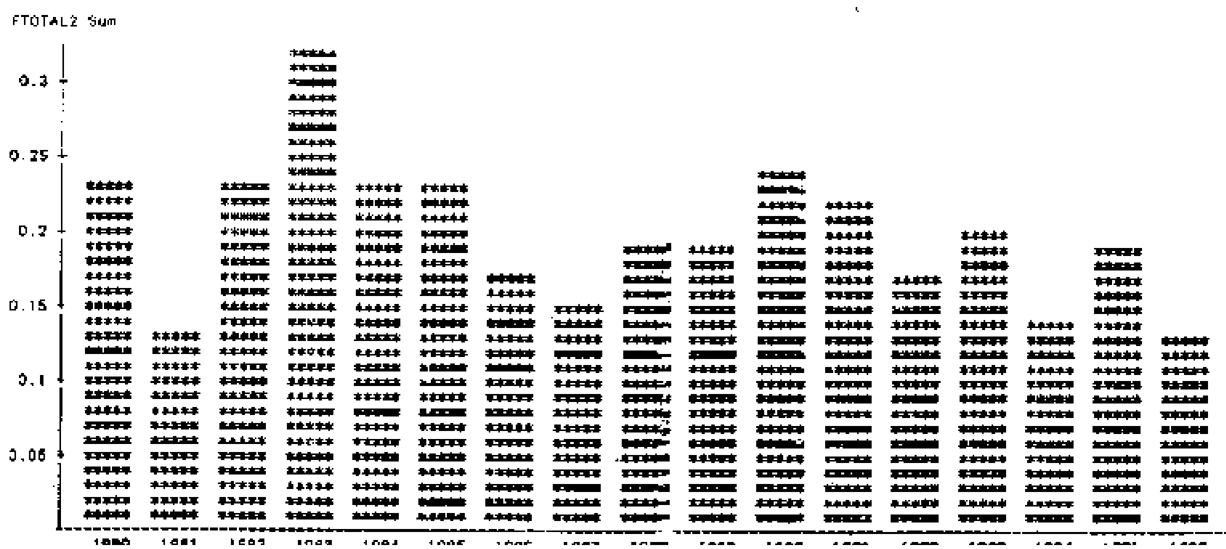


Figure 29. Total Stock Size of American Shad from the Upper Bay, 1980-1996

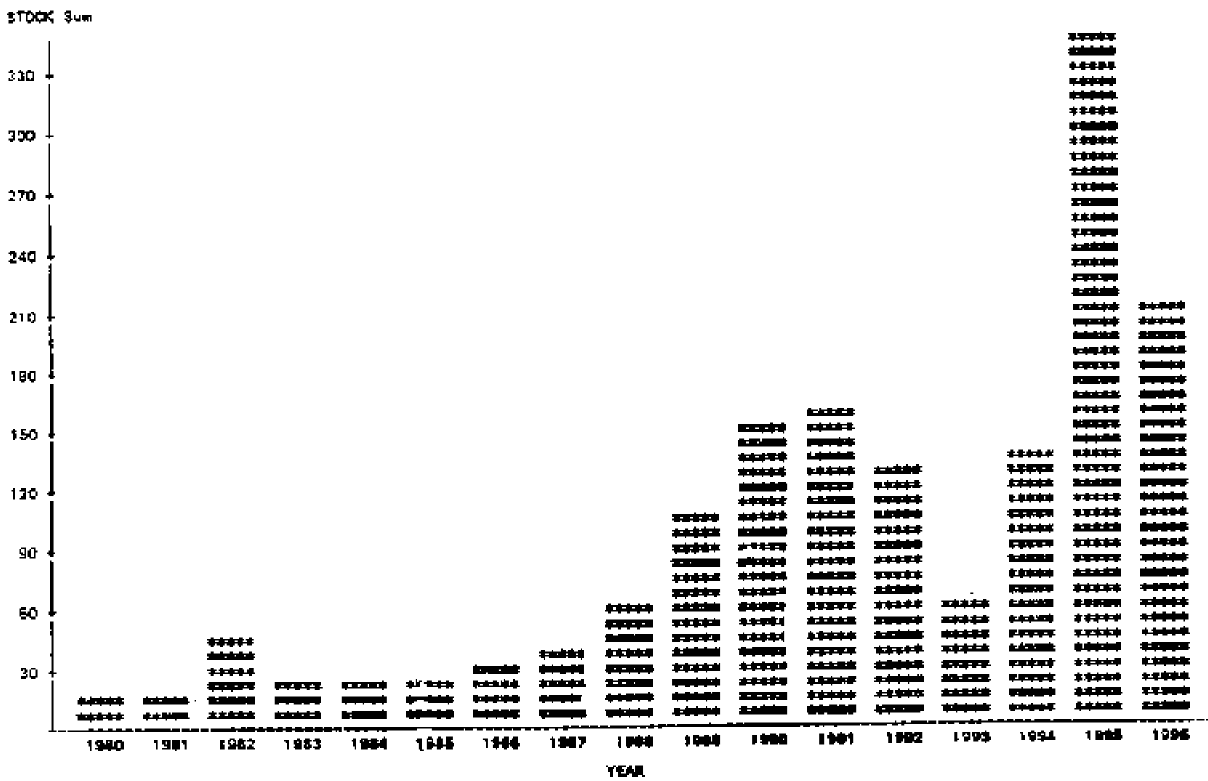


Figure 30. American Shad Natural Population Size to the Upper Bay, 1980-1996

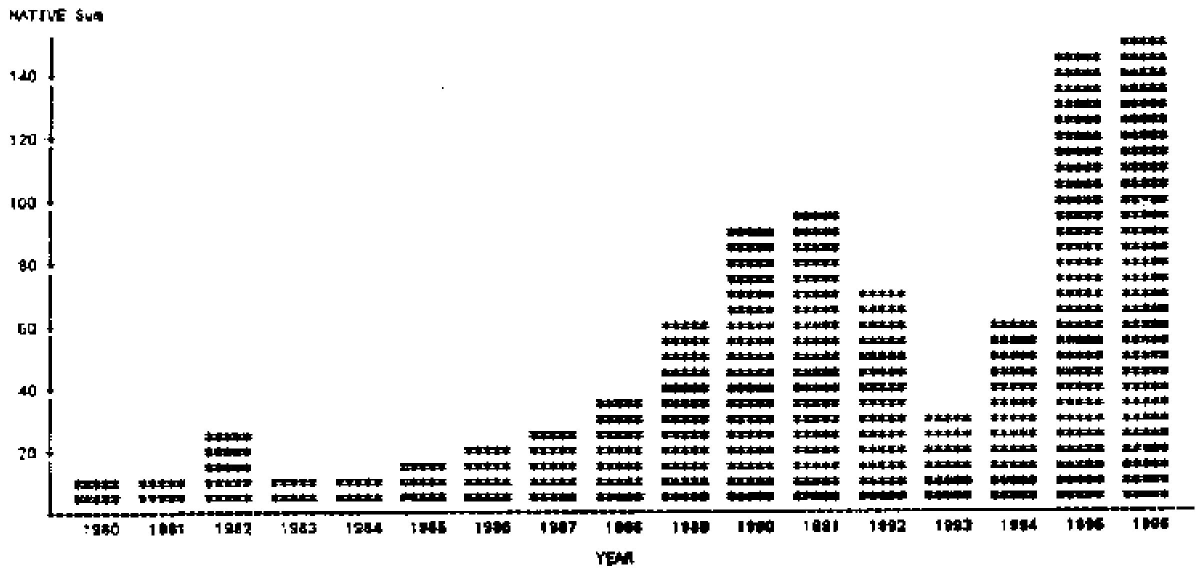


Figure 31. Juvenile Shad Relative Abundance from the Upper Bay, 1980-1995

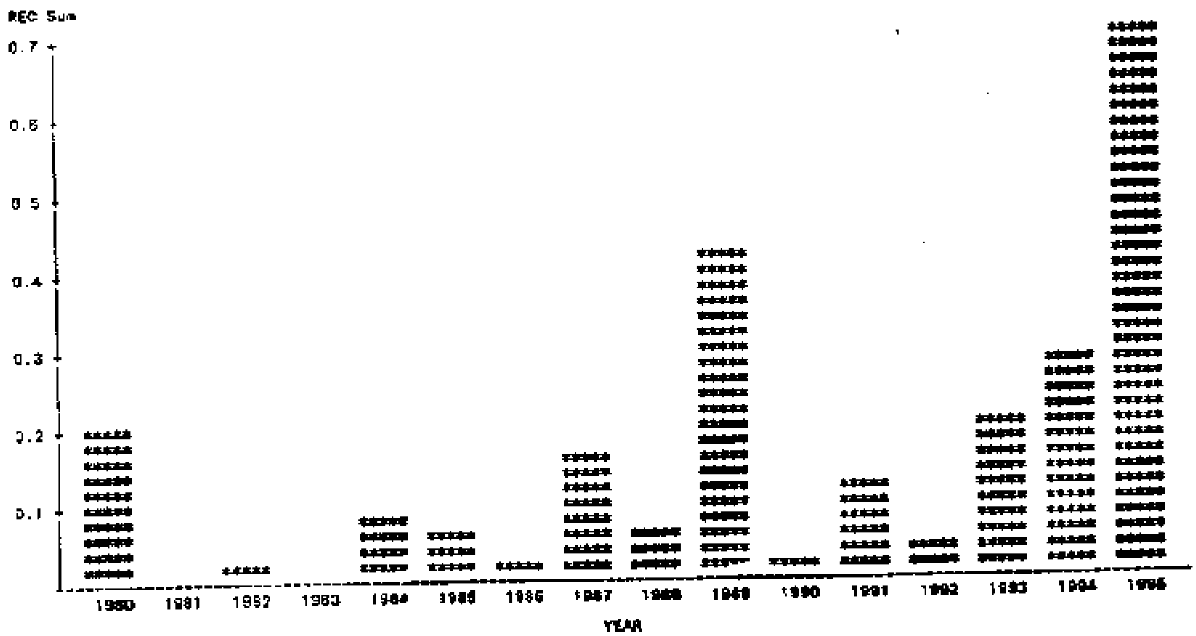


Figure 32. Coastal Fishing Mortality (F) Rates on American Shad from the Upper Chesapeake Bay, 1980-1996

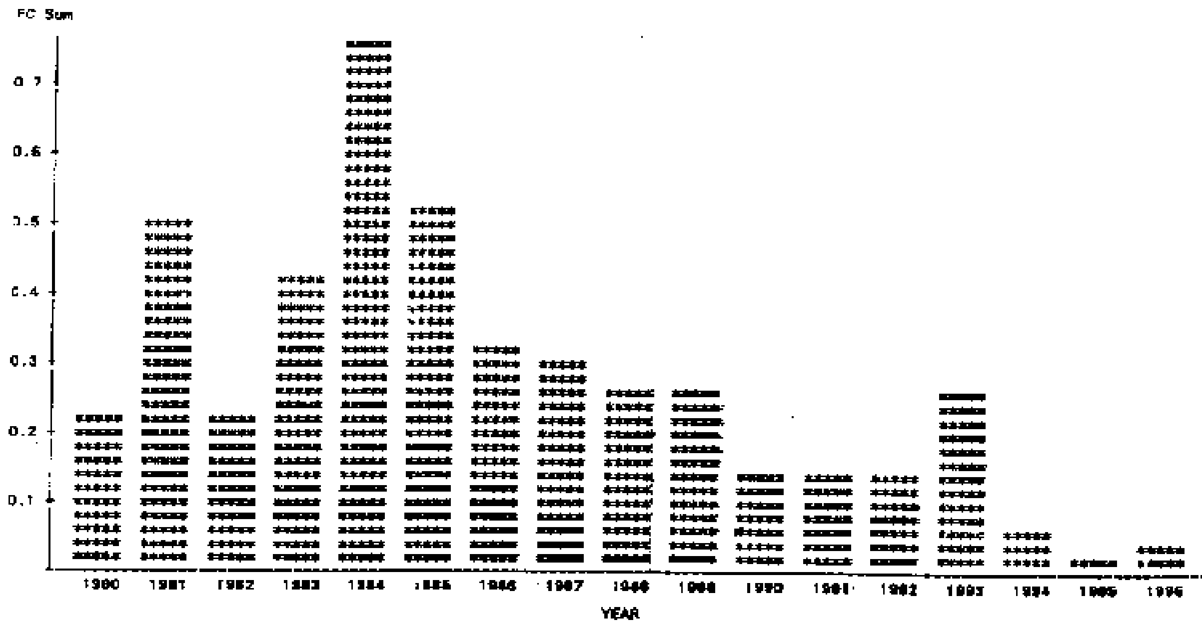


Figure 33. Natural Mortality Rates (M) on American Shad from Maryland Waters, 1980-1996

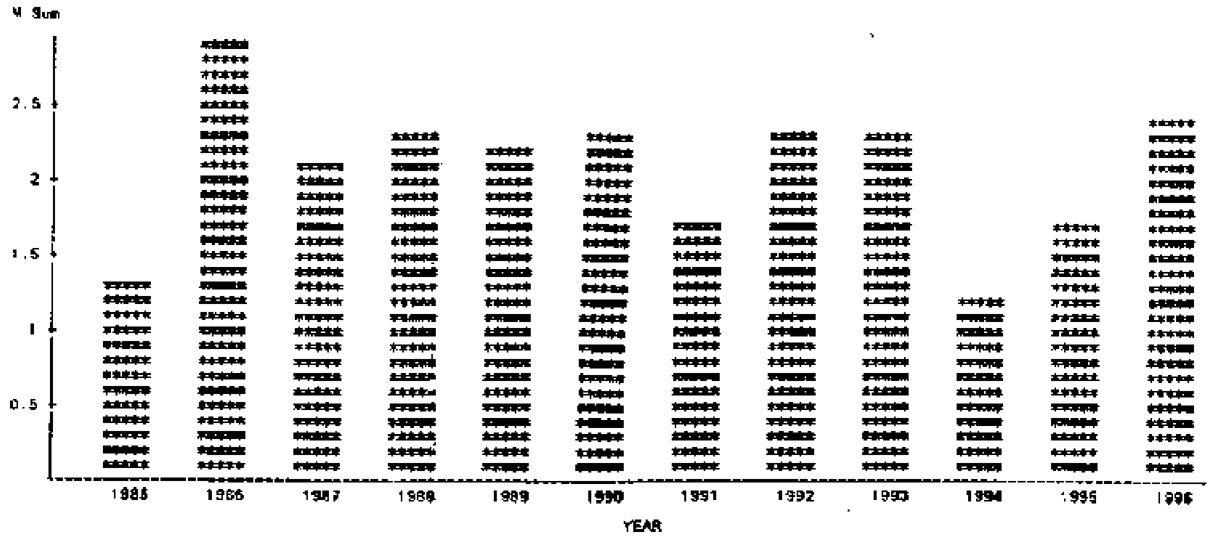


Figure 34. Rappahannock River Commercial Catch-Per-Effort for Female American Shad, 1980-1993

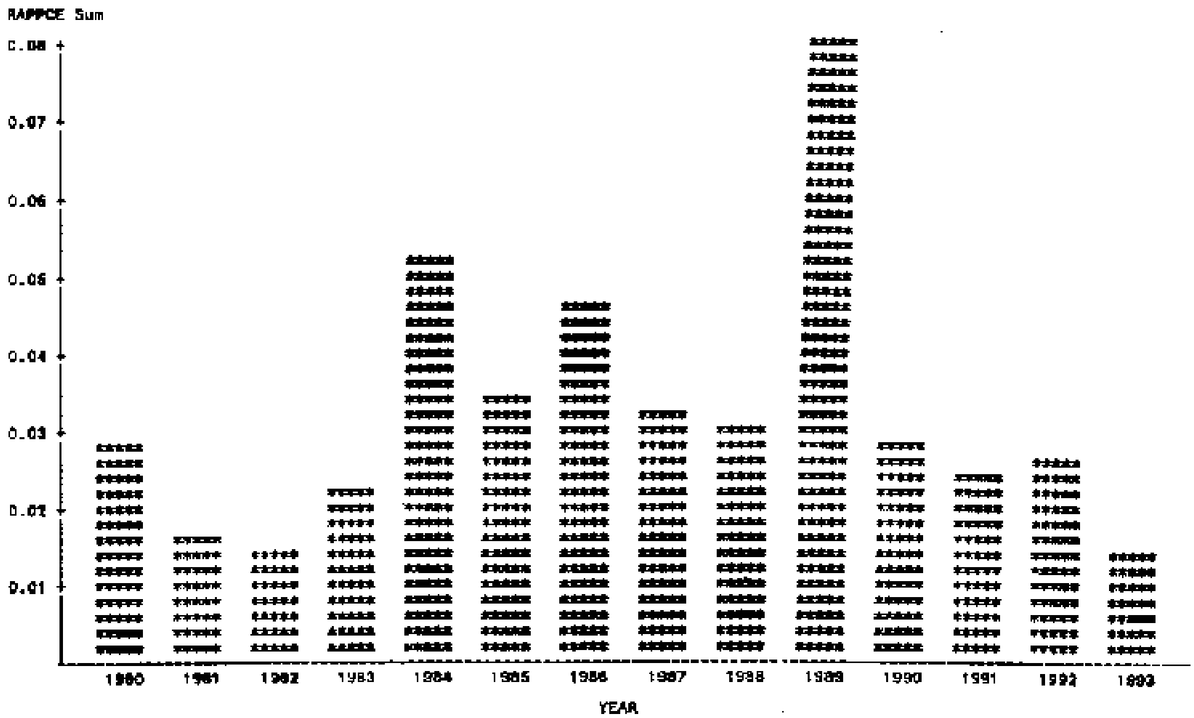


Figure 35. York River Commercial Catch-Per-Effort for Female American Shad, 1980-1993

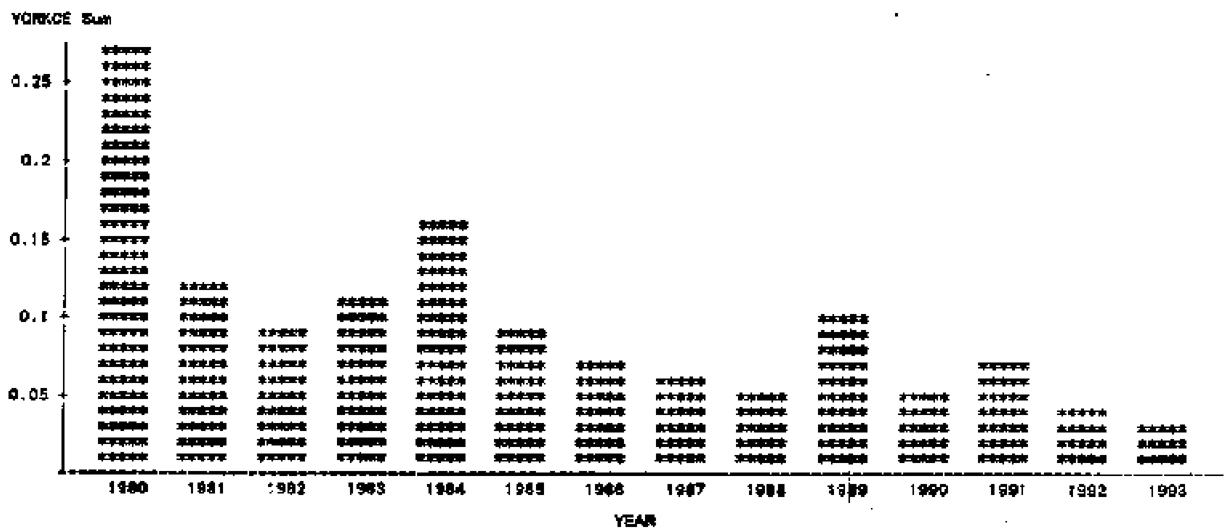


Figure 36. James River Commercial Catch-Per-Effort for Female American Shad, 1980-1993

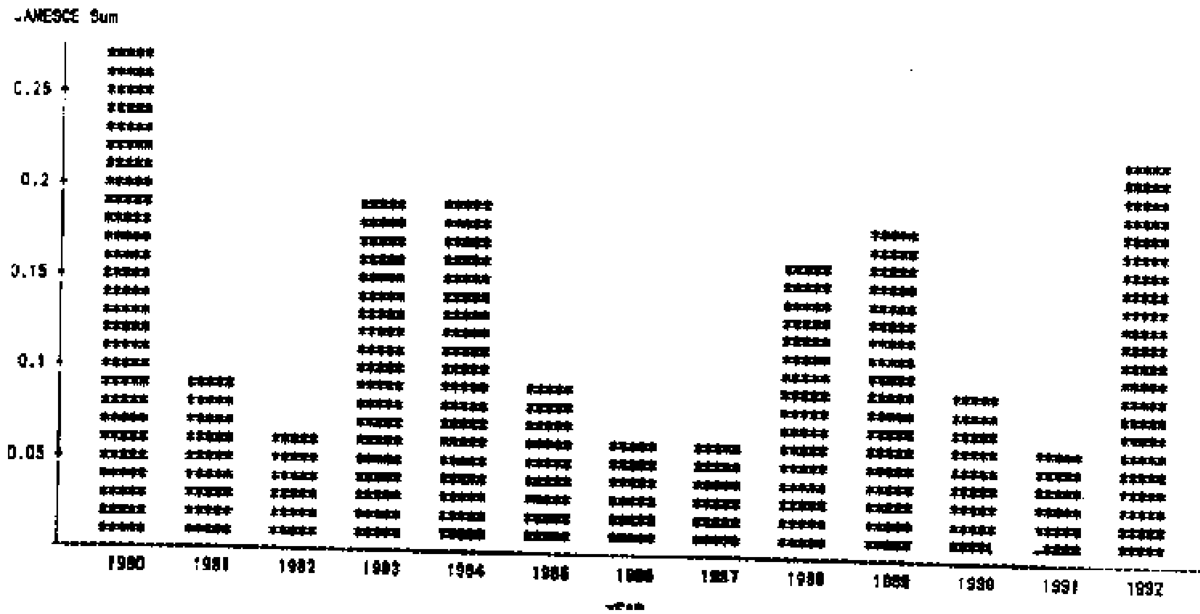


Figure 37. Relative Exploitation Rate on Rappahannock River Female Shad from the Coastal Commercial Fishery, 1980-1993

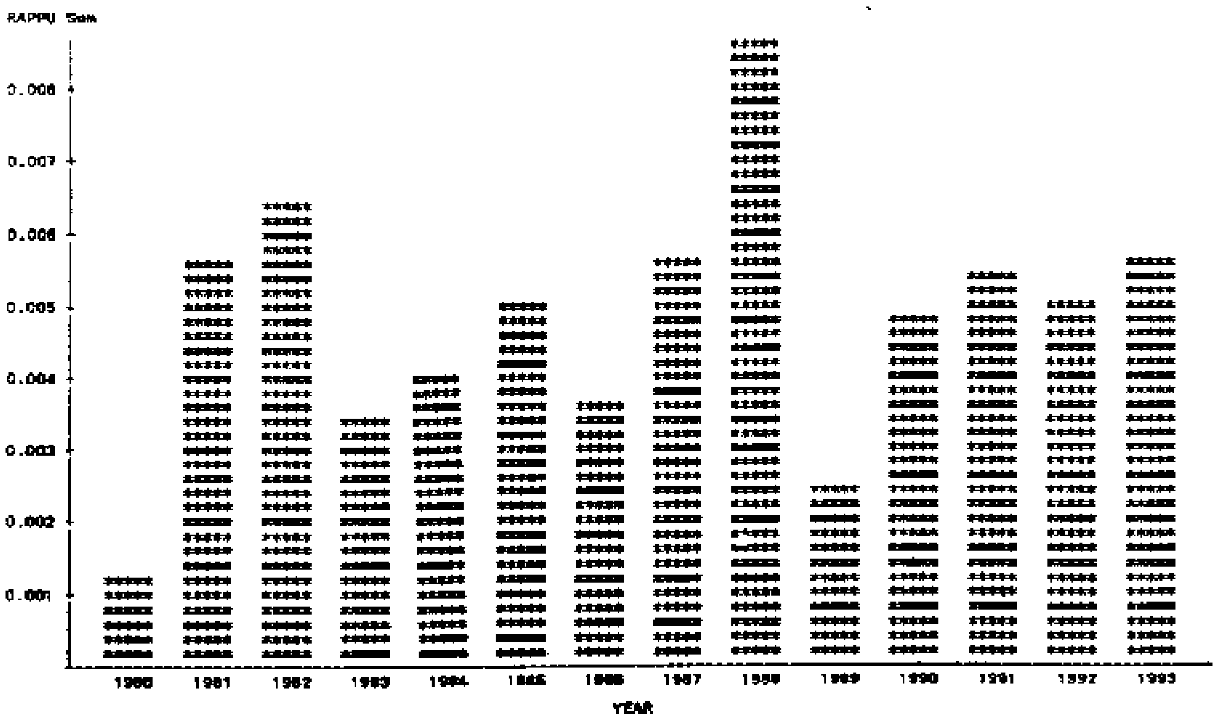


Figure 38. Relative Exploitation Rate on York River Female Shad from the Coastal Commercial Fishery, 1980-1993

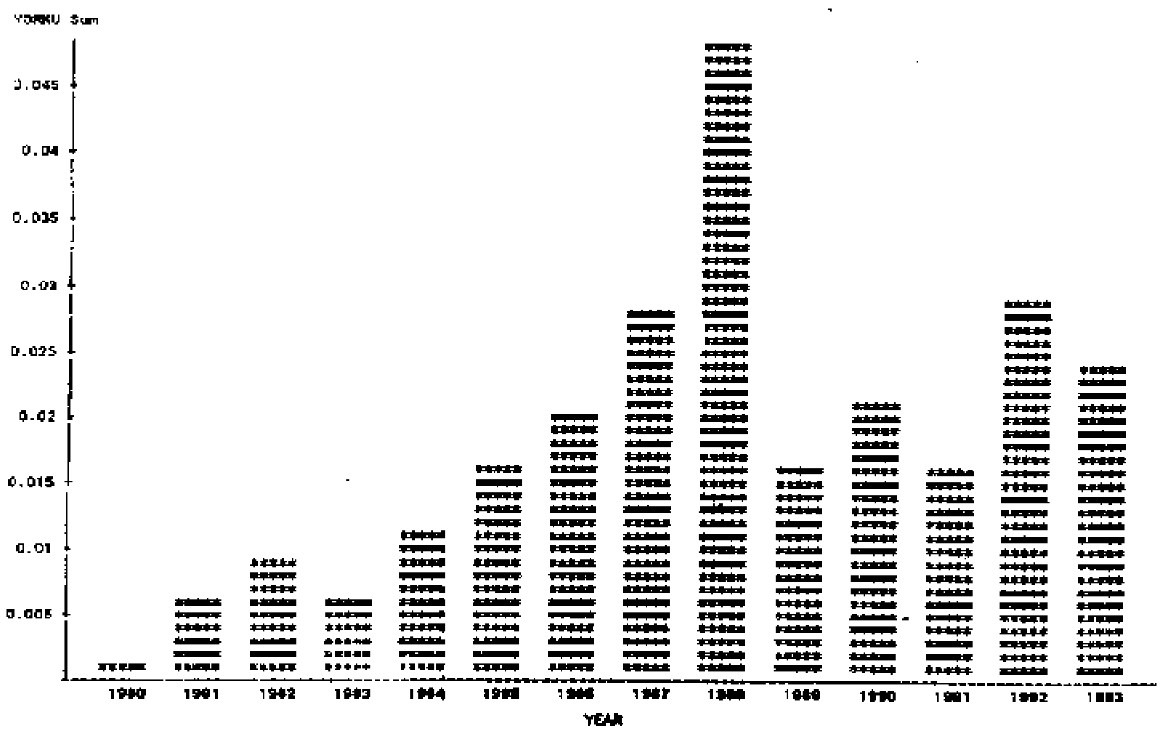


Figure 39. Relative Exploitation on James River Female Shad from the Coastal Commercial Fishery, 1980-1993

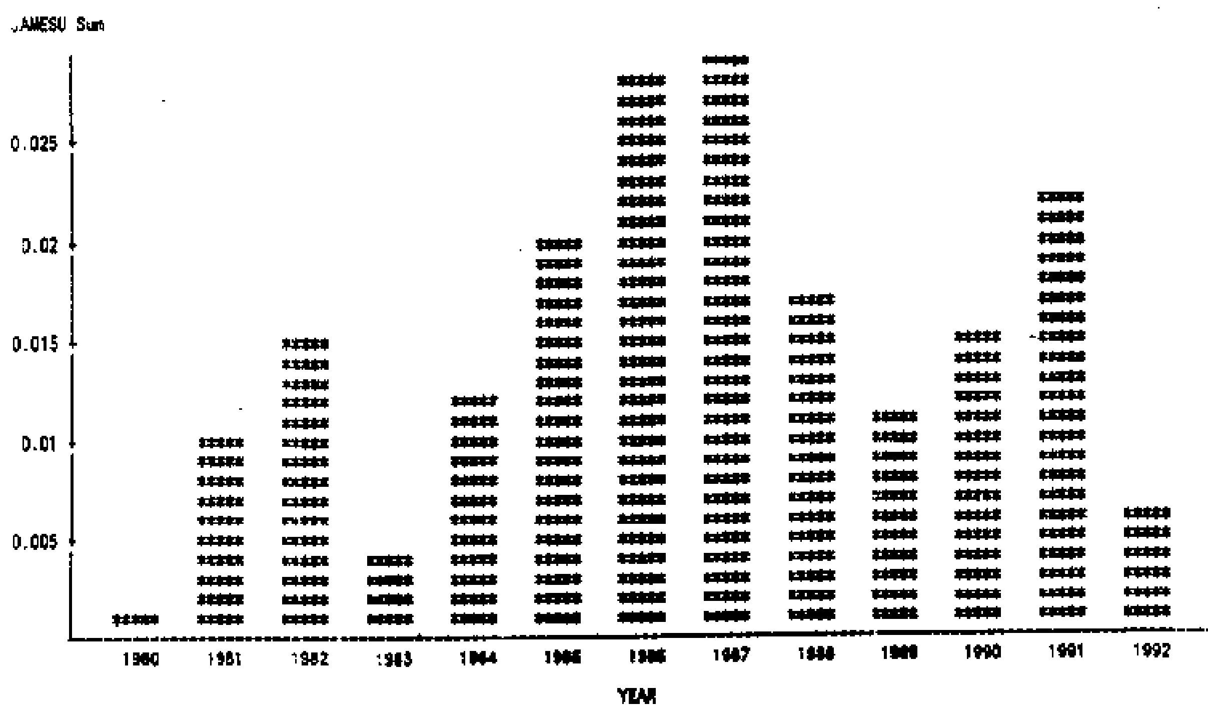


Figure 40. Estimated Coastal Commercial Shad Landings (LBS.) from Virginia Rivers, 1980-1995

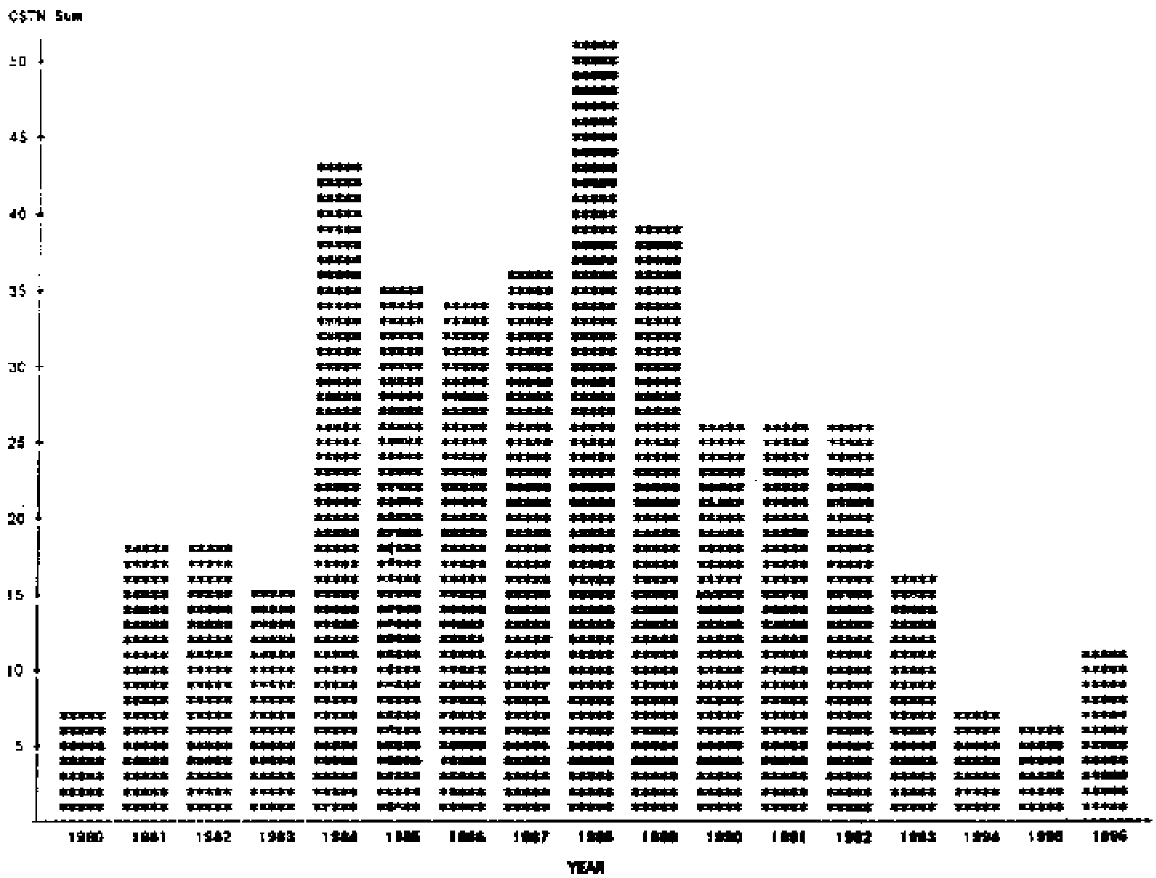


Figure 41. Juvenile Shad Abundance (Maximal CPE) from the Mattaponi River, 1979-1987 and from 1991-1996

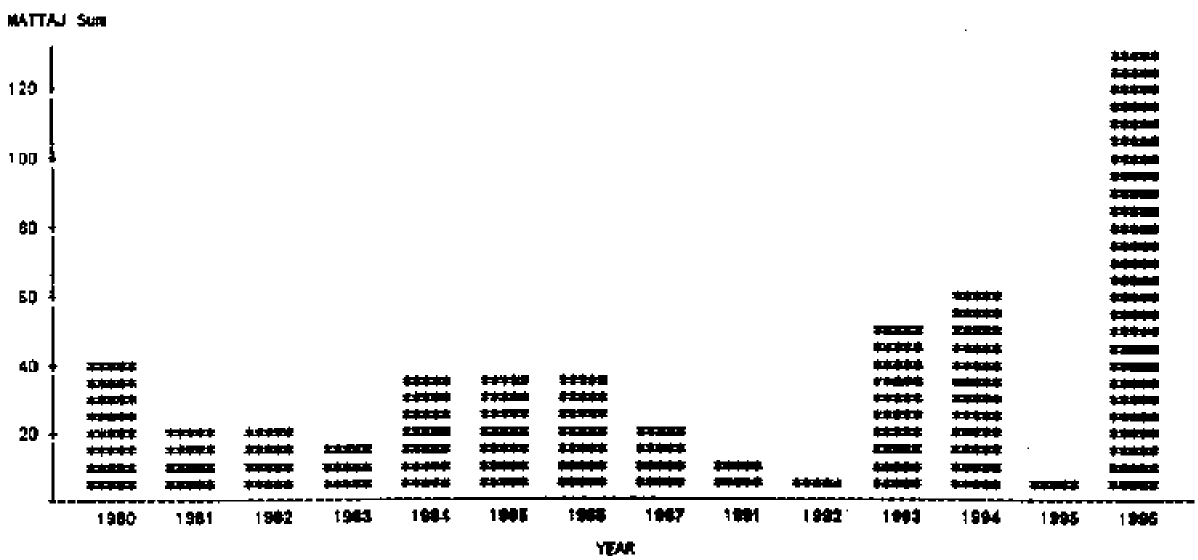


Figure 42. Juvenile Shad Abundance (Maximal CPE) from the Pamunkey River, 1979-1987 and from 1991-1996

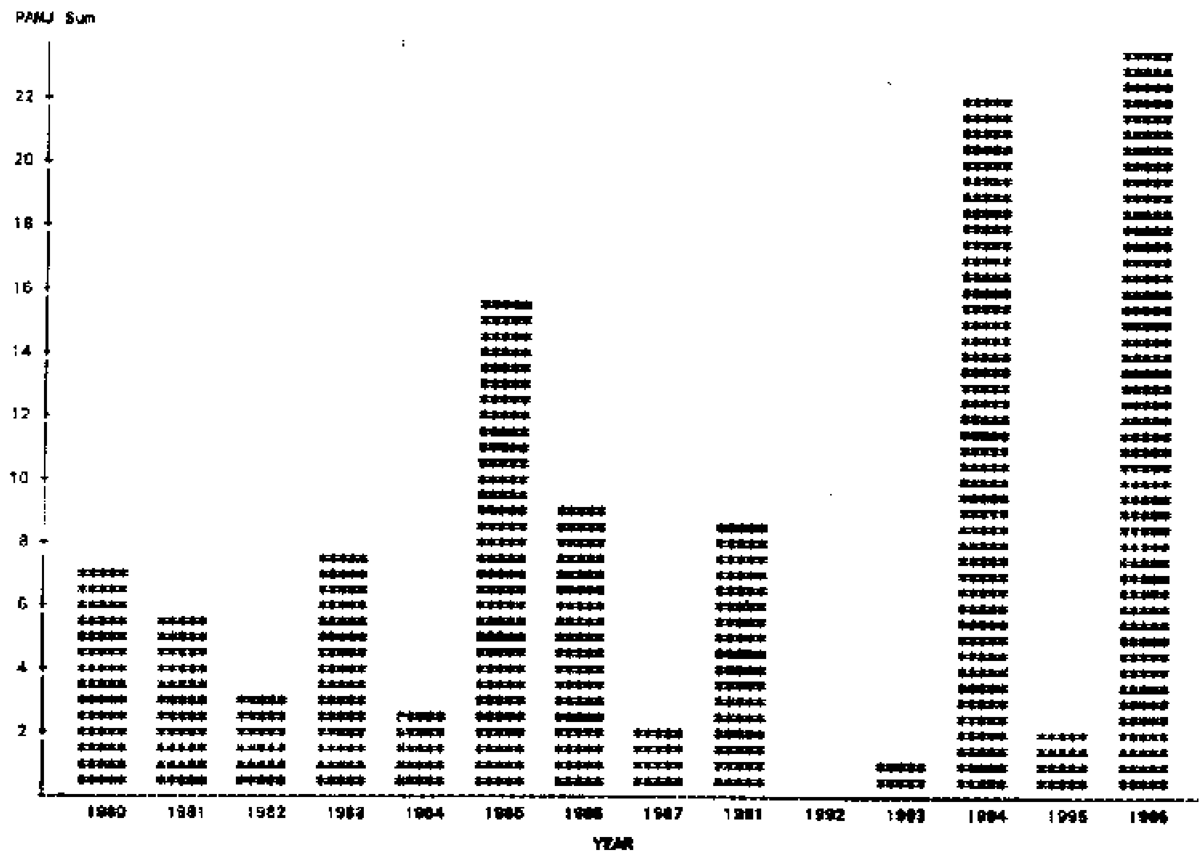


Figure 43. North Carolina Commercial Shad Landings (LBS. *1000) from Albemarle Sound, 1980-1996

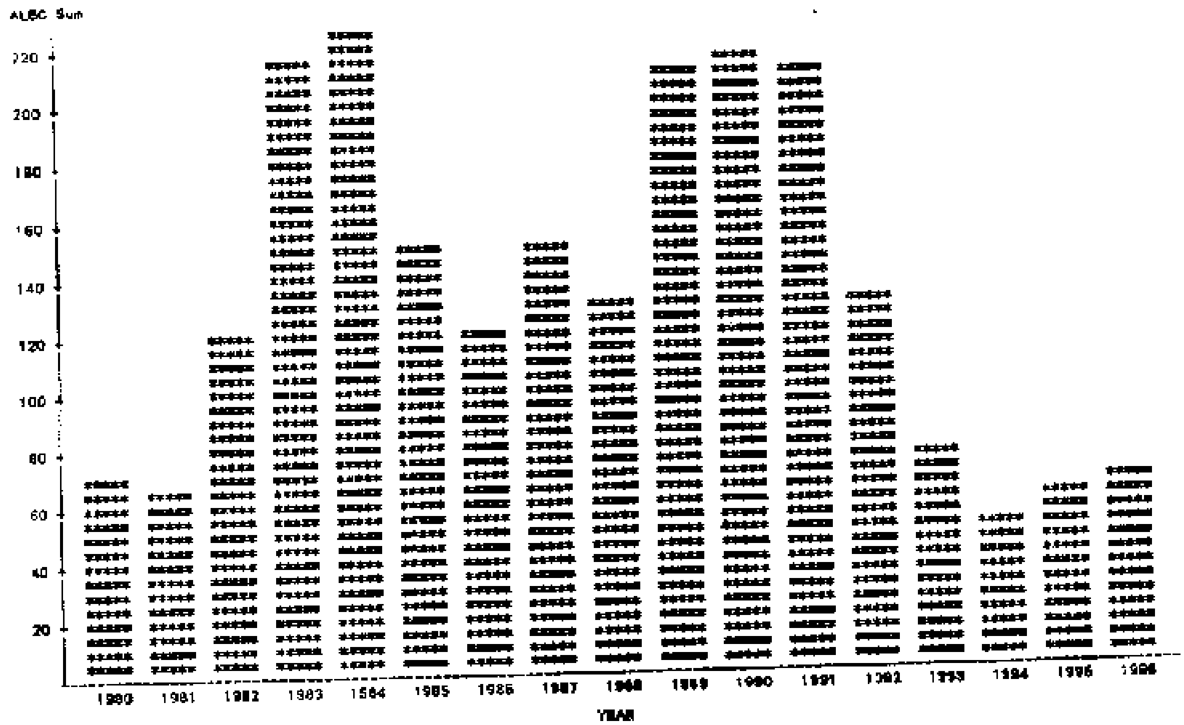


Figure 44. Estimated Coastal Commercial Shad Landings (N *1000) from North Carolina Rivers, 1980-1996

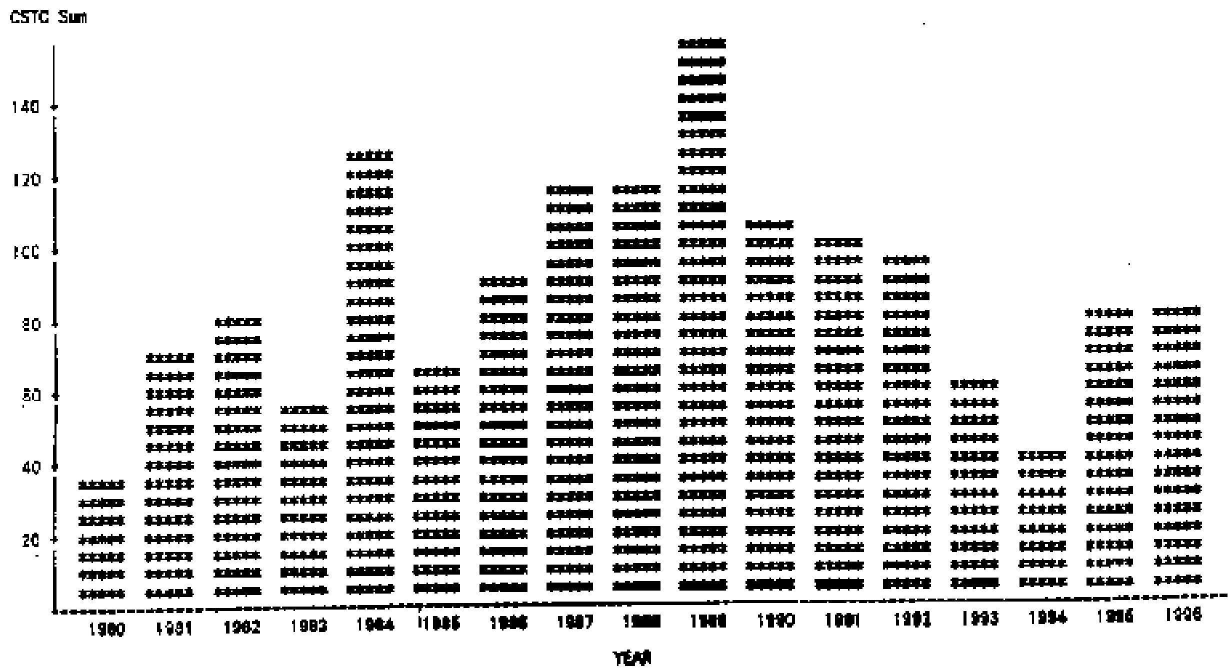


Figure 45. Total Mortality Rates (Z) for American Shad from Albemarle Sound, North Carolina, 1980-1993

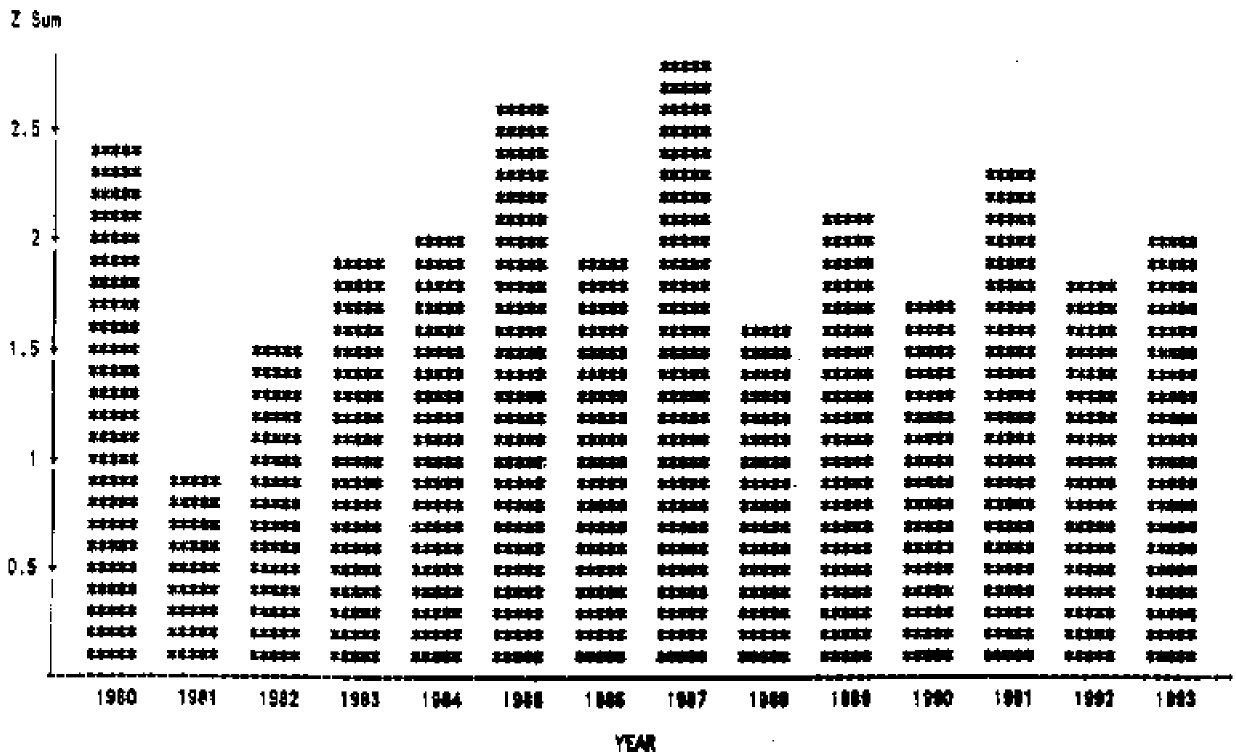


Figure 46. North Carolina Commercial Landings (LBS. *1000) of American Shad from the Pamlico River, 1980-1996

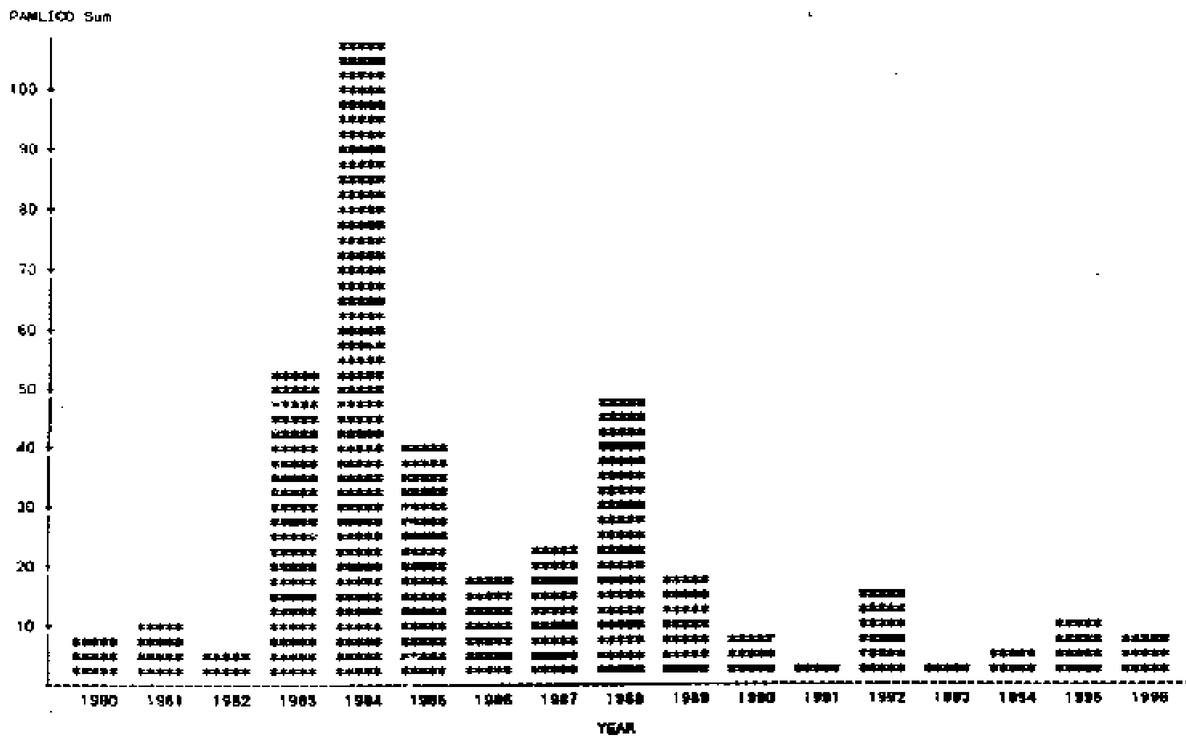


Figure 47. North Carolina Commercial Landings (LBS. *1000) of American Shad from the Neuse River, 1980-1996

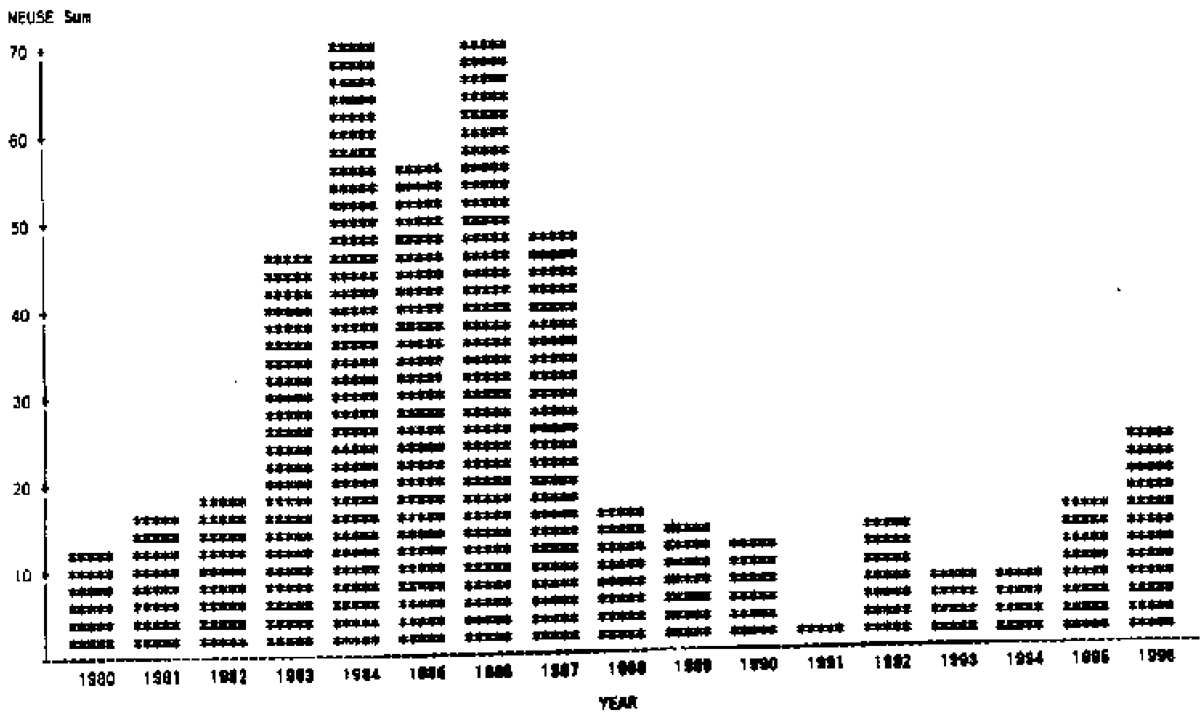


Figure 48. North Carolina Commercial Shad Landings (LBS. *1000) from Cape Fear River, 1980-1996

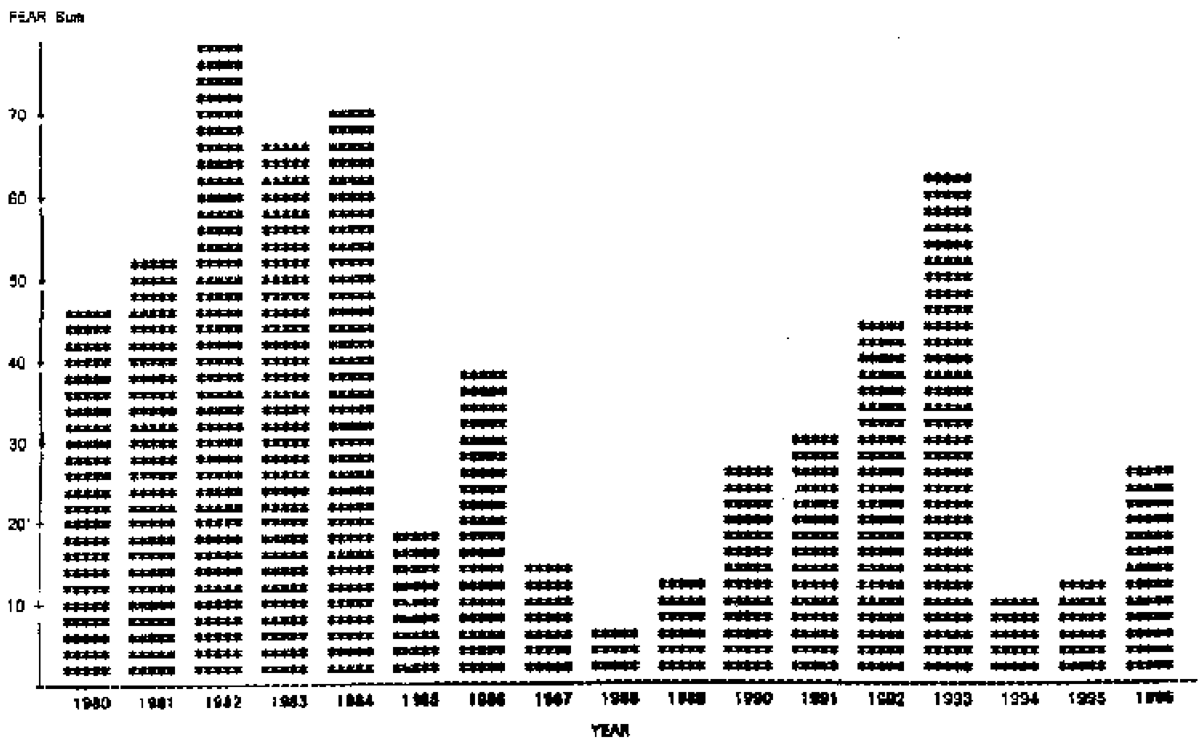


Figure 49. Inriver Commercial Landings (LBS *1000) Adjusted for Underreporting of American Shad in the Waccamaw-Pee Dee River, 1980-1996

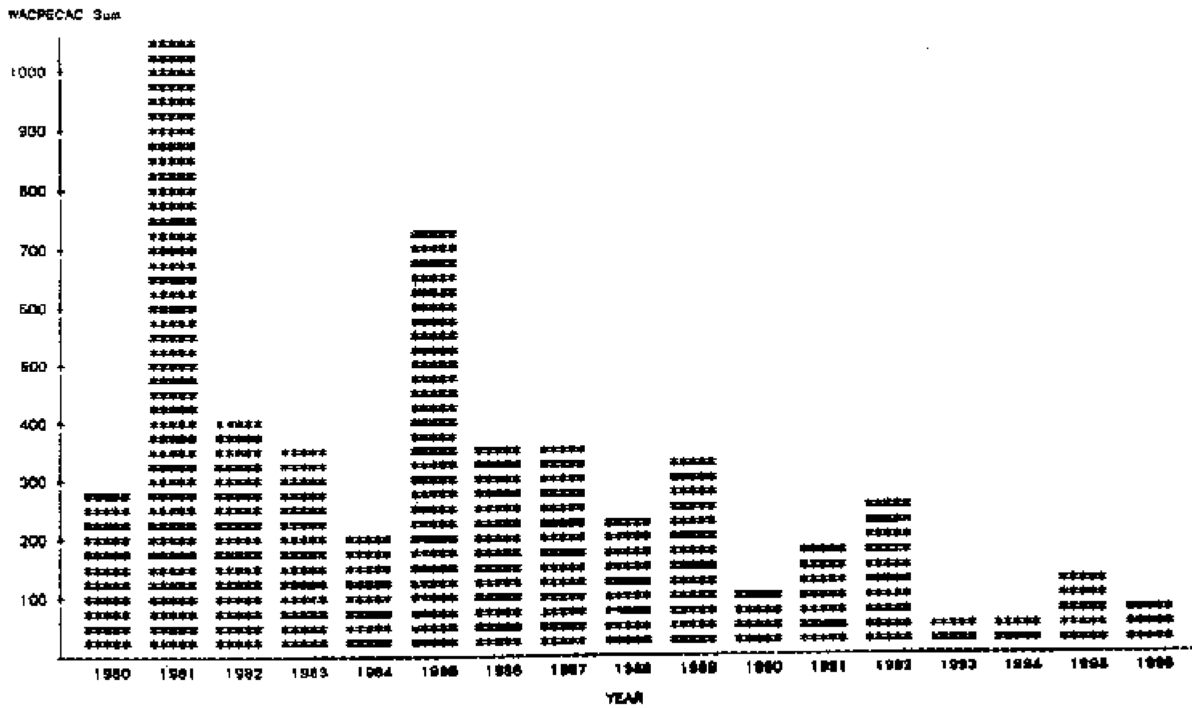


Figure 50. Inriver Commercial Landings (LBS. *1000) Adjusted for Underreporting of American Shad in the Edisto River, 1980-1996

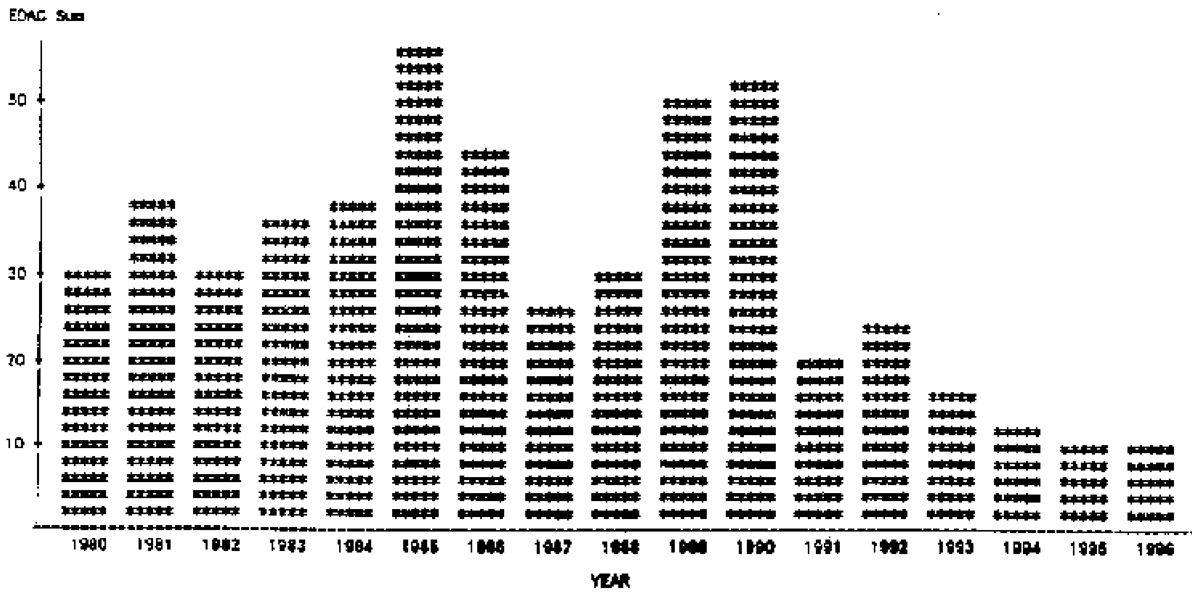


Figure 51. Inriver Commercial Landings (LBS. *1000) Adjusted for Underreporting of American Shad in the Savannah River, 1980-1996

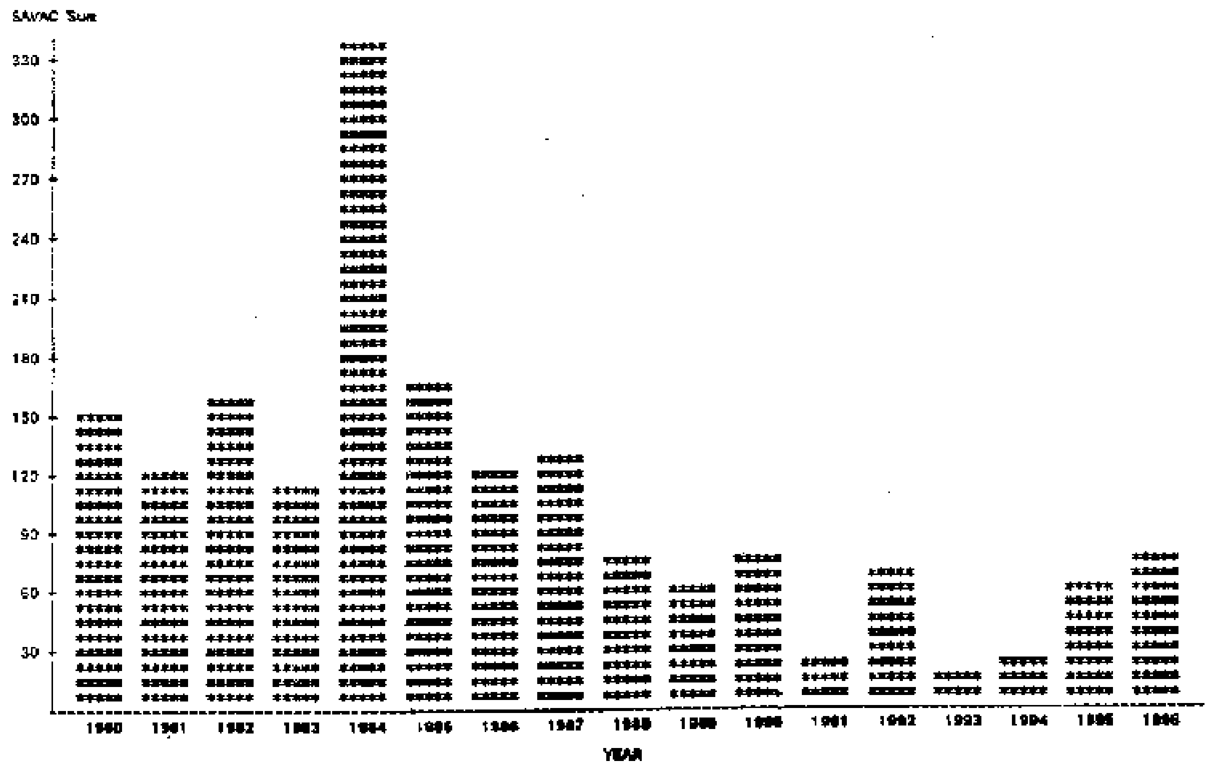


Figure 52. Inriver Commercial Landings (LBS. *1000) Adjusted for Underreporting of American Shad in the Santee River, 1990-1996

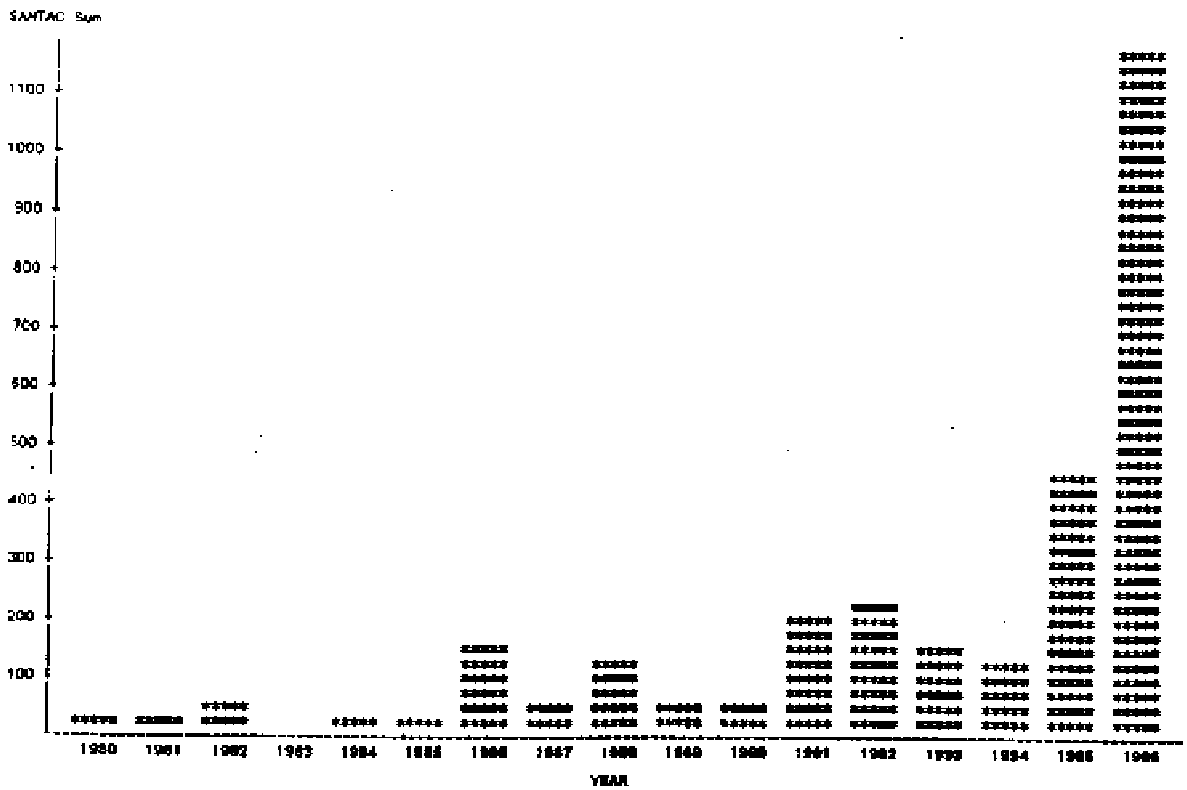


Figure 53. Stock Size (N *1000) of American Shad in the Santee River, 1990-1996

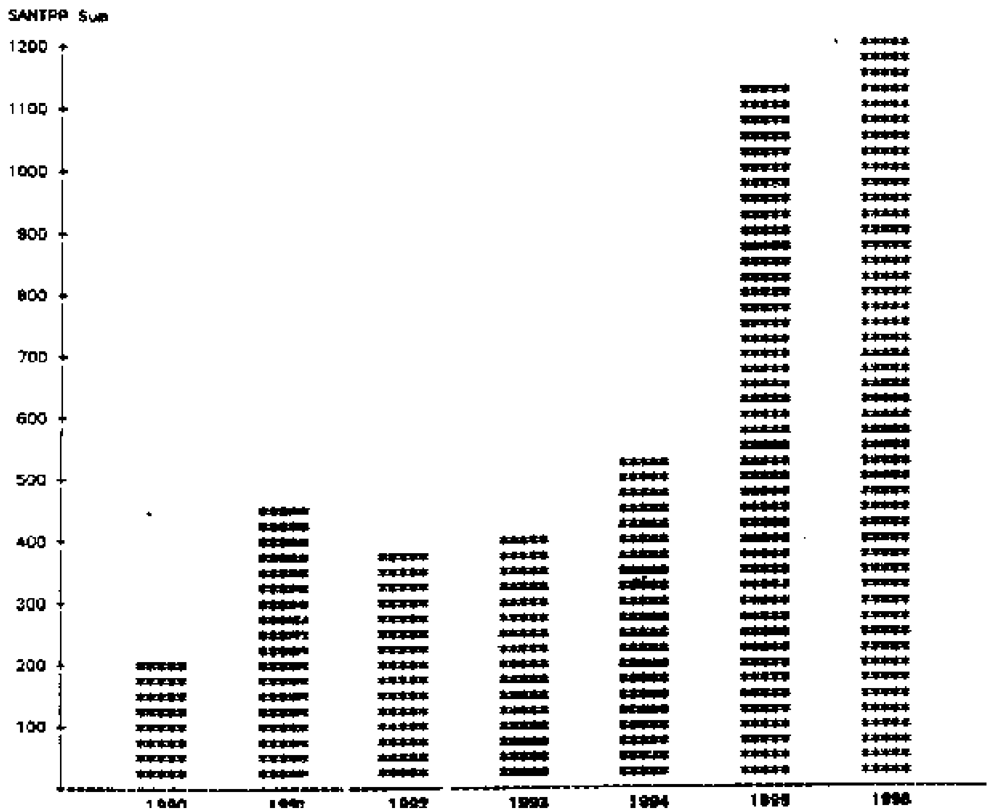


Figure 54. Population Size (River+Coastal Landings) of American Shad in the Edisto River, 1989-1990 and 1994-1996

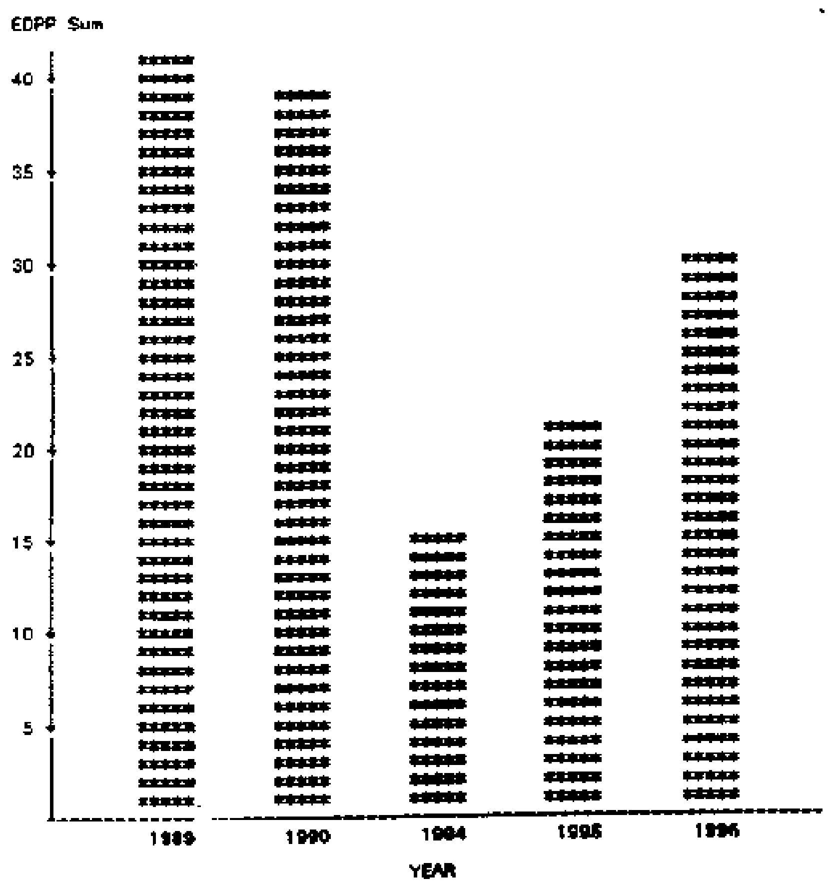


Figure 55. Population in Numbers for Altamaha River Shad, 1982-1996

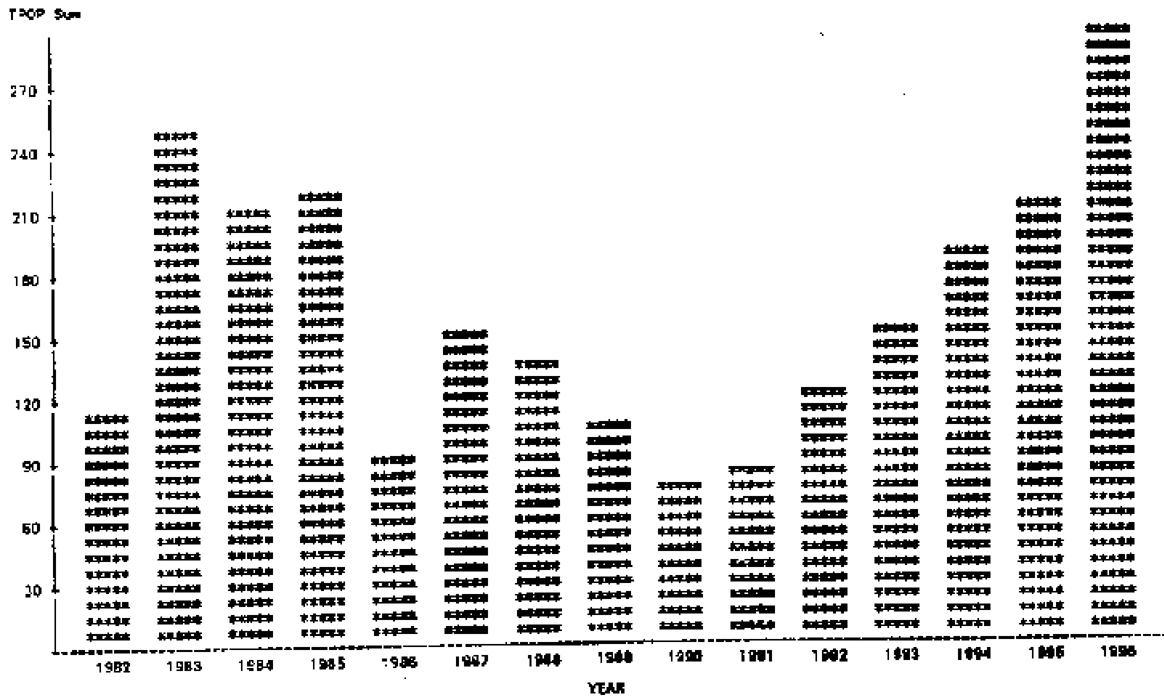


Figure 56. Adjusted Inriver Commercial Landings (LBS. *1000) of Altamaha River Shad, 1982-1996

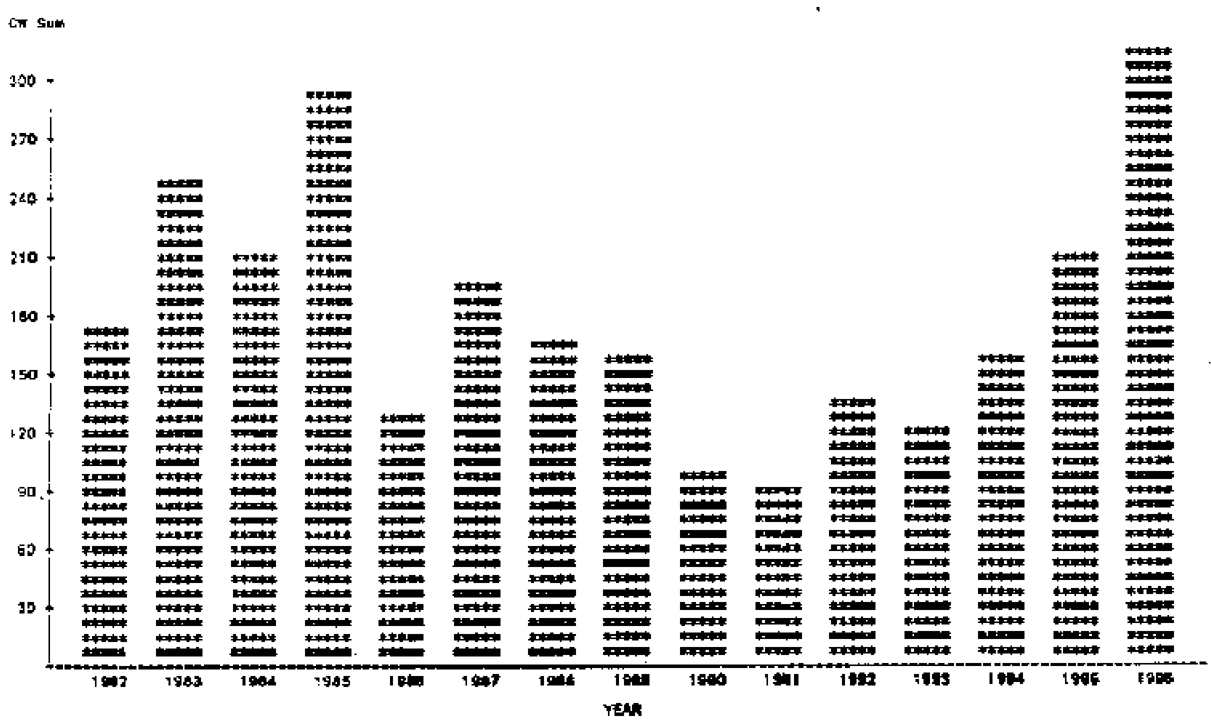


Figure 57. Adjusted Coastal Commercial Landings (#*1000) of Altamaha River Shad, 1982-1996

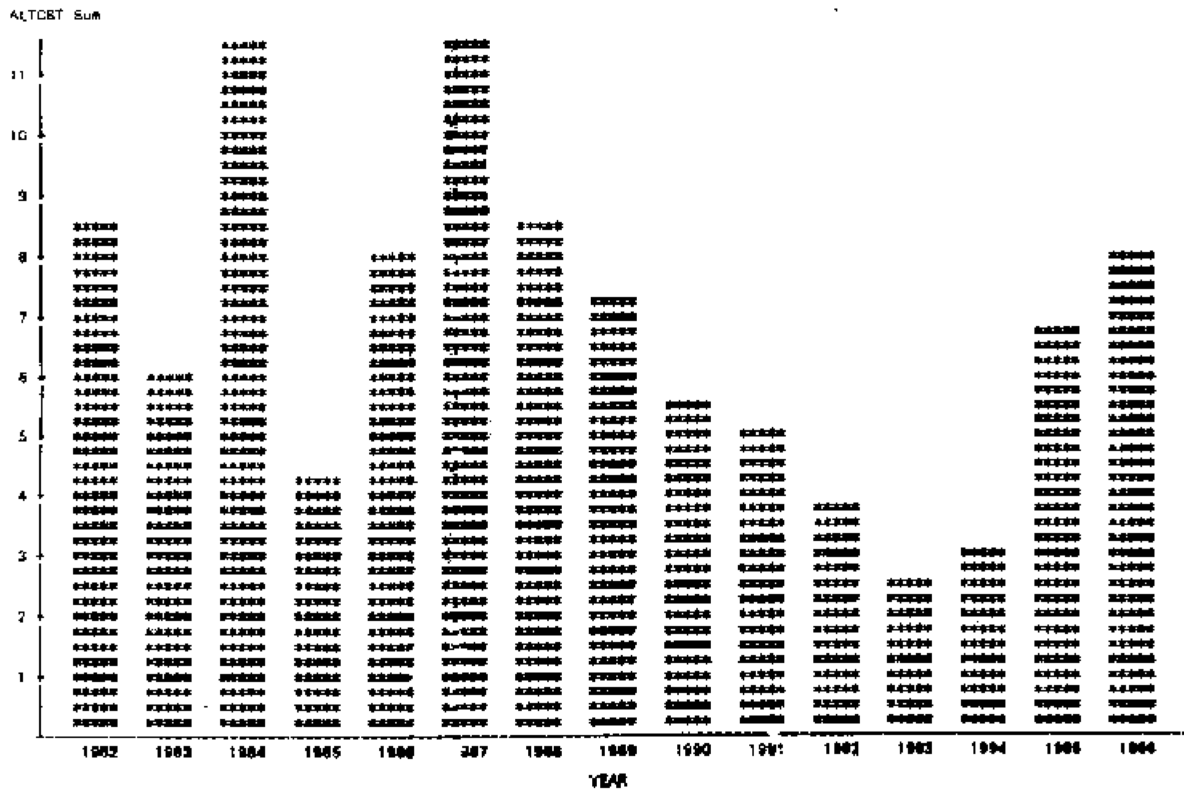


Figure 58. Inriver Fishing Mortality Rates (F) on Altamaha River Shad, 1982-1996

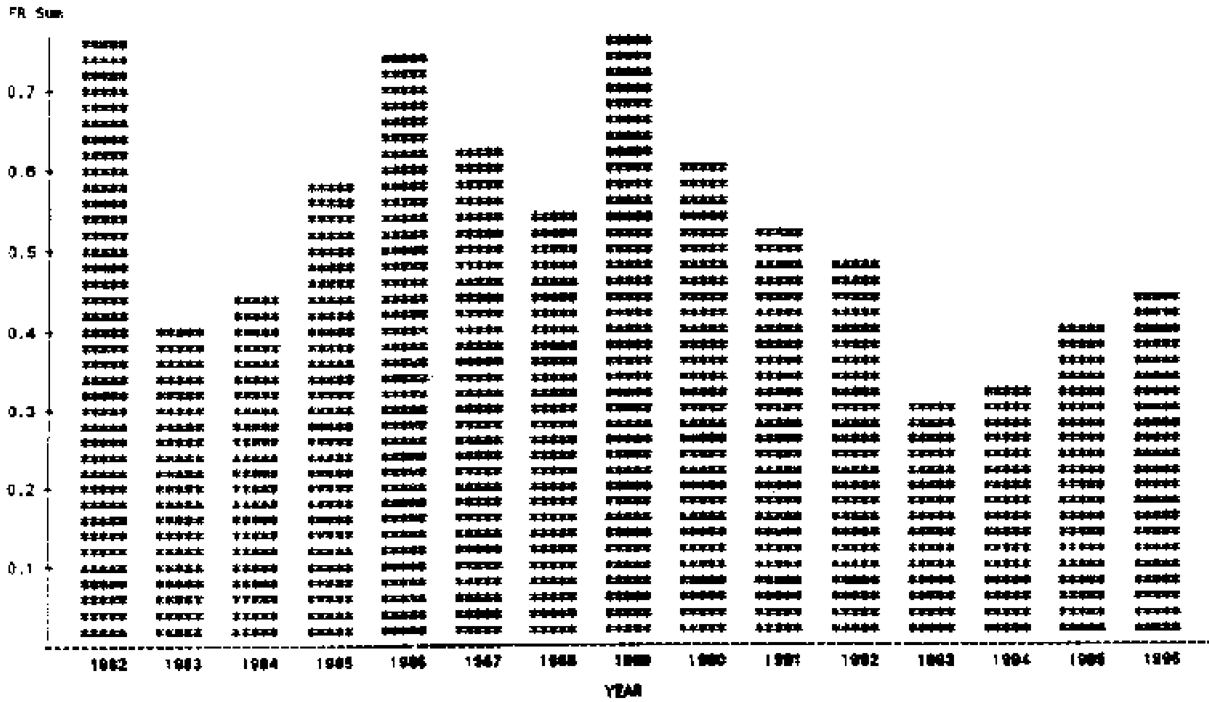


Figure 59. Coastal Fishing Mortality Rates (F) on Altamaha River Shad, 1982-1996

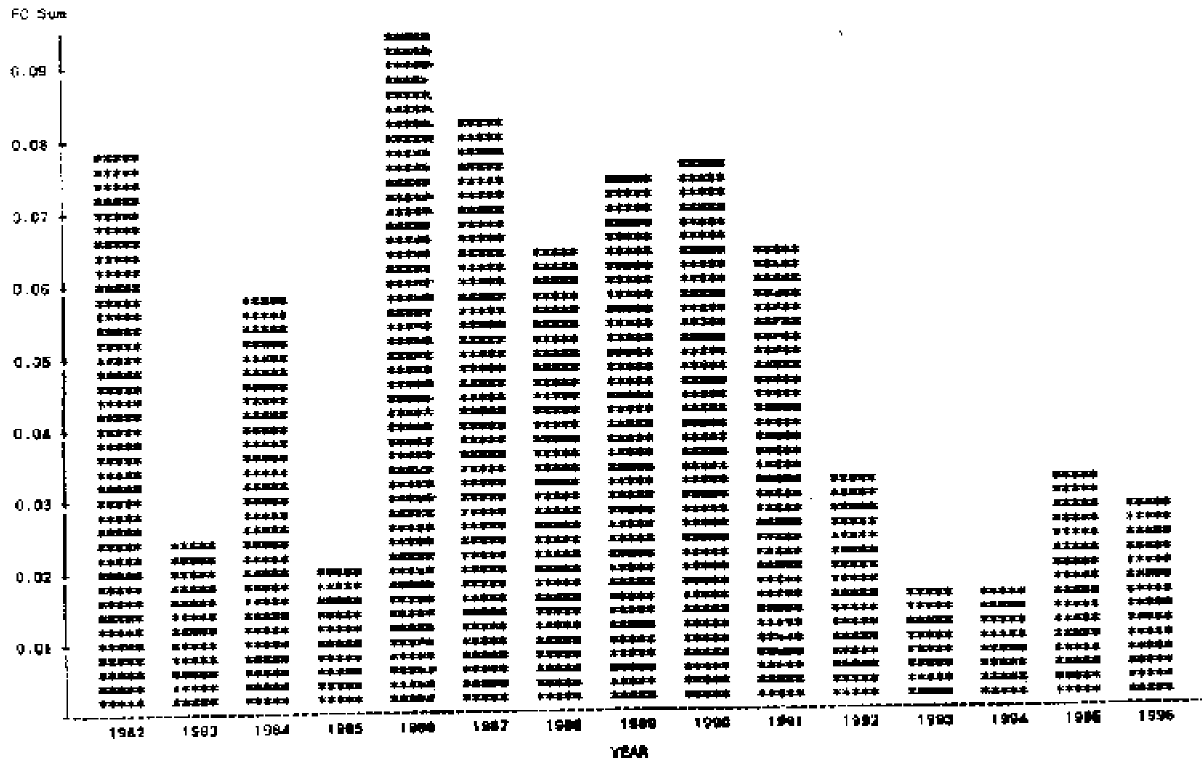
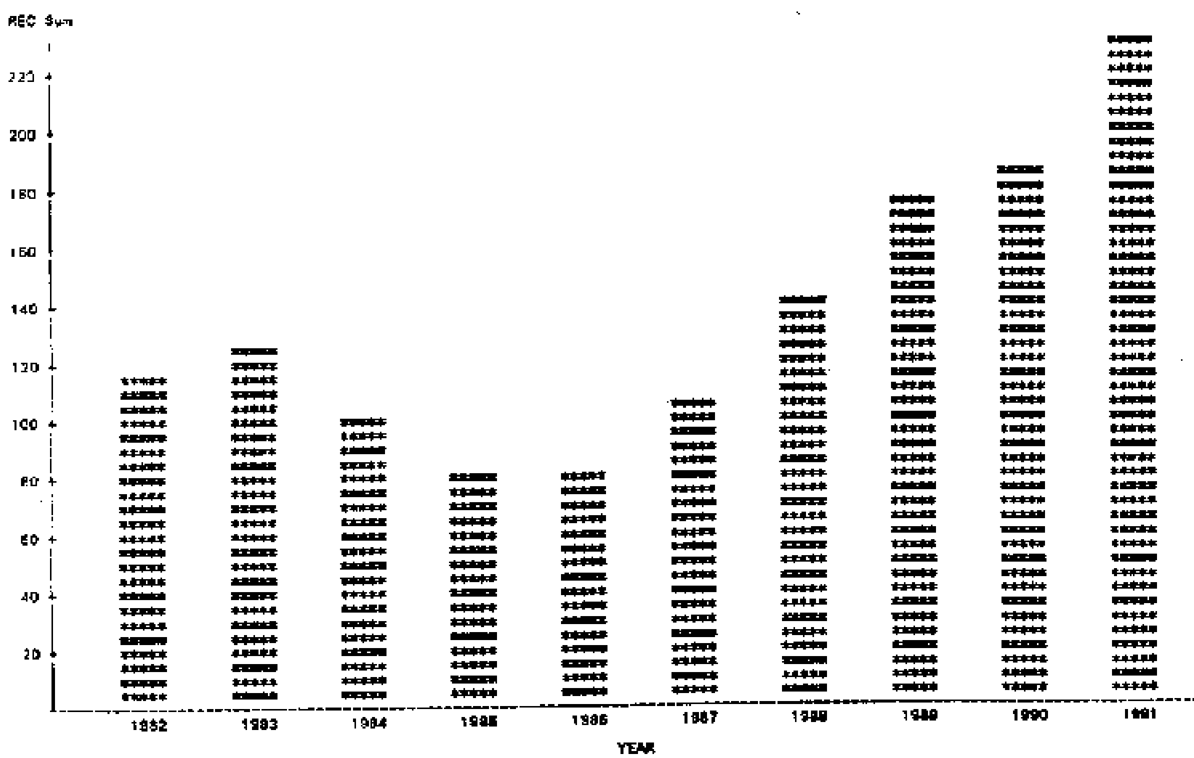


Figure 60. Recruitment to the Altamaha River Shad Stock, 1982-1991



Appendix 1

Table 1. Shad Juvenile Indices and Coastal Commercial Landings (LBS. *1000 for Maine, 1979-95

OBS	YEAR	JUV	LANDINGS
1	1979	0.25	18.5
2	1980	0.83	28.0
3	1981	3.43	90.6
4	1982	0.64	25.9
5	1983	1.11	38.8
6	1984	0.81	33.4
7	1985	3.26	16.1
8	1986	0.37	23.0
9	1987	1.92	26.7
10	1988	0.41	31.7
11	1989	0.66	46.1
12	1990	3.56	11.8
13	1991	0.61	2.0
14	1992	1.14	1.5
15	1993	0.98	0.6
16	1994	0.37	1.1
17	1995	0.60	0.4

Appendix 1

Table 2. Average number of juvenile shad caught per standard seine haul by river section for the years 1979-1996 (no sample taken above Chops Point is included in this summary)

River Section	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Upper Kennebec	0.16	0.00	1.08	0.00	0.15	0.90	0.69	0.10	0.15	0.11	1.25	3.50	1.21	0.10	0.00	0.00	0.21
Androscoggin	0.00	0.29	0.29	0.17	2.18	0.00	0.40	0.08	0.17	0.00	1.29	0.83	0.00	0.67	3.63	1.00	1.89
Merrymeeting Bay	0.00	0.36	0.85	0.33	0.20	0.46	1.53	0.15	8.05	1.36	0.29	2.46	0.00	0.67	0.29	0.35	0.39
Eastern	0.00	0.00	0.00	0.00	0.00	0.67	7.00	0.50	0.00	0.51	0.00	4.20	1.17	0.00		0.50	0.33
Cathance	0.00	0.00	0.50	0.00	3.00	2.00	6.50	1.00	1.25	0.00	0.48	6.83	0.67	3.67	0.00	0.00	0.17
Abegadasset										0.50	0.33	0.00	0.33	1.67	0.00	0.00	0.17
Mid Kennebec	0.00	0.00	0.17	0.63	0.00												
Lower Kennebec	0.00	0.00	0.00	0.00													

[1]The size of the seine and method of seining was changed in 1983. For details, see METHODS (AFC-26-3)

Appendix 2

Method of estimating shad relative stock abundance and recruitment for the Merrimack River stock using Essex Dam lift data, 1983 to 1995

Year	Total Shad Lifted	# Days[1/]	Shad/Day	Recruitment[2/]
1983	5,612	54	103.9	255.8
1984	4,602	42	109.6	170.6
1985	12,294	54	227.7	140.7
1986	17,777	54	329.2	244.5
1987	16,441	54	304.5	345.9
1988	12,219	54	226.3	223.4
1989	7,513	54	139.1	129.7
1990	5,709	54	105.7	222.9
1991	13,462	54	249.3	-
1992	20,415	54	378.1	-
1993	8,562	54	158.6	-
1994	4,341	54	80.4	-
1995	13,790	54	255.4	-

1/ Days lifted from May 15 to July 7 (54 days).

2/ $Recruitment_t = 0.28*Pop_{t+4} + 0.68*Pop_{t+5} + 0.12*Pop_{t+6}$

where: Pop_{t+4} = the relative population size in year t+4;

0.28, 0.68 and 0.12 = the average contribution of age 4, 5 and 6 year old female shad to the Connecticut River stock.

Appendix 3

Table 1. Population estimates (numbers) of American shad in the Pawcatuck River RI, juvenile shad indices (JI) of abundance (arithmetic mean/seine haul), adult recruitment (numbers) to the adult stock and instantaneous total mortality (Z) rates from 1974 to 1996.

Year	Population size[1/] #	JI	Recruitment[2/] #	Z
1974	0	-	0	-
1975	19	-	24	-
1976	175	-	214	-
1977	14	8.4	181	-
1978	114	5.3	140	-
1979	255	-	312	-
1980	315	-	386	-
1981	266	-	326	3.62
1982	178	-	219	3.13
1983	228	-	280	2.39
1984	1265	-	591	1.24
1985	4219	17.7	920	1.54
1986	3031	1.8	545	2.74
1987	724	0.1	30	3.30
1988	580	1.3	394	2.34
1989	533	0.1	30	2.00
1990	904	0.3	91	0.86
1991	1900	2.3	697	0.53
1992	2119	7.6	2303	1.06
1993	797	14.4	4363	-
1994	270	8.3	2514	-
1995	739	2.1	636	-
1996	1508	0.6	181	-

1/ Estimates of stock size in numbers from 1974 to 1983 were based on the population size in lbs. from Gibson and Crecco (1988, Appendix 1, pages A-1, A-2) divided by 4.5 lbs. The population estimates from 1984 to 1996 were reported by Powell (1995).

2/ Estimates of recruitment in numbers from 1974 to 1983 were taken from Gibson and Crecco (1988, Appendix 1, pages A-1, A-2), whereas recruitment from 1984 to 1996 were derived as the juvenile index scaled to the recruitment estimates from 1985 to 1995.

Appendix 3

Table 2. Adult Shad Recruitment (Rec), Adult Shad Population Size (LBS. *1000), Juvenile Abundance (JUV) Total Mortality (Z) In the P 1

OBS	YEAR	REC	POP	JUV	Z	RICST
1	1974	0	0	.	.	.
2	1975	24	87	.	.	.
3	1976	214	786	.	.	.
4	1977	181	663	8.42	.	.
5	1978	140	513	5.30	.	.
6	1979	312	1146	.	.	.
7	1980	386	1416	.	.	2.0
8	1981	326	1198	.	3.60	31.4
9	1982	219	803	.	3.10	79.3
10	1983	280	1026	.	2.40	23.5
11	1984	.	5693	.	1.20	36.6
12	1985	.	18986	17.72	1.50	90.8
13	1986	545	13640	1.80	2.70	52.4
14	1987	30	3258	0.08	3.30	103.9
15	1988	394	2610	1.32	2.30	122.0
16	1989	30	2999	0.07	2.00	42.0
17	1990	91	4068	0.25	0.90	22.8
18	1991	697	8550	2.27	0.53	27.8
19	1992	2303	9536	7.63	1.10	13.3
20	1993	4363	3587	14.36	.	40.6
21	1994	2514	1215	8.30	.	17.9
22	1995	636	3325	2.10	.	28.0
23	1996	181	7540	0.60	.	0.0

Appendix 4

Table 1. Population estimates (numbers) of adult Connecticut River shad (SPOP) from 1966 to 1997, adult (REC) shad recruitment to the adult stock adjusted for May-June river flow from 1966 to 1982 (Lorda and Crecco 1987), and indices (SJI) of juvenile shad abundance (arithmetic mean catch/tow or haul) from 1966 to 1996.

Year	SPOP #	REC #	SJI catch/haul
1966	621,300	257,400	32.8
1967	742,300	243,700	20.2
1968	945,800	200,000	11.1
1969	1,108,180	228,500	19.0
1970	1,140,500	181,900	27.8
1971	1,128,600	290,600	65.7
1972	390,900	378,100	15.3
1973	353,700	219,800	12.7
1974	952,500	273,500	21.4
1975	847,500	263,600	23.7
1976	936,900	240,000	22.4
1977	361,900	414,200	57.5
1978	560,700	449,100	18.6
1979	557,000	494,700	47.9
1980	685,000	369,600	21.3
1981	909,300	302,600	12.5
1982	939,300	267,300	4.8
1983	1,574,500	.	16.6
1984	1,231,100	.	11.2
1985	727,600	.	15.9
1986	748,400	.	17.0
1987	587,500	.	44.3
1988	647,600	.	24.0
1989	979,400	.	61.6
1990	816,400	.	43.0
1991	1,195,900	.	49.4
1992	1,628,100	.	97.4
1993	749,200	.	79.6
1994	325,600	.	107.9
1995	304,500	.	28.8

1996	667,000	.	68.0
1997	725,000	.	.

Appendix 4

Table 2. American shad population estimates (numbers), Connecticut River adjusted commercial (CT Comm) and recreational landings (CT Sport) landings in numbers, commercial fishing effort (gillnet days) and combined inriver annual harvest rates (u) and instantaneous fishing rates (F) on Connecticut River shad from 1980-1997.

Year	Population Size #	CT Comm Landings #	CT Comm Effort (days)	CT Sport Landings #	River $u^{2/}$	$F^{3/}$
1980	685,000	88,329	897	12,189	0.15	0.16
1981	909,300	97,684	907	68,771	0.18	0.20
1982	939,300	81,132	790	44,058	0.13	0.14
1983	1,574,500	99,328	840	99,372	0.13	0.14
1984	1,231,100	88,579	575	71,305	0.13	0.14
1985	727,600	89,303	575	41,160	0.18	0.20
1986	748,400	117,770	590	102,225	0.29	0.34
1987	587,500	64,732	525	92,619	0.27	0.31
1988	647,600	77,179	351	52,906	0.20	0.22
1989	979,400	72,996	450	60,059	0.14	0.15
1990	816,400	57,642	400	37,831	0.12	0.13
1991	1,195,900	70,479	500	84,706	0.13	0.14
1992	1,628,100	50,039	410	89,323	0.09	0.10
1993	749,200	32,358	400	64,855	0.13	0.14
1994	325,600	38,989	350	45,014	0.26	0.30
1995	304,500	26,045	368	14,425	0.13	0.14
1996	667,000	29,233	352	25,678	0.08	0.09
1997	725,000	.	.	.	.	.

[1/] Landings data have been reported in pounds, assumed average weight = 5.0 lbs. for converting weight to numbers.
[2/] u = (commercial+recreational catch)/ population size.
[3/] $F = -\log(1 - u)$.

Appendix 5

Table 1. Coastal Landings (LBS. *1000), Inriver Landings (LBS. *1000), Population Size (N *1000), Inriver Fishing Mortality, Coast 3

OBS	YEAR	CATCH	FT	E2	TIME	LARV	CSTC	Q	CATCH2	ACSTW	EFFORT	UR	POPM
1	1980	1313	235	167	1.2	0.46	34	.00093	2526	163.2	285.6	0.23326	11421.01
2	1981	620	220	176	1.2	0.78	52	.00093	1240	249.6	264.0	0.21770	5945.45
3	1982	379	271	119	1.2	0.59	82	.00093	758	441.6	325.2	0.26098	3345.99
4	1983	459	273	139	1.2	0.57	63	.00093	918	302.4	327.6	0.26263	3797.79
5	1984	701	390	184	1.2	0.38	68	.00093	1402	326.4	468.0	0.35289	4289.30
6	1985	756	317	148	1.2	0.67	67	.00093	1512	321.6	380.4	0.29796	5398.02
7	1986	799	214	174	1.2	1.09	61	.00093	1598	202.8	256.8	0.21246	7814.69
8	1987	664	179	192	1.2	0.68	71	.00093	1368	340.8	214.8	0.18108	7895.64
9	1988	783	189	113	1.2	0.73	88	.00093	1566	422.4	226.8	0.19016	8657.38
10	1989	486	180	150	1.2	1.04	108	.00093	972	518.4	216.0	0.18199	5869.37
11	1990	464	232	122	1.2	1.17	143	.00093	928	686.4	278.4	0.22811	4764.63
12	1991	329	166	112	1.2	0.32	134	.00093	658	643.2	199.2	0.16911	4694.19
13	1992	286	167	128	1.2	0.62	91	.00093	572	435.8	200.4	0.17004	3800.81
14	1993	138	149	119	1.2	0.39	95	.00093	276	456.0	178.8	0.15319	2257.63
15	1994	158	162	179	1.2	0.65	66	.00093	316	316.8	194.4	0.16539	2227.42
16	1995	191	147	.	1.2	.	67	.00093	382	321.6	176.4	0.15130	2646.35
17	1996	121	147	.	1.2	.	71	.00093	242	340.8	176.4	0.15130	1940.25

OBS	POPN	CN	UC	FC	FR	FTOTAL	ESCAP	REC
1	2379.38	547.083	0.01429	0.01435	0.26561	0.28000	8795.01	319.20
2	1238.64	258.333	0.04198	0.04289	0.24552	0.28841	4705.45	618.70
3	697.08	157.917	0.13198	0.14164	0.30244	0.44398	2587.99	392.35
4	791.21	191.250	0.07963	0.08297	0.30467	0.38764	2879.79	379.05
5	895.69	292.083	0.07593	0.07896	0.43524	0.51420	2897.30	282.70
6	1124.17	315.000	0.05980	0.06145	0.35377	0.41522	3684.02	445.85
7	1628.06	332.917	0.03747	0.03819	0.23882	0.27701	6216.69	698.25
8	1644.92	285.000	0.04316	0.04412	0.19976	0.24389	6527.64	385.70
9	1803.62	326.250	0.04879	0.05002	0.21092	0.26095	7091.38	485.45
10	1220.70	202.500	0.08447	0.08263	0.20088	0.29351	4887.37	691.60
11	990.55	193.333	0.14436	0.15591	0.25891	0.41482	3826.63	778.05
12	944.67	137.083	0.14186	0.15298	0.18526	0.33824	3876.19	212.80
13	791.84	119.167	0.11492	0.12208	0.18637	0.30845	3228.81	412.30
14	470.34	57.500	0.20198	0.22562	0.16628	0.39191	1981.63	259.35
15	464.05	65.833	0.14223	0.15342	0.18079	0.33421	1911.42	432.25
16	592.99	79.583	0.11299	0.11990	0.16406	0.28396	2464.36	.
17	404.22	50.417	0.17566	0.19316	0.16406	0.35721	1698.35	.

Appendix 5

Table 2. Coastal Landings (LBS. *1000), Inriver Landings (LBS. *1000), Population Size (N *1000), Inriver Fishing Mortality, Coast 1

OBS	YEAR	ACSTW	CATCH2	POPN	FR	FC	FTOTAL
1	1980	163.2	2626	3263.01	0.18564	0.01047	0.19611
2	1981	249.6	1240	1690.30	0.17160	0.03125	0.20285
3	1982	441.6	758	920.81	0.21138	0.10526	0.31664
4	1983	302.4	918	1060.16	0.21294	0.06126	0.27420
5	1984	316.8	1402	1179.60	0.30420	0.05758	0.36178
6	1985	321.6	1512	1504.95	0.24726	0.04554	0.29280
7	1986	292.8	1598	2226.56	0.16692	0.02778	0.19470
8	1987	340.8	1368	2258.07	0.13962	0.03195	0.17157
9	1988	422.4	1566	2468.20	0.14742	0.03630	0.18372
10	1989	518.4	972	1653.93	0.14040	0.06753	0.20793
11	1990	686.4	928	1310.96	0.18096	0.11550	0.29646
12	1991	643.2	658	1262.74	0.12948	0.11218	0.24166
13	1992	436.8	532	998.48	0.13026	0.09556	0.22582
14	1993	456.0	276	619.06	0.11622	0.16660	0.28282
15	1994	316.8	316	620.61	0.12636	0.11244	0.23880
16	1995	321.6	382	801.63	0.11466	0.08728	0.20194
17	1996	340.8	242	536.40	0.11466	0.14198	0.25664

Appendix 5

Table 3. Coastal Landings (LBS. *1000), Inriver Landings (LBS. *1000), Population Size (N *1000), Inriver Fishing Mortality, Coast 3

OBS	YEAR	CATCH	FT	E2	TIME	LARV	CSTC	Q	CATCH2	ACSTW	EFFORT	UR	POPW
1	1980	1313	238	187	1.2	0.48	34	.00065	2626	163.2	265.6	0.16943	15682.46
2	1981	620	220	176	1.2	0.78	82	.00065	1240	248.6	264.0	0.15768	8113.43
3	1982	379	271	119	1.2	0.59	92	.00065	758	441.6	325.2	0.19053	4419.90
4	1983	459	273	139	1.2	0.67	63	.00065	918	302.4	327.6	0.19180	6088.76
5	1984	701	390	184	1.2	0.38	66	.00065	1402	316.8	468.0	0.26229	5662.10
6	1985	756	317	148	1.2	0.67	67	.00065	1512	321.6	380.4	0.21906	7223.74
7	1986	799	214	174	1.2	1.05	61	.00065	1598	292.8	256.8	0.15373	10607.47
8	1987	684	179	192	1.2	0.68	71	.00065	1368	340.8	214.8	0.13031	10838.73
9	1988	783	189	113	1.2	0.73	88	.00065	1566	422.4	226.8	0.13707	11847.34
10	1989	486	180	150	1.2	1.04	108	.00065	972	518.4	216.0	0.13099	7936.63
11	1990	454	232	122	1.2	1.17	143	.00065	928	686.4	278.4	0.16553	6292.69
12	1991	329	166	112	1.2	0.32	134	.00065	558	643.2	199.2	0.12145	6061.16
13	1992	266	167	128	1.2	0.62	91	.00065	632	436.8	200.4	0.12213	4792.71
14	1993	138	149	119	1.2	0.39	95	.00065	276	456.0	178.8	0.10972	2971.43
15	1994	158	162	179	1.2	0.65	66	.00065	316	316.8	194.4	0.11870	2978.92
16	1995	191	147	.	1.2	.	67	.00065	382	321.6	176.4	0.10833	3847.84
17	1996	121	147	.	1.2	.	71	.00065	242	340.8	176.4	0.10833	2574.70

OBS	POPN	CN	UC	FC	FR	FTOTAL	ESCAP	REC
1	3263.01	547.083	0.01042	0.01047	0.18564	0.19611	13036.46	319.20
2	1690.30	258.333	0.03076	0.03125	0.17160	0.20285	5873.43	518.70
3	920.81	157.917	0.09991	0.10526	0.21138	0.31664	3661.90	392.35
4	1060.16	191.250	0.05943	0.06126	0.21294	0.27420	4170.75	379.08
5	1179.60	292.083	0.05595	0.05758	0.30420	0.36178	4260.10	252.70
6	1504.95	315.000	0.04452	0.04554	0.24726	0.29280	5711.74	446.55
7	2226.66	332.917	0.02740	0.02778	0.16692	0.19470	9089.47	698.25
8	2258.07	285.000	0.03144	0.03195	0.13962	0.17157	9470.73	385.70
9	2468.20	326.250	0.03566	0.03630	0.14742	0.18372	10381.34	485.45
10	1653.93	202.500	0.06530	0.06753	0.14040	0.20793	6966.85	591.60
11	1310.96	193.333	0.10906	0.11550	0.18098	0.29648	6364.69	778.05
12	1262.74	137.083	0.10612	0.11218	0.12948	0.24166	5403.16	212.80
13	998.48	110.833	0.09114	0.09556	0.13026	0.22582	4260.71	412.30
14	619.06	57.500	0.15346	0.16660	0.11622	0.28282	2695.48	759.35
15	620.61	65.833	0.10635	0.11244	0.12636	0.23880	2662.92	432.25
16	801.63	79.583	0.08358	0.08728	0.11466	0.20194	3465.84	.
17	536.40	50.417	0.13236	0.14198	0.11466	0.25664	2332.70	.

Appendix 5

Table 4. Explanation and definition of Hudson River shad data from 1931 to 1994 used in the assessment. See Appendix Table A1 for associated Hudson River shad data.

Parameter	Years	Definition	Source
Catch	1931-94	Reported Comm. Catch (lbs.*1000)- Kathy Hattala	
F_t	1931-94	Licensed ft. of gill net - see Methods Section	
E2	1937-94	Not used in analysis	
Time	1931-94	Days open to Comm. Fishery- see Methods section	
Larv	1974-94	Utilities Postlarval shad index- K. Hattala	
Q	1974-94	Comm. Catchability Coefficient- see Methods	
Catch2	1931-94	Comm. adjusted for 50% underreporting- assumed	
Effort	1931-94	Fishing effort (F_t*time)- see Methods	
Uint	1931-94	Annual fishing rate- see Methods	
Popw	1931-94	Hudson Population size (lbs.*1000)- see Methods	
Popn	1931-94	Hudson Population # -assumed av. weight=5.0 lbs	
CN	1931-94	Adjusted Comm. Catch #- assumed av. weight	
F	1931-94	Instantaneous Fishing Rate- see Methods	
Escape	1931-94	Spawning Stock-Popw -Catch2- see Methods	
Rec	1974-94	Adult Recruitment based on Larv- see Methods	
CPE	1931-94	Catch Per Unit Effort - see Methods	
CE	1937-94	Not used in analysis	

Appendix 5

Table 5. Comparison between the relative magnitude of the Hudson River shad stock size (lbs. * 1000) and the Connecticut River shad stocks from 1940 through 1951 based on the studies of Talbot (1954) for the Hudson River and Fredin (1954) for the Connecticut River. The average population estimates were used to scale (scalar = 2.93) the Hudson River stock size to that of the Connecticut River.

Year	Hudson River	Connecticut River
	lbs * 1000	
1940	4,521	1,247
1941	4,552	1,665
1942	4,634	1,517
1943	4,484	1,602
1944	5,473	1,701
1945	5,480	1,391
1946	4,167	1,647
1947	2,588	1,215
1948	3,225	1,085
1949	2,741	842
1950	1,398	590
1951	1,639	801
Mean	3,742	1,275
SE	402	109
Scalar	2.93	

Appendix 6

Table 1. Explanation and definition of Delaware River shad data from 1960 to 1995 used in the assessment. See Appendix Table A2 for associated Delaware River shad data.

Parameter	Years	Definition	Source
Catch	1960-95	Reported Comm. lbs.*1000- see Methods Section	
CPE	1960-95	Shad Catch/ Effort from Lewis- Russ Allen	
POP	1975-95	Population Size (N*1000)- Art Lupine	
JUV	1980-95	Shad Juvenile Indices- Art Lupine	
ADC	1960-95	Adjusted Landings for underreporting and Rec.	
ST	1960-95	Estimated Stock Size-N*1000- See Methods	
CN	1960-95	Adjusted Comm. Catch #- av. weight 4.5 lbs.	
Stock	1960-95	Total Stock Size-#*1000- see Methods	
U	1960-95	Annual Fishing Mortality- see Methods	
F	1960-95	Instantaneous Fishing Rate- see Methods	
Popw	1960-95	Population size (lbs.*1000)- see Methods	
SSBW	1960-95	Spawning Biomass- (Popw - ADC) - see Methods	
REC	1980-95	Adult Recruitment from Juvenile- see Methods	
REC2	1981-95	Not used in Assessment	
CPUE	1960-95	Comm. Catch Per Effort - see Methods	

Appendix 6

Table 2. New Jersey Commercial Landings American Shad 1952-1995 (In Pounds)

Year	Hudson Estuary	Coastal	Delaware Estuary	Other Unknown	Total
1952	589,500	375,560	106,000	331.24	1,402,300
1953	473,722	NA	67,000	138,078	678,800
1954	664,706	102,808	28,000	30,086	825,600
1955	1,006,644	298,500	14,000	7,356	1,326,500
1956	1,101,432	221,400	38,000	0	1,360,832
1957	1,029,475	234,291	43,000	0	1,306,766
1958	612,302	337,393	92,000	2,117	1,043,812
1959	678,744	340,171	57,000	0	1,075,915
1960	449,700	215,400	108,000	7,500	780,600
1961	352,544	102,405	174,000	3,751	632,700
1962	309,531	48,852	72,000	49,217	479,600
1963	215,454	78,842	99,000	48,704	442,000
1964	103,781	77,939	190,000	58,280	430,000
1965	117,563	26,464	227,000	21,473	392,500
1966	48,424	32,521	172,000	0	272,945
1967	99,867	21,893	118,000	7,938	247,700
1968	141,272	46,249	48,000	5,079	240,600
1969	120,428	56,413	5,000	5,659	187,500
1970	135,671	35,394	16,000	8,335	195,400
1971	100,760	17,088	8,400	14,552	140,800
1972	119,473	23,974	26,200	93,453	263,100
1973	98,248	19,688	21,700	3,164	142,800
1974	51,500	33,173	19,244	17,583	121,500
1975	37,097	49,339	35,898	0	122,334
1976	29,122	30,075	51,503	0	110,700
1977	63,754	92,269	41,863	0	197,886
1978	110,905	59,281	71,826	0	242,012
1979	59,812	64,640	24,436	0	148,888
1980	161,650	68,456	NA	50,642	280,748
1981	100,570	67,134	NA	95,557	263,261
1982	48,933	115,295	NA	185,700	349,928
1983	72,162	132,300	68,700	0	273,162
1984	76,775	143,200	73,045	0	293,020
1985	53,400	166,100	72,200	0	291,700
1986	118,998	92,284	82,431	41,522	335,234
1987	31,823	75,059	129,508	31,373	267,763
1988	111,700	114,013	136,745	72,082	434,540
1989	63,695	225,578	190,385	45,280	524,938
1990	57,419	227,596	262,064	64,566	611,645
1991	29,060	127,967	279,478	17,463	453,968
1992	28,570	125,323	202,051	10,884	366,828
1993	8,600	152,161	187,483	14,193	362,437
1994	NA	NA	NA	261,619	261,619
1995	1,204	162,853	128,876	0	292,933
1996		121,091	48,874		169,965

Appendix 6

Table 3. Inriver Landings (LBS. *1000), Coastal Landings, Stock Size, Inriver F, Coastal F, Total F and Recruitment to the Delaw 1

OBS	YEAR	ADC	CSTW	STOCK2	FR2	FC2	FTOTAL2	REC
1	1980	4.8	202.5	228.07	0.005844	0.21979	0.22563	237.5
2	1981	10.0	324.0	620.22	0.004062	0.12340	0.12746	326.8
3	1982	19.8	580.5	642.40	0.008607	0.22416	0.23276	290.7
4	1983	20.4	405.0	344.53	0.017971	0.30276	0.32073	644.1
5	1984	26.0	477.0	534.78	0.013567	0.22091	0.23448	473.1
6	1985	46.2	450.0	533.27	0.023981	0.20767	0.23165	364.8
7	1986	92.6	409.5	706.58	0.034000	0.13787	0.17187	385.7
8	1987	61.2	472.5	832.60	0.018868	0.13480	0.15367	414.2
9	1988	83.4	594.0	864.53	0.025626	0.16568	0.19131	364.8
10	1989	58.0	724.5	1005.89	0.015373	0.17442	0.18979	378.1
11	1990	112.4	931.5	1089.98	0.028696	0.21061	0.23931	689.7
12	1991	69.6	882.0	1069.47	0.017866	0.20245	0.22031	391.4
13	1992	102.0	612.0	1041.67	0.025346	0.13991	0.16525	218.5
14	1993	65.2	621.0	849.49	0.020574	0.17728	0.19785	642.2
15	1994	46.8	418.5	800.40	0.014811	0.12352	0.13833	366.7
16	1995	52.2	423.0	615.60	0.022490	0.16570	0.18819	431.3
17	1996	22.2	463.5	899.93	0.006210	0.12155	0.12776	868.3

.

Appendix 7

Table 1. Population Size (N *1000), Bay Juvenile Index, Coastal Landings (# *1000), Total Stock, Inbay F, Coastal F, Total F, Nat 1

OBS	YEAR	POP	REC	COASTC	STOCK	FB	FC	FT	NATIVE	ARTIF
1	1980	5.5	0.19	3	14.838	0.76652	0.22589	0.99241	8.606	6.232
2	1981	9.4	0.00	6	15.411	0.00120	0.49319	0.49439	8.939	6.473
3	1982	37.6	0.01	9	47.350	0.01975	0.21081	0.23056	27.463	19.887
4	1983	12.1	0.00	7	20.450	0.10577	0.41900	0.52478	11.861	8.589
5	1984	8.1	0.06	11	20.562	0.16599	0.76562	0.93160	11.926	8.636
6	1985	14.3	0.05	10	24.487	0.01303	0.52488	0.53790	14.203	10.285
7	1986	22.9	0.02	9	33.213	0.05573	0.31606	0.37179	19.263	13.949
8	1987	27.4	0.15	10	38.975	0.05589	0.29649	0.35238	22.605	16.370
9	1988	42.7	0.06	14	59.775	0.06954	0.26685	0.33639	34.670	25.106
10	1989	75.8	0.42	23	101.538	0.03546	0.25685	0.29233	56.892	42.646
11	1990	123.8	0.02	21	153.500	0.06792	0.14712	0.21503	89.030	64.470
12	1991	139.9	0.12	20	159.975	0.00054	0.13355	0.13409	94.385	65.590
13	1992	105.3	0.03	17	126.200	0.03637	0.14469	0.18105	68.148	58.052
14	1993	47.6	0.19	14	61.600	0.00000	0.25783	0.25783	32.0032	29.568
15	1994	129.5	0.27	8	137.500	0.00000	0.05994	0.05994	60.500	77.000
16	1995	333.9	0.70	8	341.900	0.00000	0.02368	0.02368	143.598	198.302
17	1996	203.2		10	213.200	0.00000	0.04604	0.04604	149.240	63.960

Appendix 7

Table 2. Stock origin (% wild and hatchery origin fish) of adult shad returning to the Conowingo Dam and the Upper Bay stock, 1989-96 Data from Dick St. Pierre (USFWS) and Carol Markham (MD DNR).

Year	% Hatchery Fish	
	Conowingo Dam	Upper Bay
1989	71	-
1990	70	-
1991	69	-
1992	76	-
1993	83	52
1994	89	44
1995	85	42
1996	55	70
Average		52

Table 3.

MEMO TO: Vic Crecco
Chairman, ASMFC Shad Stock Assessment Committee

FROM: Dale Weinrich and Carol Markham
Maryland Department of Natural Resources

SUBJECT: Comments Concerning Draft Stock Assessment of American Shad From Selected Atlantic Coast Rivers

1. In Table 1, page 31, Maryland and Virginia intercept landings are distinct from on another and should be analyzed separately. Table 1 should read as follows:

YEAR	MARYLAND	VIRGINIA
1980		95,914
1981		275,679
1982		276,995
1983	20,043	207,707
1984	19,085	644,338
1985	150,030	332,157
1986	126,223	355,588
1987	119,304	395,227
1988	264,642	426,838
1989	487,812	399,761
1990	283,649	325,176
1991	233,993	399,634
1992	198,833	432,193
1993	77,885	490,154
1994	33,644	230,106
1995	44,931	148,000
1996	94,97	

2. Table 2, page 32, also continues this same type of error by lumping Maryland and Virginia tag data into a single unit. Since only 1 of 58 (2%) tags recovered by Jesien in 1991 and 1992 came from the Upper Bay, the 38% figure listed in incorrect. You must separate tagging and recovery locations (Ocean City vs. Rudee Inlet, VA Bay vs. MD Bay) in order to accurately estimate these percentages. In addition, the 38% figure used in Table 2 assumes that the 10 (19%) tagged fish recovered in the VA ocean were destined for Chesapeake Bay. This assumption is highly tenuous and further inflates the percentage contribution estimates. This lumping seems even more erroneous because the Upper Bay and Virginia rivers were analyzed separately.

3. Tables 3 and 4, pages 34 and 35, should again be broken out and not lumped together as BAY. Were these numbers adjusted by taking the values from Table 1, adding 50% for under-reporting, and multiplying by 38%?

4. The Z values referred to on page 13 and presented in Appendix 7 are incorrect. Appendix 7

should read as follows:

YEAR	POPULATION SIZE	REPEAT SPAWNERS (Sexes combined)		Z
1984	8,074	0.4	32	
1985	14,283	9.1	1300	1.83
1986	22,902	2.4	550	3.26
1987	27,345	6.9	1887	2.50
1988	42,683	4.8	2049	2.59
1989	75,820	4.7	3564	2.48
1990	123,830	4.9	6068	2.52
1991	139,862	14.8	20700	1.79
1992	105,255	11.4	11999	2.46
1993	47,563	17.0	8086	2.57
1994	129,492	10.4	13466	1.26
1995	333,891	7.1	23706	1.70
1996	203,216	13.6	27637	2.49

It is interesting to note that total instantaneous mortality using a cohort-specific CPUE-at-age catch curve for the years 1985 through 1989 estimated Z at 0.59, o.92, 0.71, 0.62, and 1.30, respectively.

5. A reference is made on page 13 to Maryland Bay commercial landings, fishing effort date, (drift, anchor, and stake gillnets licensed) and CPE having been collected from 1990 to 1995. The problem with this is that I do not see this information in appendix 7 and even if I did I would view it as suspect since we have had a moratorium on shad fishing in the Maryland Bay since 1980.

6. The 38% figure used to determine the relative contribution of Bay shad to the VA-MD intercept fishery is , again, highly erroneous since the two must be separate. A second flaw in this exercise concerns the assumption that the upper Bay stock comprised 50% of the total Bay stock. What is meant by the upper Bay; Susquehanna River only? Susquehanna River/Flats? Analysis of total Bay shad landings, MD and VA combined vs Maryland mainstream Bay plus Susquehanna River, Flats, and Northeast River from 1962 through 1990 indicate that only 16.2% of the reported landings came from the "Upper Bay". Finally, total Maryland shad landings as a percentage of total Bay landings (MD + VA) from 1929 through 1980 averaged 26.8%.

7. The following discussion concerns the table in Appendix 7.

POTJUV: Why was this index used instead of the Bay-wide or the Upper Bay juvenile index? What relevance does the Potomac have with the Upper Bay?

YEAR	BAYWIDE INDICES
1980	0.19
1981	0.00
1982	0.01
1983	0.00
1984	0.08
1985	0.05
1986	0.02

1987	0.15
1988	0.06
1989	0.42
1990	0.02
1991	0.12
1992	0.03
1993	0.19
1994	0.27
1995	0.70

REC: Does recruitment refer to juveniles or spawning adults, and how was it calculated?

CST: What commercial landings totals were used to derive this column; MD, VA, or MD + VA? Also, shouldn't this column equal the adjusted commercial landings found in Table 4?

FB: How can these estimates be made if a shad moratorium has existed in Maryland's Chesapeake Bay since 1980? Does FB include Virginia data? What about the mortality associated with the Conowingo fish lifts; is it included under F or under M? It needs to be included somewhere since every adult transported upstream above the dams does not leave the system alive.

We could not duplicate the results in this table (Appendix 7). Better explanations with actual procedures and calculations would be appreciated.

8. In Table 5, page 36, the M values assigned to the upper Bay seem extraordinarily high. We have been utilizing the ICES 95th percentile formulation procedure of $3/T_{max}$ to estimate natural mortality and since our max age is 7, M would equal 0.43. Also in Table 5, we see total maturation by age 7, not age 6.

9. How were the numbers used in Figure 23 derived?

10. We currently utilize two different techniques to estimate upper Chesapeake Bay American shad instantaneous mortality (Z). Our tag-recapture data is used to estimate the mortality rate of shad captured at Conowingo Dam and lifted above the four hydrostations (F_{lift}). A cohort-specific CPUE-at-age catch curve is estimates instantaneous mortality of the entire population. Fish lift data is only used when calculating CPUE-at-age because CPUE from different gears is not additive.

Appendix 8

Table 1. Annual indices of shad juvenile production (maximal mean CPUE) in the Mattaponi and Pamunkey Rivers from 1979-1994 (Bruce Hill per. Comm.).

Year	Mattaponi	Pamunkey
1979	38.1	57.4
1980	38.8	7.1
1981	18.0	5.3
1982	21.1	3.0
1983	16.5	7.5
1984	34.4	2.5
1985	35.9	15.5
1986	36.6	8.9
1987	18.9	2.1
1988	- [1/]	-
1989	-	-
1990	-	-
1991	10.2	8.5
1992	2.6	0.2
1993	47.7	0.9
1994	62.0	22.1

[1/] - = no data taken or insufficient sample size.

Appendix 8

Table 2. Coastal Shad Landings from Virginia (N. *1000), inriver landings, coastal effort, inriver effort, Pamunkey River Juv. Inde

OBS	YEAR	CSTN	BAYC	COASTE	BAYE	RAPPM	RAPPF	YORKM	YORKF	JAMESM	JAMESF	PAMI	MATTAJ	RAPPE	YORKE	JAMESE
1	1980	7.00		.	.	0.0046	0.027	0.026	0.270	0.029	0.271	07.1	38.8	364	1222	1359
2	1981	18.00	.		.	0.0052	0.016	0.013	0.124	0.010	0.094	05.3	18.0	539	1177	900
3	1982	13.00	.	.	.	0.0059	0.014	0.014	0.088	0.033	0.062	3.0	21.1	377	1188	629
4	1983	15.00	.	.	.	0.0081	0.022	0.030	0.108	0.056	0.190	07.5	16.5	296	1301	1469
5	1984	43.00	.	.	.	0.0220	0.052	0.043	0.163	0.040	0.189	02.5	34.4	170	1067	831
6	1985	35.00	.	.	.	0.0190	0.034	0.038	0.093	0.025	0.090	15.5	35.9	164	983	602
7	1986	34.00	.	.	.	0.0140	0.046	0.039	0.074	0.040	0.064	08.9	36.6	57	824	150
8	1987	36.00	96.3	210.00	150.00	0.0160	0.032	0.011	0.059	0.009	0.065	02.1	18.9	60	825	948
9	1988	51.00	35.9	312.00	152.00	0.0120	0.029	0.014	0.046	0.023	0.157		.	45	776	473
10	1989	39.00	56.0	416.00	112.00	0.0120	0.080	0.026	0.103	0.064	0.180	.	.	47	797	48
11	1990	26.00	38.4	497.00	121.00	0.0030	0.027	0.004	0.053	0.017	0.092	.	.	62	860	48
12	1991	26.00	22.3	570.00	109.00	0.0020	0.024	0.005	0.069	0.009	0.060	08.5	10.2	56	766	55
13	1992	26.00	5.2	583.00	116.00	0.0020	0.025	0.002	0.039	0.028	0.221	0.2	02.6	20	780	144
14	1993	16.00	25.3	527.00	81.00	0.0020	0.014	0.016	0.029	.	.	0.9	47.7	13	439	.
15	1994	7.00	.	555.00	.	.		.	.	.	.	22.1	62.0	.	.	.
16	1995	6.00		534.00	.	.			.	.	.	2.2	06.4	.	.	.
17	1996	11.00	.	559.00	.	.		.	.		.	23.4	178.3	.	.	.

Appendix 8

Table 3. Annual indices of shad juvenile production (maximal mean CPUE) in the Mattaponi and Pamunkey Rivers from 1979-1996 (Bruce Hill per. Comm.).

Year	Mattaponi	Pamunkey
1979	38.1	57.4
1980	38.8	7.1
1981	18.0	5.3
1982	21.1	3.0
1983	16.5	7.5
1984	34.4	2.5
1985	35.9	15.5
1986	36.6	8.9
1987	18.9	2.1
1988	- [1/]	-
1989	-	-
1990	-	-
1991	10.2	8.5
1992	2.6	0.2
1993	47.7	0.9
1994	62.0	22.1
1995	6.4	2.2
1996	128.3	23.4

[1/] - = no data taken or insufficient sample size.

Appendix 8

Table 4. Virginia American shad landings, by water system

Year	Atlantic	Seaside	Misc	Chesapeake	James	York	Rappahannock	Potomac	Other	Total
1973	1202	13686	ND	535148	1375450	297152	67384	122188	23488	2435698
1974	46878	ND	ND	565324	617259	171367	121210	41118	4000	1567156
1975	40799	100	ND	231268	515257	198281	75853	74476	571	1136635
1976	196649	5204	ND	205335	244675	133383	28763	64048	17541	895788
1977	59232	ND	ND	61181	303658	919277	49566	31082	45066	1469032
1978	13161	ND	ND	177096	513237	429953	37796	34783	25015	1235041
1979	74462	672	ND	120396	355700	410861	17104	12306	2594	994095
1980	69483	26431	ND	190986	265938	195426	11149	11570	2892	973875
1981	224467	51212	ND	56083	31685	126194	4282	2837	1348	499119
1982	79192	197803	ND	12760	101271	186515	739	1600	5474	585354
1983	206175	1532	1990	34245	189628	231820	4846	2628	58	672922
1984	503291	141047	59	101944	240389	278099	1405	3302	200	1269736
1985	278157	54000	ND	57597	28637	213988	ND	235	370	632984
1986	266321	89267	ND	77151	1450	127406	ND	261	11259	573115
1987	307227	88000	607	97047	3970	128077	ND	573	7379	632880
1988	200834	228004	ND	9420	ND	42912	500	1141	443	483254
1989	182461	217300	80	41709	2	60560	ND	893	121	503126
1990	202687	122489	254	85603	217	40161	30	1821	871	454163
1991	334703	64931	5	24198	50	23302	67	1965	1246	450467
1992	384282	47911	377	35428	954	5262	1333	1951	696	478194
1993	385564	105388	ND	28484	3112	24359	972	213	2106	551600

Note: 1993 landings were collected from a mandatory reporting system; prior years' collections were from a voluntary system.

Appendix 8

Table 5.

COMMONWEALTH of VIRGINIA

Marine Resources Commission
2600 Washington Avenue
P. O. Box 756
Newport News, Virginia 23607-0756

George Allen
Governor

Becky Norton Dunlop
Secretary of Natural Resources

William A. Pruitt
Commissioner

June 16, 1997

MEMORANDUM

TO: Vic Crecco, Chairman
ASMFC Alosid Assessment Committee

FROM: Rob O'Reilly

SUBJECT: American Shad Stock Composition of Coastal Intercept Fisheries

Please find an update of the Virginia coastal American shad landings form 1980 through 1996, below.

As you know, I do not support the results (recaptures) from the 1991-92 Rudee Inlet, Virginia American shad tagging study, as a sound representation of the Virginia intercept fishery for shad.

At the time of this study the major Virginia intercept fishery was located in the northern coastal area of Virginia, from Quinby to Chincoteague. The intercept fishery off Virginia Beach and Rudee Inlet has been a minor fishery since 1988. The following table illustrates this fact. Data are in pounds of American shad.

Year	Southern Virginia Coastal	Northern Virginia Coastal
1980	61,243	34,228
1981	138,406	137,273
1982	57,794	197,805
1983	42,423	165,284
1984	409,851	231,087
1985	181,375	148,047
1986	215,859	139,717
1987	133,200	261,172
1988	75,247	353,591
1989	64,567	335,194
1990	21,758	264,702
1991	103	399,464

Appendix 8

Table 6. CPUE based on VIMS Anadromous Program logbook data 1980-1993. American shad

		Males		Females		Gillnet
River	Year	CPUE	Kilograms	CPUE	Kilograms	Season Length of Net (m)
Rappahannock	1993	0.0023	30.68	0.0142	186.77	13175.40
York		0.0159	6967.01	0.0294	12913.80	439332.00
James		——	——	——	——	
Rappahannock	1992	0.0020	39.96	0.0250	499.10	19943.00
York		0.0023	1819.26	0.0385	30001.00	780103.20
James		0.0276	3963.54	0.2213	31769.20	143588.90
Rappahannock	1991	0.0024	136.06	0.0244	1376.55	56429.60
York		0.0053	4047.8	0.0692	52986.68	765872.00
James		0.0087	473.68	0.0595	3253.55	54639.90
Rappahannock	1990	0.0030	184.11	0.0270	1676.26	62061.00
York		0.0035	3027.39	0.0529	45507.07	859770.10
James		0.0173	840.27	0.0919	4452.84	48478.10
Rappahannock	1989	0.0121	573.7	0.0802	3805.60	47479.10
York		0.0263	20995.6	0.1027	81927.90	797443.90
James		0.0636	3079.8	0.1804	8737.90	48423.30
Rappahannock	1988	0.0116	523.9	0.0286	1287.60	45026.60
York		0.0143	11074.1	0.0457	35546.00	776454.70
James		0.0232	1097.6	0.1573	7436.00	47274.80
Rappahannock	1987	0.0161	960.3	0.0318	1903.00	59784.80
York		0.0111	9122.1	0.0553	45661.30	825028.20
James		0.0088	830.6	0.0645	6114.90	94828.60
Rappahannock	1986	0.0138	790.2	0.0464	2662.20	57398.50
York		0.0390	32133	0.0743	61218.40	823826.50
James		0.0403	6063.8	0.0636	9556.50	150297.60
Rappahannock	1985	0.0187	3066.2	0.0335	5488.00	163778.40
York		0.0297	29172.7	0.0930	91414.30	982648.10
James		0.0249	15008	0.0895	53831.50	601563.30
Rappahannock	1984	0.0217	3697.8	0.0520	8866.20	170424.60
York		0.0433	46191.1	0.1627	173727.60	1067621.80
James		0.0404	33544.1	0.1890	157028.50	830866.40
Rappahannock	1983	0.0081	2410.2	0.0216	6389.50	296068.40
York		0.0296	38542.1	0.1083	140830.20	1300885.10
James		0.0554	81407.1	0.1896	278574.80	1468940.30
Rappahannock	1982	0.0059	2226.6	0.0136	5107.40	376752.40
York		0.0144	17079.5	0.0875	103981.60	1187954.00
James		0.0328	20605.2	0.0623	39177.40	628693.30
Rappahannock	1981	0.0052	2806.9	0.0155	8362.30	538701.90
York		0.0130	15249.3	0.1240	146000.10	1177230.10
James		0.0102	9219.4	0.0936	84274.00	900170.20
Rappahannock	1980	0.0046	1673.4	0.0268	9772.80	364649.40
York		0.0260	31779.7	0.2695	329485.50	1222527.50
James		0.0287	39036.3	0.2711	368268.50	1358642.30

Rob,

Please note that there are no logbook data available for the James River in 1993. The above is a compilation that I did from files that Phil Sadler had created. We may need to do some further checking on these data when I can get the raw data into an Access database.

Bobby

Appendix 9

Table 1. American shad landings and percentage, other than Albermarle Sound and Atlantic Ocean, NC, 1972-1996

	Cape Fear River		Core Sound		Neuse River		Pamlico River		Pamlico Sound		Other Areas		State Total
Year	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	lb
1972	66,968	14.3	4,534	1.0	81,715	17.4	92,799	19.8	92,069	19.7			468,484
1973	32,120	10.0	3,047	0.9	69,526	21.7	30,300	9.4	105,237	32.8			321,000
1974	20,219	5.5	5,829	1.6	61,091	16.8	32,167	8.7	132,926	36.0			368,833
1975	22,949	9.5			27,764	11.5	34,157	14.2	69,307	28.7			241,240
1976	7,288	4.4			34,161	20.4	32,150	19.2	13,743	8.2			167,190
1977	16,106	13.3	2,575	2.1	6,144	5.1	13,432	11.1	3,171	2.6			121,022
1978	32,999	8.2	6,733	1.7	31,726	7.9	40,908	10.2	124,243	30.9	1,600	0.4	402,017
1979	52,104	18.7	3,676	1.3	31,611	11.4	10,971	4.0	69,486	25.0			278,070
1980	45,486	22.8	17,473	8.8	11,615	5.8	6,430	3.2	44,664	22.4	1,010	0.5	199,206
1981	52,911	15.1	1,920	0.5	15,549	4.4	9,761	2.8	97,106	27.6	105	0.03	351,500
1982	78,184	19.0	4,788	1.2	18,129	4.4	5,080	1.2	122,898	29.9			411,852
1983	65,728	14.7	2,664	0.6	45,378	10.2	53,794	12.1	58,324	13.1	175	0.03	445,879
1984	69,040	11.8	11,039	1.9	70,305	12.0	108,410	18.5	85,177	14.6	53	0.01	584,843
1985	17,788	5.4	10,235	3.1	56,620	17.2	40,675	12.3	52,607	15.9			329,639
1986	37,048	10.0	14,918	4.0	70,880	19.0	18,138	4.8	49,357	13.2			373,794
1987	14,003	4.3	2,683	0.7	47,117	14.4	22,640	6.9	50,168	15.3	50	0.01	327,646
1988	5,266	1.9	4,433	1.6	15,110	5.3	46,607	16.5	33,485	11.8			283,050
1989	12,719	4.0	5,450	1.7	13,452	4.2	17,012	5.3	27,158	8.3	250	0.07	323,336
1990	26,519	8.5	1,648	0.5	11,543	3.7	6,520	2.1	14,803	4.8	423	0.1	313,550
1991	30,040	10.9	1,652	0.6	2,880	1.0	2,568	0.9	9,827	3.6	443	0.2	276,507
1992	44,250	18.6	63	0.02	13,808	5.8	14,231	5.9	8,548	3.5	2,283	0.9	237,858
1993	62,278	34.8	86	0.04	8,538	4.8	3,033	1.7	3,102	1.7			178,790
1994	10,871	9.9	166	0.1	7,216	6.5	4,039	3.6	4,944	4.5	129	0.1	110,975
1995	11,180	5.5	22	0.01	15,311	7.4	9,573	4.6	5,232	2.5	581	0.4	205,836
1996	26,818	13.4	534	0.4	24,439	12.2	8,672	4.3	9,115	4.6	5,357	2.7	199,558

Appendix 9

Table 2. Coastal Commercial Landings (LBS *1000) from North Carolina Rivers, Coastal Commercial Landings in Numbers (N *1000) FR 1

1	1980	147	37	68.7	45.5	11.6	6.4	2.41
2	1981	272	68	66.7	52.9	15.5	9.8	0.89
3	1982	312	78	118.0	78.2	17.1	5.1	1.48
4	1983	225	56	216.0	65.7	45.4	53.7	1.88
5	1984	498	125	227.0	69.0	70.3	108.4	2.05
6	1985	262	65	148.0	17.8	56.6	40.7	2.55
7	1986	370	92	120.0	37.0	70.9	18.1	1.87
8	1987	463	116	149.0	14.0	47.1	22.6	2.76
9	1988	482	116	128.0	5.3	15.1	46.6	1.64
10	1989	613	153	209.0	12.7	13.5	17.0	2.14
11	1990	424	106	214.0	26.5	11.5	6.5	1.73
12	1991	400	100	209.0	30.0	2.9	2.6	2.30
13	1992	371	93	131.0	44.3	13.8	14.2	1.75
14	1993	241	60	73.0	62.3	8.5	3.0	2.02
15	1994	152	38	50.0	10.9	7.2	4.0	.
16	1995	242	81	60.0	11.2	15.3	9.6	.
17	1996	323	81	65.0	26.8	24.4	8.7	.

Appendix 9

Table 3. Commercial landings and value of American shad in North Carolina, Atlantic Ocean and the Albemarle Sound area, 1972-1995, and percentages contributed by area.

	Landings in Pounds			Percent (lb)		Value in Dollars		
	State	Atlantic	Albemarle	Atlantic	Albemarle	State	Atlantic	Albemarle
Year	Total	Ocean	Sound	Ocean	Sound	Total	Ocean	Sound
1972	468,484		130,399		27.8	111,609		26,997
1973	321,000		80,770		25.2	85,491		22,102
1974	368,833		116,502		31.6	105,668		28,531
1975	241,240		87,063		36.1	82,815		29,280
1976	167,190	1,547	78,301		46.8	65,227		30,014
1977	121,022		79,594		65.8	54,764		35,234
1978	402,017	5,000	158,908	1.2	39.5	144,986	530	38,233
1979	278,070	25,064	85,158	9.0	30.6	121,662	6,915	26,389
1980	199,206	3,943	68,695	2.0	34.5	88,112	2,641	21,343
1981	351,500	107,415	66,732	30.6	19.0	189,793	48,798	29,330
1982	411,852	63,979	118,794	15.5	28.8	183,483	21,524	38,473
1983	445,879	3,788	216,058	0.8	48.5	187,360	2,248	80,039
1984	584,843	13,511	227,308	2.3	39.0	241,009	3,938	73,151
1985	329,639	3,159	148,555	1.0	45.1	152,547	766	54,173
1986	373,794	63,085	120,367	16.9	32.2	228,819	28,626	73,152
1987	327,646	41,162	149,923	12.6	45.8	215,115	29,194	81,354
1988	283,050	50,088	128,061	17.7	45.2	171,962	40,844	67,866
1989	323,396	38,548	208,807	11.9	64.6	214,896	34,309	125,949
1990	313,550	37,064	214,954	11.8	68.5	170,161	27,088	101,527
1991	276,507	19,217	209,900	6.9	75.9	221,880	15,039	156,039
1992	237,858	23,956	131,499	10.0	55.3	194,341	23,178	117,471
1993	177,897	28,122	73,604	15.8	41.4	149,419	24,622	55,387
1994	110,986	33,896	50,314	30.5	45.3			
1995	192,321	89,936	60,760	46.7	31.6			

Appendix 9

Table 4.

NAME: ASII.WK1

STATE: North Carolina

SPECIES: American Shad

SAMPLING PROGRAM: Juvenile Survey

LOCATION: Albemarle Sound Area

GEAR: 60' Bag Seine

YEAR	NUMBER PER UNIT OF EFFORT	AMOUNT OF EFFORT
1972	0.01	27
1973	0.3	63
1974	0.02	65
1975	0.1	66
1976	0	66
1977	0.16	65
1978	0.1	58
1979	0.27	52
1980	0.4	81
1981	0.04	69
1982	0.4	68
1983	0.01	69
1984	0.1	70
1985	1.44	71
1986	0.08	69
1987	0.11	69
1988	0.1	76
1989	0	66
1990	0	69
1991	0	68
1992	0	57
1993	0	57
1994	0	57
1995	0.01	57

Appendix 9

Table 5. Total mortality (Z) estimates for American shad in Albemarle Sound, NC based on the frequency of repeat spawners between 1972 and 1993. Age and spawning history data were taken from the NC commercial fishery.

Year	Frequency of Spawning Scars				$Z^{1/}$
	1	2	3	4	
1972	109	45	14	2	1.32
1973	78	11	9	3	1.00
1974	15	3	0	0	1.61
1975	77	11	1	0	2.17
1976	104	47	3	0	1.77
1978	29	1	0	0	3.40
1979	56	4	1	0	3.37
1980	105	125	47	1	2.41
1981	84	192	127	52	0.89
1982	198	154	40	8	1.48
1983	28	73	12	1	1.88
1984	213	180	73	3	2.05
1985	177	51	4	0	2.55
1986	87	39	6	0	1.87
1987	169	63	4	0	2.76
1988	207	144	28	0	1.64
1989	130	85	10	0	2.14
1990	118	113	20	0	1.73
1991	198	62	2	7	2.30
1992	179	179	31	0	1.75
1993	169	99	3	0	2.02

1/ SPFQ = a + Z* N,

where: SPFQ = the number of fish with N spawning scars;
N = number of spawning scars (ie 1,2,3 or 4).

Appendix 10

Table 1. Riverine Fishing Mortality Rate (FMR) for American Shad

River System	Years of Study	Number of Shad Tagged		Tag Returns				Riverine FMR (%) (calculated)	
				Within River		Outside River			
		&	%	&	%	&	%	&	%
Edisto	1989	82	7	35	0	5	0	48.6	0.0
	1990	95	11	41	3	2	0	45.6	30.0
	Total	177	18	76	3	7	0	46.9	18.8
Santee	1991	464	64	62	6	6	0	14.7	10.3
	1992	646	71	112	4	39	0	23.4	7.5
	Total	1110	135	174	10	45	0	19.7	9.3
Combahee	1993	7	5	0	0	0	0	ID[1]	ID
Edisto	1994	43	4	12	0	0	0	27.9	ID
	1995[2]	210	42	34	4	0	1	16.2	11.8
	1996[3]	213	25	23	1	0	0	10.8	4.0
	1997	139	6	19	0	1	0	14.4	0.0
	Total	605	77	88	5	1	1	14.7	7.8

[1] Insufficient data collected to determine FMR

[2] Flood conditions through much of the season caused a noticeable reduction in effort (as compared to that of more normal season) within the set net fishery and likely reduced the efficiency of this gear type as well.

[3] Below normal water temperatures lingered through much of the season and apparently delayed the spawning run. Many shad moved upriver after the closure of the gill-net season.

Table 2.

Inconsistencies in Population Indicators - Santee River

YEAR	1997 ASSESSMENT ^	PASSAGE	"REPORTED" LANDINGS ^
1990	14,630	81,358	2,672
1991	101,570	176,141	13,280
1992	35,630	146,693	15,131
1993	39,140	157,848	9,525
1994	35,457	211,546	8,785
1995	-	445,000	30,615
1996	-	477,000	79,799

^ Pounds divided by 3.5 lbs./fish to produce numbers of shad

$50 Reward Tags vs. Non-Designated Reward Tags

YEAR	RIVER	NO. NDES.	% RETURN	NO. $50	% RETURN
1990	Edisto	86	45.3	9	44.4
1994 & 1995	Edisto[1]	22	31.8	7	14.3
1991 & 1992	Santee[1]	768	22.3	37	24.3

[1] Only fish of comparable size and tagged during same period were used in comparisons
NDES = Non-designated reward tags
$50 = designated $50 reward tags

Table 3. South Carolina Shad Landings

Year	Winyah Bay	Waccamaw R.	Pee Dee R.	Black R.	Wac-Pee Dee Total	Santee R.	Cooper R.	Edisto R.	Combahee R.	Savannah R. - SC	Total Inshore	Ocean Intercept	Statewide
1979	NR	37602	13549	12475	63626	9494	NR	11625	3769	25058	113983	83608	197071
1980	NR	50036	7105	9266	66407	4473	NR	7046	1768	35637	115481	155072	270553
1981	69062	105280	57209	19479	251030	4020	NR	9078	4578	28154	296860	149552	446412
1982	25068	59597	7196	5649	97510	9004	NR	6995	3345	36578	153342	245088	398428
1983	19677	40073	15089	1677	55516	1462	NR	8496	3182	27280	175826	205522	391348
1984	6361	10459	25959	3780	46559	4362	2647	8383	1544	79134	143418	392944	536362
1985	56417	86485	13838	2313	159049	6554	NR	13159	3399	39358	231523	137556	369079
1986	108063	55882	5734	10849	180460	35491	NR	10568	679	28697	256226	225429	481655
1987	41660	26020	5421	2698	80119	10000	NR	5970	[illegible]	30318	126880	359617	486597
1988	20524	20831	3219	1615	54208	30513	399	6951	1203	17890	111145	258397	369542
1989	55123	17129	5359	309	77820	17359	NR	11836	2675	13785	118575	278230	346817
1990	10426	6118	7715	NR	24259	9551	NR	12379	754	96992	83732	161374	225106
1991	20789	3992	2330	17387	44058	45480	NR	4800	550	5590	101480	144252	245741
1992	51110	7596	2935	NR	61658	52960	NR	5034	260	15436	135840	109165	215046
1993	5204	2444	1207	77	8882	33038	NR	3582	78	3607	49895	64036	114621
1994	10056	1501	1928	NR	13485	30747	NR	1675	NR	4943	50290	71909	122159
1995	16275	6741	3526	NR	26542	107154	NR	2491	NR	16008	153203	132321	285604
1996	10057	6338	421	1282	20406	278296	NR	7272	NR	18655	320629	222044	542673
1997													

Appendix 10

Table 4. Age composition of male American shad from commercial catches by area and year.

AREA	AGE / YEAR	III N	III (%)	IV N	IV (%)	V N	V (%)	VI N	VI (%)	VII N	VII (%)
Ocean Fishery	1979	1	(6.25)	2	(12.50)	13	(81.25)	0	(0.00)	0	(0.00)
	1980	0	(0.00)	8	(36.36)	14	(63.64)	0	(0.00)	0	(0.00)
	1981	0	(0.00)	1	(3.45)	23	(79.31)	5	(17.24)	0	(0.00)
	1982	-	-	-	--	-	--	-	--	-	(0.00)
Waccamaw-Pee Dee Drainage	1979	0	(0.00)	46	(45.54)	51	(50.50)	4	(3.96)	0	(0.00)
	1980	0	(0.00)	51	(27.42)	133	(71.51)	2	(1.08)	0	(0.00)
	1981	0	(0.00)	23	(11.27)	167	(81.86)	14	(6.86)	0	(0.00)
	1982	1	(0.38)	23	(8.75)	178	(67.68)	61	(23.19)	0	(0.00)
Santee River	1979	0	(0.00)	4	(21.00)	14	(73.70)	1	(5.30)	0	(0.00)
	1980	0	(0.00)	12	(25.53)	35	(74.47)	0	(0.00)	0	(0.00)
	1981	1	(1.20)	7	(8.43)	63	(75.90)	12	(14.46)	0	(0.00)
	1982	1	(2.17)	5	(10.87)	29	(63.04)	11	(23.91)	0	(0.00)
Edisto River	1979	1	(1.70)	29	(50.00)	28	(48.30)	0	(0.00)	0	(0.00)
	1980	0	(0.00)	25	(34.25)	48	(65.75)	0	(0.00)	0	(0.00)
	1981	0	(0.00)	10	(16.13)	44	(70.97)	8	(12.90)	0	(0.00)
	1982	0	(0.00)	10	(12.99)	64	(83.12)	3	(3.90)	0	(0.00)
Savannah River	1979	2	(2.10)	51	(53.10)	43	(44.80)	0	(0.00)	0	(0.00)
	1980	0	(0.00)	17	(16.35)	86	(82.69)	1	(0.96)	0	(0.00)
	1981	1	(0.64)	29	(18.47)	115	(73.25)	12	(7.64)	0	(0.00)
	1982	0	(0.00)	8	(6.84)	93	(79.49)	16	(13.68)	0	(0.00)
All Areas	1979	4	(1.40)	132	(45.50)	149	(51.40)	5	(1.70)	0	(0.00)
	1980	0	(0.00)	113	(26.26)	316	(73.15)	3	(0.69)	0	(0.00)
	1981	2	(0.37)	70	(13.08)	412	(77.00)	51	(9.53)	0	(0.00)
	1982	2	(0.40)	46	(9.14)	364	(72.37)	91	(18.09)	0	(0.00)

Table 5.

SAMPLING PROGRAM: Juvenile Trawling
LOCATION: Altamaha River
Gear: 4.6 Meter Semi-balloon Otter Trawl

YEAR	CPUE (FISH/1000 M**2)	% S.E.
1982	9.7	31.4
1983	1.9	18.1
1984	15.9	21.0
1985	1.1	22.0
1986	1.2	24.8
1987	3.7	44.0
1988	1.8	19.6
1989	5.0	22.3
1990	1.1	17.4
1991	2.9	15.6

** Juvenile indices of abundance did not track changes in relative year-class strength over time. Nine of the ten years of data showed no significant difference **

Appendix 11

Population Size (N *1000), Coastal Landings (N *1000), Inriver Landings (N *1000), Recruitment, FR, FC and FT for the Altamaha River

OBS	YEAR	TPOP	ALTCST	ACATCH	REC	FR	FC	FT
1	1982	114354	8.54	56.180	115	0.75502	0.077485	0.83251
2	1983	247.10	6.10	79.530	124	0.40048	0.024996	0.42547
3	1984	206.59	11.59	68.250	101	0.43078	0.057737	0.48852
4	1985	219.27	4.27	94.600	80	0.57982	0.019666	0.59948
5	1986	88.93	7.93	42.120	81	0.73397	0.093400	0.82737
6	1987	148.59	11.59	63.020	106	0.61619	0.071210	0.69740
7	1988	136.54	8.54	53.760	142	0.54473	0.064587	0.60931
8	1989	103.32	7.32	50.880	174	0.75502	0.073483	0.82851
9	1990	75.49	5.49	31.500	231	0.59784	0.075505	0.67334
10	1991	79.88	4.88	30.000	.	0.51083	0.063037	0.57386
11	1992	119.66	3.66	44.080	.	0.47804	0.031064	0.50910
12	1993	147.44	2.44	37.700	.	0.30111	0.01668	0.31779
13	1994	190.05	3.05	50.490	.	0.31471	0.016179	0.43269
14	1995	211.71	6.71	67.650	.	0.40048	0.032207	0.47379
15	1966	292.33	7.93	102.384		0.44629	0.027502	

```
//EPJ5254W   JOB (EP,AGCY,1,5),'HOWELL',
//   MSGLEVEL=(1,1),CLASS=A,TIME=1
/*LOGONID EPJ0000
//STEP1     EXEC SAS
//GDEVICE0 DD DSN=EPP.R5.SASGRAPH.DEVICES,DISP=SHR
//SYSIN     DD *

* APPENDIX 12. THOMPSON -BELL YPR AND SHEPHERD S-R MODELS FOR
SHAD;
* WEIGHT = SSB;
* AGE-SPECIFIC M;
DATA CALC;

ARRAY L_AGE{40} A1-A40;
ARRAY MIG{25} M1-M25;
ARRAY MAT{25} MAT1-MAT25;
ARRAY M{20} M01-M020;
ARRAY R{20} R01-R020;
                                                  /* NATURAL MORTALITY
*/
A=  1.20;                                        /* --+
*/
B=1.5;                                             /*   |- STOCK /
RECRUITMENT      */
K=2121;                                          /* THOUSANDS OF IBS.
*/

* AGES AT LENGTH;
L_AGE{16} =3.0;
L_AGE{19} =5.0;


* MIGRATION RATES (PERCENT LEFT IN RIVERS);

MIG{1}=0.9;
MIG{2}=0.9;
MIG{3}=0.9;
MIG{4}=0.0;
MIG{5}=0.0;
MIG{6}=0.0;
MIG{7}=0.0;
MIG{8}=0.0;
DO I= 9 TO 12;
MIG{I}= 0.0;
END;

*MATURATION RATES (FRAC MATURE);
MAT{1}=0.0;
MAT{2}=0.0;
MAT{3}=0.0;
MAT{4}=0.2;
MAT{5}=0.6;
```

```
MAT{6}=1.0;
MAT{7}=1.0;
MAT{8}=1.0;
MAT{9}=1.0;
DO MA=10 TO 12;
MAT{MA}=1.0;
END;

*AGE-SPECIFIC NATURAL MORTALITY;


M{1}=0.3;
M{2}=0.3;
M{3}=0.3;
M{4}=0.36;
M{5}=0.48;
M{6}=0.60;
M{7}=0.60;
M{8}=0.60;
DO MO=9 TO 12 ;
M{MO}=0.60;
END;

* PARTIAL REC VECTOR;

R{1}=0.0;
R{2}=0.0;
R{3}=0.0;
R{4}=0.45;
R{5}=1.00;
R{6}=1.00;
R{7}=0.90;
DO RO= 8 TO 12;
R{RO}=0.80;
END;

DO BAYREC=  16;                    /* LGTH AT RECRUIT TO BAY FSHY  */
 DO COASTR= 16;                    /* LGTH AT RECRUIT TO COAST FSHY*/

 DO FR= 0.0, 0.01 to 1.4 by 0.01; /* FISHING MORTALITY IN RIVER
*/
 DO FO= 0.0;                         /* FISHING MORTALITY IN OCEAN */


DISCARD=0;
                                                   /* RELEASE MORTALITY
*/
PIECESB= 1;
PIECESC=0;

   DO AGE= 1 TO 12 ;
     X=1.0;
     M_AGE = L_AGE(BAYREC);                        /* MEAN AGE AT MIN
LENGTH (BAY) */
```

```
     D_AGE = M_AGE - AGE;                               /* DELTA AGE
*/
     IF 0 < D_AGE < 0.5 THEN DO;                       /* SUBLEGAL DURING ALL
OR PART  */
       RATIO = D_AGE/0.5 ;                             /*  OF FIRST HALF OF
YEAR       */
       FPRIMEB1 = X*  DISCARD * RATIO;/* F PRIME 1ST HALF OF YEAR
*/
       FPRIMEB2 = 0;                         /* F PRIME 2ND HALF OF YEAR
*/
       BAYF1 = FO* X*(1.0 - RATIO); /* F IN OCEAN 1ST HALF OF
YEAR            */
       BAYF2 = FO*X;                   /* F IN OCEAN 2ND HALF OF YEAR
*/
       END;
     ELSE IF D_AGE >= 0.5 THEN DO;                        /* SUBLEGAL DURING
ALL OR PART  */
       IF D_AGE > 1.0 THEN D_AGE = 1.0;       /*  OF SECOND HALF OF
YEAR       */
       RATIO =(D_AGE-0.5)/0.5 ;
       FPRIMEB1 = X* DISCARD;          /* F PRIME 1ST HALF OF YEAR
*/
       FPRIMEB2 = X*DISCARD * RATIO;/* F PRIME 2ND HALF OF YEAR
*/
       BAYF1 = 0;                        /* F IN OCEAN 1ST HALF OF YEAR
*/
       BAYF2 = FO* X*(1.0 - RATIO);    /* F IN OCEAN 2ND HALF OF
YEAR      */
       END;
     ELSE DO;                                           /* LEGAL DURING WHOLE
YEAR       */
       FPRIMEB1 = 0;                                    /* F PRIME 1ST HALF
OF YEAR      */
       FPRIMEB2 = 0;                                    /* F PRIME 2ND HALF
OF YEAR      */
       BAYF1 = FO;                       /* F 1ST HALF OF YEAR
*/
       BAYF2 = FO;                     /* F 2ND HALF OF YEAR
*/
       END;


                                                        /* SCALING FOR
FISHING RATE      */
     M_AGE = L_AGE(COASTR);                             /* MEAN AGE AT MIN
LNGTH (COAST)*/
     D_AGE = M_AGE - AGE;                               /* DELTA AGE
*/
     IF 0 < D_AGE < 0.5 THEN DO;                       /* SUBLEGAL DURING ALL
OR PART  */
       RATIO = D_AGE/0.5 ;                             /*  OF FIRST HALF OF
YEAR       */
       FPRIMEC1 =X *DISCARD * RATIO;                   /* F PRIME 1ST HALF OF
YEAR      */
```

```
       FPRIMEC2 = 0;                              /* F PRIME 2ND HALF
OF YEAR      */
       COASTF1 =FR * X*(1.0 - RATIO);   /* F IN RIVER 1ST HALF OF
YEAR   */
       COASTF2 = FO*X;               /* F IN OCEAN 2ND HALF OF YEAR
*/
       END;
     ELSE IF D_AGE >= 0.5 THEN DO;               /* SUBLEGAL DURING
ALL OR PART   */
       IF D_AGE > 1.0 THEN D_AGE = 1.0;         /*  OF SECOND HALF OF
YEAR       */
       RATIO =(D_AGE-0.5)/0.5;
       FPRIMEC1 = FO * DISCARD;                /* F PRIME 1ST HALF OF
YEAR      */
       FPRIMEC2 =FO *DISCARD * RATIO;          /* F PRIME 2ND HALF OF
YEAR      */
       COASTF1 = 0;                             /* F 1ST HALF OF YEAR
*/
       COASTF2 =FO * X*(1.0 - RATIO);           /* F 2ND HALF OF YEAR
*/
       END;
     ELSE DO;                                   /* LEGAL DURING WHOLE
YEAR       */
       FPRIMEC1 = 0;                            /* F PRIME 2ND HALF
OF YEAR      */
       FPRIMEC2 = 0;                            /* F PRIME 2ND HALF
OF YEAR      */
       COASTF1 = FR * X;        /* F IN RIVER 1ST HALF OF YEAR
*/
       COASTF2 = FO * X;             /* F IN OCEAN 2ND HALF OF YEAR
*/
       END;

     FB1 =(BAYF1*R{AGE})+(FPRIMEB1*R{AGE});      /* OCEAN F 1ST
HALF OF YR      */
     FB2 =(BAYF2*R{AGE})+(FPRIMEB2*R{AGE});   /* OCEAN F 2ND HALF
OF YR      */
     FC1 =(COASTF1*R{AGE})+(FPRIMEC1*R{AGE});   /* RIVER F 1ST
HALF OF YR    */
     FC2 =(COASTF2*R{AGE})+(FPRIMEC2*R{AGE});   /* OCEAN F 2ND
HALF OF YR    */

     ZB1 =(M{AGE}) + FB1;        /* OCEAN Z 1ST HALF OF YR      */
     ZB2 =(M{AGE}) + FB2;         /* OCEAN Z 2ND HALF OF YR      */
     ZC1 =(M{AGE}) + FC1;         /* RIVER Z 1ST HALF OF YR    */
     ZC2 =(M{AGE}) + FC2;        /* OCEAN Z 2ND HALF OF YR    */

     SURVIVE=   EXP(-ZB1*0.5) * PIECESB;     /* OCEAN SURVIVORS 1ST
HALF    */
     DEATHS1=   PIECESB - SURVIVE;             /* DEATHS 1ST HALF OF
YR     */
     CATCH1=    (BAYF1/ZB1) * DEATHS1;         /* CATCH 1ST HALF OF
YR     */
     MIGRATE=   SURVIVE * (1.0-MIG{AGE});       /* NBRS THAT
```

```
MIGRATE OUT     */
     SURVIVE=  SURVIVE - MIGRATE;            /* OCEAN SURV AFTER
MIGRATE   */
     SURVIVEB= EXP(-ZB2*0.5) * SURVIVE;      /* OCEAN SURV AT END OF
YEAR  */
     DEATHS2=  SURVIVE - SURVIVEB;             /* DEATHS 2ND HALF OF
YR    */
     CATCH2=   (BAYF2/ZB2) * DEATHS2;          /* CATCH 2ST HALF OF
YR     */

     DEATHSB=  DEATHS1 + DEATHS2:              /* NBR THAT DIED IN
OCEAN      */


     SURVIVE= EXP(-ZC1 *0.5)*PIECESC;      /* RETURNING SPAWNERS*/
     DEATHS1= PIECESC-SURVIVE;                /* DEATHS 1ST HALF OF
YR */
     CATCH3=(1-EXP(-FR))*DEATHS1; /* RIVER CATCH*/
     SURVIVE= SURVIVE+MIGRATE;              /* COAST SURVIVORS 2ND
HALF */
     SURVIVEC = (SURVIVE+MIGRATE)-CATCH3;  /*RIVER SPAWNERS*/



     DEATHS2=  SURVIVE - SURVIVEC;                /* DEATHS 2ND
HALF OF YR     */
     CATCH4=   (BAYF2/ZC2) * DEATHS2;            /* CATCH 2ST HALF
OF YR     */

     DEATHSC=  DEATHS1 + DEATHS2;                 /* NBR THAT DIED
ON COAST   */
     COASTCAT= CATCH3;                             /* CATCH FROM
RIVER      */
     BAYCATCH= CATCH1 + CATCH2+CATCH4;            /* CATCH FROM
OCEAN     */

     WT=12*(1-EXP(-0.32*(AGE-0.26)))**3.0;
                                                  /* WEIGHT AT AGE
*/
     SSB=(SURVIVEB+SURVIVEC) * WT*(MAT{AGE});
     TSSB+SSB;
     XX=(A*(TSSB)-1);
     IF XX >= 0
      THEN SP=K*(XX)**(1/B);            /* SPAWNING BIOMASS
*/
      ELSE SP=0;
     IF SP>0
      THEN RECRUITS=SP/TSSB;            /* NUMBER OF RECRUITS IN
SR FUNCTION */
      ELSE RECRUITS=0;
     CATCH=BAYCATCH+COASTCAT;           /* COMBINED CATCH
*/
```

```
MIGRATE OUT     */
     SURVIVE=  SURVIVE - MIGRATE;           /* OCEAN SURV AFTER
MIGRATE   */
     SURVIVEB= EXP(-ZB2*0.5) * SURVIVE;    /* OCEAN SURV AT END OF
YEAR  */
     DEATHS2=  SURVIVE - SURVIVEB;           /* DEATHS 2ND HALF OF
YR    */
     CATCH2=   (BAYF2/ZB2) * DEATHS2;        /* CATCH 2ST HALF OF
YR     */

     DEATHSB=  DEATHS1 + DEATHS2;            /* NBR THAT DIED IN
OCEAN     */


     SURVIVE= EXP(-ZC1 *0.5)*PIECESC;     /* RETURNING SPAWNERS*/
     DEATHS1= PIECESC-SURVIVE;               /* DEATHS 1ST HALF OF
YR */
     CATCH3=(1-EXP(-FR))*DEATHS1; /* RIVER CATCH*/
     SURVIVE= SURVIVE+MIGRATE;             /* COAST SURVIVORS 2ND
HALF */
     SURVIVEC = (SURVIVE+MIGRATE)-CATCH3;  /*RIVER SPAWNERS*/




     DEATHS2=  SURVIVE - SURVIVEC;                /* DEATHS 2ND
HALF OF YR    */
     CATCH4=   (BAYF2/ZC2) * DEATHS2;           /* CATCH 2ST HALF
OF YR     */

     DEATHSC=  DEATHS1 + DEATHS2;                 /* NBR THAT DIED
ON COAST    */
     COASTCAT= CATCH3;                            /* CATCH FROM
RIVER     */
     BAYCATCH= CATCH1 + CATCH2+CATCH4;             /* CATCH FROM
OCEAN     */

     WT=12*(1-EXP(-0.32*(AGE-0.26)))**3.0;
                                                  /* WEIGHT AT AGE
*/
     SSB=(SURVIVEB+SURVIVEC) * WT*(MAT{AGE});
     TSSB+SSB;
     XX=(A*(TSSB)-1);
     IF XX >= 0
      THEN SP=K*(XX)**(1/B);              /* SPAWNING BIOMASS
*/
      ELSE SP=0;
     IF SP>0
      THEN RECRUITS=SP/TSSB;              /* NUMBER OF RECRUITS IN
SR FUNCTION */
      ELSE RECRUITS=0;
     CATCH=BAYCATCH+COASTCAT;            /* COMBINED CATCH
*/
```

```
 PIECESB=1;  PIECESC=0;
 TSSB=0;     TSPAWNER=0;
 TBAYCAT=0;  TCOASTCA=0;  TCATCH=0;
 TBAYLD=0;   TCOASTYD=0;  TYIELD=0;
 END;   /* DO COAST R */

PIECESB=1;   PIECESC=0;
TSSB=0;      TSPAWNER=0;
TBAYCAT=0;   TCOASTCA=0;  TCATCH=0;
TBAYLD=0;    TCOASTYD=0;  TYIELD=0;
END;    /* DO BAY R */

KEEP BAYREC COASTR FO FR TYIELD TSSB SP RECRUITS  TOTALYD BAYWT
COASTWT;

RUN;


PROC SORT DATA=CALC;
  BY BAYREC COASTR FO FR;
RUN;


DATA DOIT;
 SET CALC;
 BY BAYREC COASTR FO FR;
 IF LAST.FR;
RUN;


PROC PRINT;
  VAR BAYREC  FR FO TYIELD
      TSSB SP RECRUITS  TOTALYD BAYWT COASTWT;
 TITLE  'AMERICAN SHAD FROM THE HUDSON RIVER BIOMASS AND
RECRUITMENT';
 TITLE2 'ALPHA ESTIMATED FROM S-R DATA WITH RECRUITMENT ESTIMATED
FROM UTILITIES,1974-1994 ';
RUN;

/*
//
```

Attachment A: Stock Contributions for American shad landings in mixed stock fisheries along the Atlantic coast

Shad Stock Assessment Subcommittee Coastal Subgroup:
K. Hattala, R. Allen, N. Lazar and R. O'Reilly

Mixed stock fisheries for American shad occur in many coastal Atlantic states. Mixed stock fisheries occur in ocean waters in nearly all states, except FL, GA and minimally in CT. An additional mixed stock fishery occurs within non-ocean state waters of Delaware and New Jersey in lower Delaware Bay. The fisheries occur primarily on pre-spawning fish, beginning in late winter for southern states (NC-SC), late February through April in mid-Atlantic states (VA-NY), and from summer to late fall in New England waters.

During the current assessment there was a need to understand and quantify the effects of mixed stock harvest for coastal shad stocks. Our group attempted to apportion mixed stock landings using the most current, available data on distribution: several tagging and MtDNA studies. Apportionment for mixed stock fisheries was done only for the years 1980 to 1996.

Stock Groupings

It must be understood that the data used to assign stock contribution are minimal and could be improved by continued tagging or other (DNA or otolith mineral) studies. Stock composition, in real time, is thought to vary considerably on a day to day, week to week basis as shad migrate along the coast. It is not known to what degree stocks mix or intermingle, but tagging and DNA data suggest that the variability we assumed is real. Changes in stock size may also have occurred for some, or all, stocks for the period 1980 to the present. We assumed that the percentage developed would be applied for the entire period, although stock size may have changed during the 1980 -1996 period. The uncertainty associated with this assumption is high. However, it was made because no other data are available to adjust for the variation in stock size over time.

Because of the sparsity of data, our group felt it best that given the data, combining areas along the coast would result in "average" estimates. "Average" refers to the fact that as fisheries operate stocks can be selectively harvested in a short period of time or at some variable level through time, depending on the duration of the fishery and time of year. Data do not allow for a more fine tuned approach.

Mixed stock fisheries were grouped into several regional areas: southern, (SC-NC) lower mid-Atlantic: (VA-MD) upper mid-Atlantic: (DE-NJ) and northern: (NY-NE) (New England) (Table 1). These regional areas were developed based on timing of fisheries along the coast and the stocks that are affected by each regional fishery.

Regions : SC-NC, DE-NJ and NY-NE

Stock contributions (%) listed in Table 1 were developed from tagging studies for the SC-NC, DE-NJ and NY-NE (New England) areas. The SC-NC area percents were derived from two tagging studies conducted in ocean waters off North Carolina (Parker 1992, Table A1) and South Carolina (McCord 1986-1988, Table A2). Results from a recent tagging study, conducted in 1995-1997 in lower Delaware Bay, were used for the DE-NJ area (Table A3). These tagging studies occurred throughout most of the fishing season for each of the areas.

The only data available for the NY-NE area are from early studies conducted in the New York Bight (Talbot and Sykes 1958, summarized in Dadswell et al. 1987, Table A4) .

Region: VA-MD

MtDNA studies were used to apportion harvest for the VA-MD region (Table 1). Discussions occurred within the Shad Stock Assessment Subcommittee (March 1997 and July 1997 meetings) over the use of DNA versus tagging data. The DNA data was used as the tagging study conducted in ocean waters off MD and VA (Jesien 1992, Table A5) were thought to be limited in ability to sample the harvest.

For the 1980-88 period, percentages in Table 6 represent an average of three sample areas over two years: the 1992 and 1993 harvests from Virginia fisheries off Rudee Inlet and Wachapreague and the 1993 Ocean City, Maryland harvest of coastal shad. For the 1989-96 period, percent composition is based on average stock composition determined for the 1992 and 1993 Wachapreague fishery and 1992 Ocean City fishery (three sample areas).

Landings and apportionment to affected stocks

The step-wise progression of apportionment of mixed stock/ocean fishery landings are as follows:

Table 1 — Percents calculated from tagging or MtDNA studies, as explained above.

Table 2 — Landings (in thousand of pounds) of American shad listed include those from mixed stock / ocean fisheries only. They do not include landings from natal or inland systems. Sources of the landings are primarily from National Marine Fisheries Service or state reports given to our group.

Table 3 — Landings in Table 2 were adjusted based on percent reporting, listed on the first line of Table 3.

Table 4 — Adjusted landings were then added together, from each state's fishery, into the four regional groups: i.e. SC and NC were added to form the SC-NC group.

Table 5 Please note that the headings in Table 5 are the same as headings in Table 1. Table 5 lists, by year, the total pounds harvested in the affected stock or group (by state) of stocks. Each number was calculated by multiplying each percent listed in the column under each affected stock (Table 1) by the landings harvested by each of the four groups, listed in Table 4. The total harvest for an affected stock is the sum of the harvest of the four regional groups. (A blank on Table 1 equals a value of zero, so that region would not be included in the sum).

Table 6 Pounds of fish, listed in Table 5, were converted to numbers of fish by dividing by the average weight of an individual stock(s).

References

Brown, B.L. and J.M. Epifano. 1995. Mixed stock analysis of American shad in Virginia's and Maryland's coastal intercept fisheries. Report to Virginia Marine Resources Commission, Newport News VA, USA.

Dadswell, M.J., G.D. Melvin, P.J. Williams and D.E. Themelis. 1987. Influences of origin, life history and chance on the Atlantic coast migration of American shad. IN Common strategies of anadromous and catadromous fishes. American Fisheries Society, Symposium #1.

Hattala, K., R. Jesien, V. Whalon and R. Allen (in progress, 1997). Cooperative American shad tagging program in the Hudson River and lower Delaware Bay. NY State Dept. of Environmental Conservation, Univ. of Maryland- Eastern Shore, Hudson River Foundation, and NJ Dept. of Environmental Protection.

Jesien, R., S. Gaichas, J. Serafy and C. Hocutt. 1992. Stock composition of coastal Maryland and Virginia American shad fishery: 1992 tagging study. Report to Maryland Dept. Of Natural Resources, Annapolis, MD, USA.

McCord, W. 1988, 1987,1986. Monitoring and assessment of South Carolina's commercial shad fishery and incidental catch of sturgeons. Completion reports to National Marine Fisheries Service.

Parker, J.A. 1992. Migratory patterns and exploitation of American shad in the near shore ocean of southeastern North Carolina. N.A. Jour. of Fish. Management 12 (4) 752-759.

Talbot G. B. and J.E. Sykes. 1958. Atlantic coast migrations of American shad Fishery Bulletin 142.

Stock contributions from American shad landed in mixed stock fisheries along the Atlantic coast.

Table 1. American shad stock contributions for the Atlantic coast.

Mixed stock Fisheries	Affected Stocks FL	GA	SC	NC	VA	MD	Del. R.	Hud. R.	CT. R.	NECN
SC-NC	1.0%	7.2%	54.3%	37.5%						
VAMD1	1.0%		23.6%	20.2%	15.4%	2.6%	11.5%	3.4%	6.4%	14.6%
VAMD2	1.0%		31.7%	25.7%	9.3%	4.3%	11.7%	6.7%	3.0%	6.0%
DE-NJ						2.1%	43.8%	33.3%	18.8%	2.1%
NY-NE					0.5%	0.5%	1.0%	6.0%	50.0%	42.0%

1=1980-88
2=1989-present

Table 2. American shad landings reported for OCEAN / MIXED stock fisheries (pounds*1000, Sources: NMFS and state reports)
NOTE: Inland water landings not included

Year	SC	NC	VA	MD	DE	NJ	NY	RI	MA	NH	ME
1980	155	4	96	0	90	120	114	2	8	7	28
1981	160	107	276	0	184	131	56	31	17	6	91
1982	245	64	277	0	327	280	74	79	29	3	26
1983	206	4	208	20	218	197	33	24	14	3	39
1984	393	14	644	19	206	209	34	37	30	5	33
1985	138	3	332	150	190	215	94	91	22	7	16
1986	225	63	356	126	205	157	73	52	60	17	23
1987	360	41	395	119	246	185	12	104	41	41	26
1988	258	50	429	265	291	234	16	122	51	46	32
1989	228	39	400	488	217	399	23	42	14	31	46
1990	161	37	325	284	475	449	5	23	6	38	12
1991	144	19	400	234	480	384	25	28	1	18	2
1992	109	24	432	139	275	286	21	13	0	10	1
1993	65	28	487	78	303	320	8	41	0	7	0
1994	72	34	204	34	226	217	6	18	0	22	1
1995	132	103	146	50	170	280	14	28	0	31	0
1996	222	58	232	95	262	210	25	0	0	0	0

Table 3. Landings (from Table 2., pounds * 1000) adjusted based on percent reporting**.

%>>	50%	50%	70%	60%	60%	50%	50%	50%	50%	50%	50%
Year	SC	NC	VA	MD	DE	NJ	NY	RI	MA	NH	ME
1980	310	8	137	0	179	239	227	4	17	14	56
1981	299	215	394	0	369	261	117	63	33	11	181
1982	490	128	396	0	654	560	147	158	59	5	52
1983	411	8	297	40	436	393	66	47	27	7	77
1984	786	27	920	38	411	418	67	73	59	10	67
1985	275	6	475	300	380	430	188	182	45	15	32
1986	451	126	508	252	409	314	146	105	120	34	46
1987	719	82	565	239	492	369	23	208	82	83	53
1988	517	100	613	529	582	467	31	244	101	92	64
1989	456	77	571	976	433	798	46	84	27	61	93
1990	323	74	465	567	950	899	11	46	11	76	24
1991	289	38	571	468	960	769	53	56	1	36	4
1992	218	48	617	398	551	571	42	27	1	20	3
1993	130	56	487	156	606	640	15	81	1	13	0
1994	144	68	204	67	452	434	12	36	0	43	2
1995	265	206	146	100	339	560	29	55	0	61	0
1996	444	116	232	190	523	420	51	0	0	0	0

No adjustment for Virginia, data from mandatory reporting 1993-96, R. O'Reilly
** The percent reporting used for all states needs resolving at TC level, KAH 8/19/97

Table 4. Adjusted landings (pounds * 1000) by AREA GROUPING

Year	SC-NC	VA-MD	DE-NJ	NY-NE
1980	318	137	419	318
1981	514	394	630	405
1982	618	396	1214	422
1983	419	337	829	224
1984	813	959	829	277
1985	281	775	811	460
1986	577	760	723	451
1987	802	803	861	448
1988	617	1142	1049	532
1989	534	1547	1232	311
1990	397	1032	1848	168
1991	327	1039	1729	151
1992	266	1015	1122	92
1993	186	643	1246	110
1994	212	271	886	93
1995	471	246	899	146
1996	560	422	943	51

Table 5. State stock(s) affected by mixed stock fisheries (pounds * 1000)

Year	FL	GA	SC	NC	VA	MD	Del. R.	Hud. R.	CT. R.	NECN
1980	5	23	205	147	24	14	202	163	246	162
1981	9	37	372	272	67	26	325	248	346	241
1982	10	45	429	312	67	38	581	443	464	260
1983	8	30	307	225	56	27	404	301	289	161
1984	18	59	658	498	159	44	476	325	356	274
1985	11	20	336	262	129	39	449	324	432	323
1986	13	42	493	370	127	37	409	294	410	315
1987	16	58	626	463	134	41	474	341	437	324
1988	18	44	606	462	190	54	596	420	536	412
1989	21	38	780	613	146	94	724	517	433	[illegible]
1990	14	29	543	424	97	84	932	684	462	171
1991	14	24	507	400	97	82	880	644	432	162
1992	13	19	466	371	96	68	611	437	287	123
1993	6	13	305	241	60	54	622	456	309	111
1994	5	15	201	152	26	31	420	316	221	74
1995	7	34	333	242	24	30	424	322	249	95
1996	10	40	438	323	39	38	463	341	215	[illegible]

Table 6. Conversion (of affected stocks) from pounds to numbers (* 1000) using average weight.

ave.wt>>	3.5	3.1	3.5	4	3.7	4	4.5	4.8	5	[illegible]
Year	FL	GA	SC	NC	VA	MD	Del. R.	Hud. R.	CT. R.	NECN
1980	1	7	59	37	7	3	45	34	49	32
1981	3	12	106	68	18	6	72	52	69	[illegible]
1982	3	14	123	78	18	9	129	92	93	52
1983	2	10	88	56	15	7	90	63	58	32
1984	5	19	191	125	43	11	106	68	71	[illegible]
1985	3	7	96	66	35	10	100	67	86	65
1986	4	13	141	92	34	9	91	61	82	63
1987	5	18	179	116	36	10	105	71	87	66
1988	5	14	173	116	51	14	132	88	107	82
1989	6	12	223	153	39	23	161	108	87	80
1990	4	9	155	106	26	21	207	143	92	34
1991	4	8	145	100	26	20	196	134	86	32
1992	4	6	133	93	26	17	136	91	57	[illegible]
1993	2	4	87	60	16	14	136	95	62	22
1994	1	5	57	38	7	6	93	66	44	[illegible]
1995	2	11	95	61	6	8	94	67	50	19
1996	3	13	125	81	11	10	103	71	43	13

Table A-1. American shad tagging studies along the Atlantic coast.

study	J. Parker 1992, Ocean tagging study - southeast NC					
release location	southeast NC		SE NC(Wrightsville)		TOTAL	
release period	Jan-Mar		Dec89-Apr			
year	1989		1990			
n-caught					320	
n-tagged					301	
% tagged					94%	
River & state(s)	returns	%tag ret.	returns	%tag ret.	returns	%tag ret.
NC - ocean	7	17.1%	6	37.5%	13	22.8%
NC - Albemarle						
NC- neuse						
NC- Cape Fear	23	56.1%	6	37.5%	29	50.9%
SC - Wac-PD	8	19.5%	3	18.8%	11	19.3%
SC - Santee						
SC - Edisto	2	4.9%			2	3.5%
GA - *Sav-Ogee*	1	2.4%	1	6.3%	2	3.5%
Total returns	41		16		57	0.18937
% of releases	13.6%		5.3%		18.9%	
mean TL	484.9		494.9			
gill net mesh	5.5					
Percent at age 4	15.6		4.4			
5	76.6		53.2			
6	7.8	one repea	42.4			

group	1989	1990	average	WMcC SC	combined
NC	73.2%	75.0%	74.1%	1.0%	37.5%
SC	24.4%	18.8%	21.6%	87.0%	54.3%
GA	2.4%	6.3%	4.3%	10.0%	7.2%
				2.0%	1.0%

SE NC: extreme southeast coast of NC below
the Albemarle, Pamlico river complexes near Cape Fear

NC	Albemarle: Chowan, Roanoke
NC	Pamlico: Tar, Neuse (on south end)
NC	Cape Fear, Black
SC	Waccamaw PeeDee
SC	Santee - Cooper
SC	Edisto
SC	Combahee

Parker J. A. 1992. Migratory patterns and exploitation of American shad in the nearshore ocean waters of southeastern North Carolina. N.A. Jour. of Fish. Management 12(4):752-759.

Table A-2. American shad tagging studies along the Atlantic coast.

study	W. McCord , SC ocean tagging									
release location	SC ocean		SC ocean		SC ocean					
release period										
year	1986		1987		1988		All years			
n-tagged	485	24.7%	125	31.2%	275	24.7%	885	25.6%	Groups	
River & state(s)	returns	%tag ret.	returns	%tag ret.	returns	%tag ret.	returns	%tag ret.		
NC-Cape Fear					1	1.5%	1	0.4%		
NC ocean	1	0.8%					1	0.4%	NC	0.9%
SC ocean	4	3.3%	5	12.8%	4	5.9%	13	5.7%		
WacPeeDee	82	68.3%	25	64.1%	37	54.4%	144	63.4%		
Georgetown			1	2.6%	1	1.5%	2	0.9%		
Santee	9	7.5%			9	13.2%	18	7.9%		
Cooper	1	0.8%			1	1.5%	2	0.9%		
Edisto	4	3.3%	1	2.6%	3	4.4%	8	3.5%		
Savannah	6	5.0%	1	2.6%	3	4.4%	10	4.4%	SC	86.8%
Ogeechee GA	2	1.7%					2	0.9%		
Altamaha GA	11	9.2%	6	15.4%	4	5.9%	21	9.3%	GA	10.1%
St. John's FL					4	5.9%	4	1.8%	FL	1.8%
unknown					1	1.5%	1	0.4%		
Total returns	120		39		68		227			99.6%

Table A-3. American shad tagging studies along the Atlantic coast.

study	Hudson/Delaware Bay Tagging, ongoing data summary: Hattala, Jesien, Allen									
release location	in Hudson River									
year	1995				1996		1997		All years	
n-caught										
n-tagged	2646				1578		1912		6139	
River & state(s)	returns	%tag ret.	95 returns	%tag ret.	returns	%tag ret.	returns	%tag ret.	returns	%tag ret.
Conn. R. (CT, MA)										
Hudson R. (NY, NJ)	50	100.0%	6	46.2%	21	91.3%	37	90.2%	114	0.90
Del. R. (PA, DE, NJ)										
Del. Bay (DE, NJ)			4	30.8%			1	2.4%	5	0.04
DE - ocean										
NJ - ocean			1	7.7%	2	8.7%	3	7.3%	6	0.05
VA - ocean			1	7.7%					1	0.01
NS Can. ocean			1	7.7%					1	0.01
Total returns	50		13		23		41		127	
% of releases	1.9%		0.5%		1.5%		2.5%		6.0%	
both years		63								
		2.4%								
gill net mesh	5,5,5,6									

study	Hudson/Delaware Bay Tagging, ongoing data summary: Hattala, Jesien, Allen											
release location	Lower Delaware Bay, inside of Cape May											
year	1995				1996		1997		All years			
n-caught												
n-tagged	105				294		508		907		adjusted NOT to include mixed stock areas	
River & state(s)	returns	%tag ret.	95 returns	%tag ret.	returns	%tag ret.	returns	%tag ret.	returns	%tag ret.		
NE/Can.											1	2.1%
Conn. R. (CT, MA)	1	14.3%					4	13.8%	5	10.2%	9	18.8%
Hudson R. (NY, NJ)	1	14.3%			5	41.7%	4	13.8%	10	20.4%	16	33.3%
Del. R. (PA, DE, NJ)	3	42.9%			4	33.3%	11	37.9%	18	36.7%	21	43.8%
Del. Bay (DE, NJ)	2	28.6%					2	6.9%	4	8.2%		
DE - ocean												
NJ - ocean			1	100.0%	3	25.0%	6	20.7%	10	20.4%		
MD Sus							1	3.4%	1	2.0%	1	2.1%
VA - ocean												
NC OUTERS							1	3.4%	1	2.0%		
Total returns	7		1		12		29		49		48	
% of releases	6.7%		1.0%		4.1%		5.7%		5.4%			

Hattala, K, R. Jesien, V. Whiston and R. Allen. (data currently being summarized) Cooperative American shad tagging program: Hudson River and lower Delaware Bay : 1995-1997

Table A-4. American shad tagging studies along the Atlantic coast.

study	Talbot and Sykes 1958				Miller 1982		Leggett (unpublished)	
release location	Hudson R. / NY Bight		Rudee Inlet / Ches. Bay		Delaware		Connecticut	
year								
n-tagged	11579		4775		2920		18374	
River & state(s)	returns	%return	returns	%return	returns	%return	returns	%return
St. Lawrence					2	1.5%		
Miramichi					4	3.0%		
Bay of Fundy	13	0.7%	3	2.6%	18	13.3%		
Gulf of Maine	9	0.5%	5	4.3%	3	2.2%		
Cape Cod	7	0.4%	4	3.5%				
Merrimack - MA					1	0.7%		
Conn. R. (CT, MA)	146	7.9%	21	18.3%	36	26.7%	311	83.4%
NY ocean	23	1.3%	5	4.3%	2	1.5%	19	5.1%
Hudson R. (NY, NJ)	1582	86.1%	31	27.0%	25	18.5%		
Del. R. (PA, DE, NJ,)					45	33.3%		
Del. Bay (DE, NJ)	20	1.1%	9	7.8%			2	0.5%
DE - ocean					1	0.7%		
NJ - ocean	13	0.7%	5	4.3%			4	1.1%
MD C Bay	10	0.5%						
VA C Bay rivers	7	0.4%					2	0.5%
VA - ocean					1	0.7%	10	2.7%
NC - ocean	5	0.3%	14	12.2%	3	2.2%	23	6.2%
NC - rivers	2	0.1%	16	13.9%			1	0.3%
SC-rivers			1	0.9%				
GA rivers			1	0.9%			1	0.3%
Total returns	1837	15.9%	115		135		373	
% of releases	15.9%		2.4%		4.6%		2.0%	

AGGREGATION AREAS

summer: Bay of Fundy, St. Lawrence estuary, off Newfoundland and Labrador

winter: off Florida, Middle Atlantic Bight, Scotian shelf.

Dadswell, M. J., G.D. Melvin, P.J. Williams and D.E Themelis. 1987. Influences of origin, life history, and chance on the Atlantic coast migration of American shad. IN Common strategies of andromous and catadromous fishes. American Fisheries Society. Symposium #1.

Table A-5. American shad tagging studies along the Atlantic coast.

Study	Roman Jesien, (report to state of MD) Ocean tagging study - MD & VA										
release location	VA Rudee Inlet		MD- Ocean City		VA - Rudee Inlet		TOTAL MD-VA		TOTAL MD-VA		
release period	Feb-Mar		Mar-Apr		Mar-Apr						
year	1991		1992		1992		1992		1991 & 92		
n-caught	3109		648		3127		3775		6974		
n-tagged	569		260		430		690		1259		
% tagged	18%		40%		14%		18%		18%		
River & state(s)	returns	%tag rel.	returns	%tag rel.	returns	%tag ret.	tot.92 rel.	%tag rel.	91-92 RET.	%tag rel.	
Merrimack - MA					1	5.0%	1	2.6%	1	2%	
Conn. R. (CT, MA)	1	5.3%	1	5.3%			1	2.6%	2	3%	
Hudson R. (NY, NJ)	2	10.5%							2	3%	
Del. R. (PA, DE, NJ.)	2	10.5%	9	47.4%	2	10.0%	11	28.2%	13	22%	
Del. Bay (DE, NJ)			2	10.5%			2	5.1%	2	3%	
DE - ocean			1	5.3%			1	2.6%	1	2%	
NJ - ocean					1	5.0%	1	2.6%	1	2%	38% NJ &NORTH
MD C Bay	1	5.3%							1	2%	
VA C Bay rivers	9	47.4%			2	10.0%	2	5.1%	11	19%	21% ches bay
VA - ocean	1	5.3%	4	21.1%	5	25.0%	9	23.1%	10	17%	
NC - ocean	3	15.8%	1	5.3%			1	2.6%	4	7%	
NC - Albemarle					3	15.0%	3	7.7%	3	5%	
NC- neuse					1	5.0%	1	2.6%	1	2%	
NC- Cape Fear					2	10.0%	2	5.1%	2	3%	
SC - Wac-PD			1	5.3%			1	2.6%	1	2%	
SC - Santee					1	5.0%	1	2.6%	1	2%	
GA - Sav-Ogee					2	10.0%	2	5.1%	2	3%	24% mixed south
Total returns	19		19		20		39		58		
% of releases	3.3%		7.3%		4.7%		5.7%		4.6%		
mean TL	513		541		517						
gill net mesh	5.5		5		5.5						
1991 rel/92 return											
VA	5										

Jesien, R., S. Gaichas. J. Serafy, and C. Hocutt. 1992. Stock composition of coastal Maryland and Virginia American shad fishery; 1992 tagging study. Report to Maryland Dept. of Natural Resources. Annapolis, MD, USA.

Table A6. Estimated stock composition (by state/area) of American shad harvest for the 1992 and 1993 coastal intercept fisheries off Maryland and Virginia, based on MtDNA studies.

State/area affected	Percent Composition	
	1980-88	1989-96
FL	1.0	1.0
SC	23.6	31.7
NC	20.2	26.7
VA	16.4	9.3
MD	2.6	4.3
Delaware R.	11.5	11.7
Hudson R.	3.4	5.7
Connecticut R.	6.4	3.0
Canadian	14.6	6.0

Data from Brown, B. And J. Epifano. 1995.

Table A-7. Summary of NMFS and/or state commercial landings (pounds) of American shad.

Mixed section is used to determine stock contribution for mixed stock fisheries.

INLAND NATAL RIVER SYSTEMS	ME	NH	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL			NJ+DE
YEAR					CT R.	HR+NJ+DE R.	DE R.	DE R.	a-1990	a-1994					TOTAL	Metric ton	DEL. R. TOTAL
1970					173100	250500	4900	0	0						428800	195	4900
1971					240700	187300	2600	0	0						430800	196	2600
1972					249700	316700	2100	0	0						570000	259	2100
1973					257600	255300	1600	0	0						526000	239	1600
1974					247200	244000	1200	300	0						492700	224	1500
1975					165300	253100	0	1900	0						420500	191	1900
1976					392000	218100	0	0	0						610100	277	0
1977					332400	237600	0	3400	0						543400	247	3400
1978					306300	454600	0	0	0						760900	346	0
1979					208800	413300	0	0	0			113563			833683	378	0
1980					310500	1313100		6270	0	877281	155253	115461	153489		3169560	1450	6270
1981					324700	620200		12898	0	223440	244285	236860	195323		2156984	981	12898
1982					280200	378900	1100	22858	0	306388	347873	153342	124465		1874400	852	23958
1983					428000	459400	4300	15205	0	465215	442091	125826	225400		2240940	1018	19505
1984					348800	701400	7400	14369	0	625398	571552	143416	214483		3196841	1453	21769
1985					402080	788084	23100	13282	0	500827	526480	231535	242012		2390868	1087	[illegible]
1986					322000	798788	17700	28822	0	217527	310768	256226	157655	13477	2172740	988	46522
1987					355800	864182	20200	10440	0	237844	286464	126890	269551	13494	2007591	913	30640
1988					189100	762800	17300	24413	0	84410	232862	111146	130204	74	1631670	754	41713
1989					181100	485700	16800	12249	0	108385	284846	116575	130557	11305	1597092	726	29049
1990					259425	465528	40084	15788	0	128867	278486	63732	66672	116920	1501543	683	56182
1991					149300	329366	33302	11713	0	50833	257390	101498	79447	4534	1170630	532	34005
1992					144300	299588	41705	9247	0	46007	213902	135940	82758	165	993631	454	51012
1993					95650	135210	19682	13309	0	66377	150068	49685	59555	0	616176	281	32500
1994					104200	157672	9068	14347	0	0	77080	50258	70177	133	483192	220	23413
1995					61576	190807	11811	14293	0	0	102852	153283	167701	0	702123	319	26104
1996						121100	1100	10038	0	0	140988	320529			593831	270	11134
1997												222661					

MIXED STOCKS / OCEAN FISHERY																	DEL. BAY & OCEAN
YEAR	ME	NH	MA	RI	CT	NY	NJ	DE	MD	VA	NC	SC	GA	FL	TOTAL	Metric ton	TOTAL
1970						5600	33500	13400							54700	26	[illegible]
1971						3000	21000	7600							31400	14	[illegible]
1972						9000	36000	8200							54200	25	48200
1973						3300	37400	7600							36800	18	[illegible]
1974						400	38900	8000							45300	22	47843
1975						300	65200	18800							82300	37	42000
1976						2500	64700	35800							102800	47	100302
1977						1200	110800	71100							185100	83	181800
1978	24511		600			2000	84000	69800							191211	87	[illegible]
1979			1200			6100	85000	94800				83800			253300	115	[illegible]
1980	37926	6900	8400	2000		113600	116700	49730		95814	3843	155072			521503	237	208420
1981	40800	5800	16700	31400		58300	120700	184814		275870	107415	149882			1080080	477	[illegible]
1982	25383	2700	23400	79300		73300	279800	527141		271888	43979	245904			1403884	636	[illegible]
1983	38700	3400	13500	22500		33000	188700	217585	10043	207787	3785	206822			963455	438	414265
1984	53414	5100	29700	38800	155	33900	208000	205851	19065	644036	13511	382846			1590049	729	414491
1985	16000	7300	22500	80000	9	93500	216200	190000	150030	332157	3159	137525			1258587	571	408263
1986	23012	16900	80100	52400	950	72200	167000	204800	128224	355594	63085	225408		47641	1404410	638	389723
1987	26400	41300	40900	100900	0	11600	184500	245993	119304	383227	41182	362817		139194	1709001	777	494459
1988	31884	45936	80532	122000	400	15500	233500	291814	254642	428806	50088	255307		283096	2050732	930	824814
1989	46446	30804	13800	41871	1175	22300	398800	210817	467812	388781	35540	229237		188900	2000445	907	918217
1990	11804	38206	5000	22700	3070	5350	448888	474802	283849	325176	37084	181374		166107	1906385	865	824728
1991	1991	19826	630	27615	680	26280	384363	460880	233988	388804	19217	144251		68880	1797723	817	844488
1992	1450	9903	300	13292	386	21130	283809	279420	186839	422196	23468	408184		48897	1420883	640	891830
1993		8549	400	40562	241	7737	330098	303108	77885	480775	28122	64836		24075	1381288	619	823163
1994	1051	21742		17936	1870	6008	216940	225904	53644	203849	33486	71869		27637	862082	382	443787
1995		30881		37940	80	14444	278818	188548	49801	148919	102984	132331		23800	977314	444	448484
1996						25280	710043	281805	94077	231713	58867	222044			1884358	482	471848
1997												113516					

TOTAL LANDINGS																
YEAR	ME	NH	MA	RI	CT	NY	NJ	DE 3	MD	VA	NC	SC	GA	FL	TOTAL	Metric ton
1970					173100	260600	38400	13400							465500	221
1971					240700	190300	23900	7000							462200	210
1972					249200	327700	38100	9200							624200	284
1973					257600	270100	29500	7600							564800	257
1974					247200	244400	41100	8500							541000	248
1975					165500	253400	65200	18700							502800	229
1976					332000	220600	64700	35600							712900	324
1977					332400	208800	110500	74500							726500	330
1978	24911		800		306300	458800	84000	69900							952111	433
1979			1200		306800	521400	85800	94900				157071			1085971	494
1980	17954	8500	8400	2000	310500	1428600	119700	96000		973875	199206	270553	168489	160800	3810684	1732
1981	60600	5600	18700	31400	324700	678500	130700	197200		488119	351500	446412	195423	241000	3209954	1459
1982	25983	2700	29400	79500	263000	452500	260833	350000		586284	411862	398428	138465	181000	3278782	1490
1983	38700	3400	13500	23500	429300	492400	201000	232600	20043	672022	445479	331345	225409	76500	3203301	1456
1984	33414	5100	29700	36600	398455	735000	216455	220008	19088	1208738	534443	538362	214463	487500	4787181	2176
1985	16000	7300	22300	90900	402000	649654	235320	203348	150030	632984	379639	359078	242012	95780	3648375	1658
1986	23012	16900	60100	52400	322350	871068	174700	324668	128223	573115	373784	481655	157665	61336	3620203	1646
1987	28400	41300	40600	103500	333900	995782	284200	345278	119304	632671	327646	468507	289551	153898	3800633	1728
1988	31681	43436	50032	122000	169500	730432	250500	427634	284842	483254	285050	369542	130304	263972	3711665	1687
1989	48498	30604	13620	41971	182275	508500	416000	278373	407812	600126	323398	348812	130567	177406	3407347	1549
1990	11894	38206	5600	22768	262495	468818	488665	815558	283848	454163	313590	225100	85522	235027	3563127	1620
1991	1881	18924	635	27815	150280	355654	407445	848434	233880	450487	276307	245741	79447	64098	2961424	1346
1992	1450	9903	306	13292	144655	288728	327374	356530	198830	478184	237658	245046	82756	48182	2441879	1110
1993	0	6549	400	40652	96902	145947	339844	412068	77868	553146	178730	114021	58555	24873	2050655	932
1994	1051	21742	0	17634	105470	163672	225995	269679	33844	303649	110975	122139	70777	27760	1374851	625
1995	0	30561	0	27960	61636	208061	281729	204043	49931	146019	295636	385604	167701	23500	1699671	773
1996	0	0	0	0	0	148300	211145	271641	84977	231713	199133	542673	0		1675189	761
1997												349277				

1. NY=Hudson River NY plus NJ Hudson landings, NJ= total for state- Hudson land.
2. FL's Ocean fishery on FL stocks
3. DE total includes Nanticoke River landings

>>> Mixed section is used to determine stock contribution for mixed stock fisheries.

LAST UPDATE: KAH 8/18/97

a- year began moratorium

SUSQUEHANNA RIVER RESTORATION			
YEAR	FISHLIFT COLLECTIO	POP. ESTIMATE no. UPPER BAY	TAILRACE
1980		5531	
1981		9357	
1982		37551	
1983		12059	
1984	167	8074	3516
1985	1546	14283	7876
1986	5195	22902	18134
1987	7667	27354	21623
1988	5146	42683	28714
1989	8218	75820	43650
1990	15719	123830	59420
1991	27227	139862	84122
1992	25721	105255	66416
1993	13400	47563	32529
1994	32330	129482	94770
1995	99000	333691	218972
1996	37813	203216	112217

Attachment B: Review of American Shad Petersen Population Estimates for the Upper Chesapeake Bay, 1980-1997

Maryland Department of Natural Resources Fisheries Service

INTRODUCTION

The American shad, Alosa sapidissima, is the largest anadromous clupeid migrating into Chesapeake Bay to spawn each spring. Historically, American shad was a valuable commercial and recreational commodity throughout the region. From 1942 to 1992 commercial landings of American shad from Maryland waters averaged approximately 1.3 million pounds. During the three-year period 1958 to 1960, sport anglers harvested nearly 44,000 American shad from the 10-mile section of the lower Susquehanna River below Conowingo Dam (Plosila 1961).

Beginning in the early 1970's both commercial and recreational catches of American shad began to sharply decline throughout Maryland. By 1979, commercial landings had declined to 34,000 pounds while recreational interest had nearly disappeared. Consequently, in 1980 the state declared a moratorium on American shad fisheries in Maryland's portion of Chesapeake Bay. This closure remains in effect today. In addition to the moratorium, the Department of Natural Resources initiated an upper Chesapeake Bay American shad study. This study was designed to monitor the recover of Upper Bay American shad and assess stock status. The principle monitoring vehicle utilized was an adult population estimate based upon a mark-recapture exercise. This paper describes this exercise and discusses its use as a tool for population estimation.

METHODS AND MATERIALS

Since 1980, adult American shad have been collected for marking and/or subsequent recapture with four gear types at various locations in the Upper Chesapeake Bay. Their use is described as follows:

1. Pound nets are non-moveable nets set at specific locations called stands. Pound nets have been sampled in the upper Chesapeake Bay for American shad continuously since 1980 except for the years 1983, 1984, 1986, and 1987 (Table 1, Figure 1). When fished, pound net cribs were pursed, forcing fish to the outer edge where they were removed by a hydraulic net and placed on a culling board for sorting and tagging. Sampling from pound nets generally occurred from late March through mid-May with effort ceasing as water temperatures increased above 15^{0}C and spent individuals or down-runners began to appear in the catches.

2. Anchor gillnets were employed to capture adult American shad in the Susquehanna River from 1980 to 1987 (Table 1). These nets were set approximately n mile west of Port Deposit, Maryland near the southern end of Spencer Island (Figure 1). Anchor gillnets were deployed after dark and fished continuously during periods of reduced turbine generation from Conowingo Dam and subsequent low river flows. Captured fish were placed in a round fiberglass tank, 48" in diameter and 30" deep equipped with a 1,500 gallon per hour bilge pump to create a circular current. Once the net was fished, the fish were transported away from the net to deeper water for tagging and release. Anchor gillnet fishing generally occurred from late April into mid-May depending on flow conditions. Since anchor gillnet could only be set and safely fished during low river flows, yearly effort was quite variable during this eight-year period. No more than two nets were fished per night.

3. The use of hook and line to capture American shad for tagging has been in continuous use since 1982 (Table 1). This effort occurs in the Conowingo tailrace approximately 250 yards below the dam face (Figure 1). Since American shad prefer certain current velocities and water depths, fishing locations have varied depending on turbine generation schedules and subsequent water discharge. Generally, the greatest amount of angling effort has been below units 8, 9, 10, and 11, the four largest turbines. Standard procedure was to anchor and simultaneously fish two rods each rigged with two shad darts, one 1/8 oz. and one 1/4 oz. Dart color was restricted to red heads with white or yellow bodies and white or yellow tails. The darts were not retrieved but rather allowed to remain in the current, a technique referred to as “dead sticking.” Length of line fished varied according to fish holding patterns while up to n oz. of extra weight was added to achieve proper depth. Hook and line effort generally began in mid-April and continued into late May or early June, depending on river flow conditions and the number of pre-spawned fish caught. Spillage of water through any of Conowingo Dam’s flood gates during high water events precluded any hook and line activity for safety reasons.

4. The two fish lifts located at the base of Conowingo Dam accounted for the vast majority of tag returns from the Upper Bay stock, although no fish were marked from these collection devices. The west lift began operation in 1972 while the east lift became operational in 1991. Prior to 1996, operating protocols for both lifts remained relatively constant. Each lift would begin operation around April 1 and continue until mid-June when the shad run concluded. The initial schedule called for operation on alternate days until five or more American shad were collected during and operating day. Thereafter, the lifts would be operated daily unless the number of shad collected declined below minimum requirements or high river flows precluded safe operations. In addition, efforts were made to maximize attraction flows though each lift by modifying specific turbine operation patterns thereby altering discharge flows into the tailrace. American shad collected at each

fish lift were counted, sorted, and set aside for later upstream transport. Trap operators would record the numbers of tagged fish as they appeared in the lifts.

Beginning in 1996, operations at the west lift were modified in order to reduce costs and allow for necessary repairs. The modified schedule called for west lift operations to begin during the last week of April and continue daily through the first week of June. Lifting schedule for this predetermined 45-day period began at 11:00 A.M. instead of 7:00 A.M. and would continue until 7 P.M.. However, lift personnel had the option to either expand their effort in order to take advantage of fish abundance or reduce effort during non-productive periods. This schedule was continued for the west lift during 1997.

In 1997, completion of upstream passage at Holtwood and Safe Harbor dams enabled Conowingo's east lift to change to a fully automated operational schedule. Lifting of fish began on April 1 and continued daily through June 15 (flow conditions permitting). Initial operations were on a half-day schedule from 11:00 A.M. to 7:00 P.M. which subsequently increased to 7:00 A.M. to 7:00 P.M. once catches reached approximately 100 shad per day. The need to sort, count, hold, and transport American shad was eliminated at the east lift in 1997 as the fish collected could now be placed in a trough for direct passage above the dam. Identification, enumeration, and tag notation were accomplished through a viewing window manned by trap personnel.

American shad collected by pound net, anchor gillnet, and hook and line were recorded, but only fish judged to be in good physical condition were marked. Individuals close to spawning, partially spent, or post-spawned were excluded from tagging. Numbered T-bar anchor tags were inserted into American shad using Floy tagging guns. Tags were inserted into the dorsal musculature posterior to the dorsal fin at an angle conducive to streamlining.

STATISTICAL ANALYSIS

Chapman's modification of the Petersen statistic was used to calculate two estimates of returning American shad; Conowingo tailrace population and total Upper Bay population. Chapman's equation is expressed as:

$$N = \frac{(C + 1)(M + 1)}{R + 1}$$

where N equals population estimate, C equals number of fish examined, M equals number of fish marked, and R equals number of marked fish recaptured (Ricker 1975). The total Upper Bay population estimate utilized American shad captured by all four gear types while the Conowingo tailrace utilized individuals captured, marked, and recaptured only form the tailrace. A problem associated with recapture of pre-spawned, tagged American shad marked only form pound nets has occurred during the course of this study. Emigration of fish out of Chesapeake Bay through the C & D Canal has been confirmed by tag returns, primarily from the Delaware River. In order to correct for this loss of marked fish in the Upper Bay estimate, an emigration factor was estimated using the following formula:

$$EF = (A + B) \times C$$

where EF = emigration factor;
A = number of pre-spawned fish tagged from pound nets and recaptured outside the Upper Bay;
B = total number of pound net marked fish later recaptured, regardless of gear type;
C = total number of fish marked from pound nets.

A list of the yearly emigration factors and the data used in their calculation is presented in Table 2. In addition, a 3% correction factor for tag loss developed by Leggett (1976) specifically for American shad, was also utilized in both estimates.

RESULTS AND DISCUSSION

Data for calculating annual Petersen estimates are presented in Tables 3 and 4. Tailrace and Upper Bay population estimates and confidence intervals are presented in Figures 2 and 3, respectively. Confidence intervals were calculated based on sampling error using the number of recaptures in conjunction with a Poisson distribution approximation (Ricker 1975).

Ricker (1975) states that application of the Petersen statistic is justified only if six assumptions are met. Discussion of these six assumptions and their relationship to the tailrace and Upper Chesapeake Bay Petersen estimates is presented below.

1. The marked fish suffer the same natural mortality as the unmarked fish.

   American shad collected by each gear were recorded but only those fish judged to be in good physical condition were tagged. Individuals that appeared stressed or had physical injury including excessive scale loss were not marked. Individuals close to spawning, partially spent, or post-spawned were also excluded from tagging.

   Lukacovic (1998) investigated the short term mortality associated with catch and release angling of American shad in the Conowingo tailrace. Of the 309 individuals observed, less than 1% died during the experiment. A similar study conducted on angled hickory shad produced no catch and release mortalities (Lukacovic and Pieper 1996).

American shad studies on Connecticut River (Leggett 1976) determined that T-bar anchor tags had little effect on mortality based on recovery of double tagged fish although some mortality may have occurred as a result of handling and tagging. Leggett (1976) noted, however, that the magnitude of this mortality was no more than 2.2% and the bias in this population estimates associated from this factor was small. He concluded that inter-year analysis based on population estimates can be considered to be unaffected by handling mortality if methodology was similar between years.

2. The marked fish do not lose their marks.

   A tag loss of 3% per year has been assumed for American shad tagged by DNR personnel. This was based on research done by Leggett (1976) who determined a 3% rate based on double tag and recovery experiments of American shad in the Connecticut River during 1972 and 1973.

   The T-bar anchor tag utilized on Upper Chesapeake Bay American shad was inserted into the fish so that the T penetrated the dorsal musculature, posterior to the dorsal fin. The tag was also inserted at an angle conducive to streamlining. Before release, the tag was gently pulled to verify it was securely being anchored.

3. The marked fish are as vulnerable to the fishing being carried on as are the unmarked ones.

   Selective vulnerability of tagged American shad may result from differences in behavior after tagging or because of the tag itself. The use of T-bar anchor tags for American shad should greatly reduce or even eliminate tag vulnerability because of their design. Unlike the Petersen disc tag, the T-bar anchor tag was not subject to entangling in nets. Since gillnets were not used in this study to collect fish for recapture, and this gear, in fact, is illegal to use during the spring in the Upper Bay, this vulnerability was further reduced.

   Leggett (1976) found that Connecticut River American shad marked with T-bar anchor tags may delay their upriver migration approximately ten days. However, he attributed some of this delay (approximately five days) to their migration through the saltwater-freshwater interface. Since salinities in the Upper Bay during the spring were less that 1 ppt., migratory delays related to this condition should be nonexistent.

4. The marked fish become randomly mixed with the unmarked fish, or the distribution of fishing effort (in subsequent sampling) is proportional to the number of fish present in different parts of the system.

Efforts to capture American shad for tagging in the Upper Chesapeake Bay began as the fish first appeared at the Aberdeen Proving Ground/Susquehanna Flats area (pound nets, mid to late March) and their subsequent arrival in Conowingo tailrace (hook and line, mid to late April). Operation schedules for the Conowingo fish lifts have varied over the years but generally one trap began fishing during the first week of April. For the three gear types, fishing continued on a regular basis (2-4 days/week for pound nets, every other day hook and line, and daily operation of the fish lifts) until pre-spawned American shad were no longer caught (mid-May pound net, late May/early June hook and line, mid-June fish lifts) due to high water temperatures.

A trend was noted between daily, cumulative catch at Conowingo fish lifts and the cumulative number of tagged fish recaptured during the last three years (Figure 4). Pearson's Product Moment correlation ($P<0.10$) of daily catch and number of recaptures (both natural log + 1 transformed) were highly correlated for these years (1997; $r^2 = 0.44$ $P<0.001$, 1996; $r^2 = 0.71$ $P<0.001$, 1995; $r^2 = 0.66$ $P<0.001$). This demonstrates that tagged American shad were randomly selected by the fish lifts in proportion to the ratio of tagged/untagged fish.

Ricker (1975) states that bias associated with non-random sampling is highly unlikely when different gears are used to capture fish for marking and subsequent recapture. No fish were marked from Conowingo Dam fish lifts, while 96% of recaptures during the eighteen years of this study have been by the two fish lifts.

5. Recruitment to the catchable population is negligible during the time of recoveries.

Since this study's inception in 1980, the capture and marking of adult American shad in the Upper Chesapeake Bay has generally begun in mid/late March and continued until late May or early June. Operation of one or both fish lifts at Conowingo Dam has normally commenced during the first week of April and continued until approximately June 15, weather permitting. This capture-mark-recapture exercise, therefore, has occurred over a relatively short period of time, usually from 70 to 90 days.

Tagging studies conducted in the Connecticut River (Leggett 1976) from 1965 to 1973 were quite similar to those in the Upper Chesapeake Bay in terms of duration and adult marking. Leggett 1976 concluded that since this capture-mark-recapture exercise took place over a relatively short period of time (during the annual spawning migration April to late-May, early June) and only fully recruited adult fish were present in this spawning run, recruitment was not a factor in his Connecticut River population estimates. Ricker (1975) notes that if the effects of recruitment have been excluded, recoveries made over a period of time longer than a day or other short interval provide "no obstacle" to the accuracy of the population estimate.

6. All marked fish in the sample are recognized and reported.

Prior to 1997, American shad captured form both fish lifts at Conowingo Dam were individually handled so that all fish, both marked and unmarked, could be totaled. In 1997, the east fish lift became fully automated; consequently, total count and number of tagged shad were recorded by two trained observers at the east lift viewing chamber. These changes in east lift operating procedure increased the chances of missing both tagged and untagged American shad, which would, therefore, reduce the accuracy of the catch and recapture components of the Petersen statistic. Operating procedures at the west fish lift remained unchanged from 1996 and American shad captured in this trap were individually handled for later transport above York Haven Dam.

In order to compensate for this loss of accuracy from the east lift, attempts were made to analyze the 1997 Petersen estimate through various statistical procedures. This was done to determine the extent missed marked and unmarked fish had on the accuracy of the 1997 Petersen estimate and to what degree, if any, corrections could be made.

Relative abundance of American shad can be estimated and associated trends noted by examining the annual CPUE data of the various collecting gears. Measures of relative abundance from pound nets, hook and line, and the Conowingo fish lifts have been calculated as the geometric means (based on loge transformations) of fish caught per pound net day, fish caught per angling hour, and fish caught per lift hour, respectively. These data were loge transformed and geometric means used in order to normalize the data.

Analysis of these CPUE estimates indicates that the catch of adult American shad has been linearly increasing in all three gear types over time: (pound net: $r^2 = 0.46$, $P<0.01$; hook and line: $r^2 = 0.60$, $P<0.001$; fish lifts: $r^2 = 0.61$, $P<0.001$; Figure 5).

Comparisons of these CPUE estimates to the tailrace and Upper Bay Petersen estimates form 1980 to 1996 (Table 5) indicate:

- hook and line and fish lift CPUE's were correlated with loge transformed tailrace estimates (Figure 6).

- pound net, hook and line, and fish lift CPUE's were correlated with loge transformed Upper Bay estimates (Figure 7);

Annual CPUEs and trap catch (Table 6) were regressed against the corresponding natural log transformed population estimate for the years 1991-1996. The population estimates were then estimated for those regressions whose slopes were significant ($P<0.20$) by inserting the 1997 CPUE into the equation and solving (Table 7).

Ricker (1975) noted that population estimates based on the Schaefer statistic will often provide more accurate estimates than a Petersen estimate. In the Schaefer method, both time of marking and time of recovery are divided into separate periods. A separate population estimate is then calculated for each period based on the portion of the population available for marking in time period i and available for recovery in time period j. The total population

is then the sum of these independent estimates. Ricker (1975) points out that by providing independent population estimates in successive time periods, the bias associated with nonrandom marking and sampling for recoveries was reduced. Specifically, since American shad enter the Upper Chesapeake Bay in several distinct waves or pushes, by stratifying these periods of tagging and recovery into separate independent estimates, the limiting effects of migratory behavior on the accuracy of the Schaefer estimate are reduced. Schaefer population estimates were calculated for both the Conowingo Dam tailrace and Upper Chesapeake Bay (Figure 8 and 9) and were correlated with the Petersen estimates ($r^2 = 0.58$, $P = 0.04$, respectively).

LITERATURE CITED

Leggett, W. C. 1976. The American shad, Alosa sapidissima, with special reference to its migrations and population dynamics in the Connecticut River. In D. Merriman and L. M. Thorpe (eds.). The Connecticut River ecological study: The impact of a nuclear power plant. Am. Fish. Soc. Monogr. I. 252p.

Lukacovic, R. 1998. (In preparation). Recreational catch and release mortality of American shad (Alosa sapidissima) below Conowingo Dam.

Lukacovic, R. L. Pieper. 1996. Evaluation of the mortality rate of hickory shad (Alosa mediocris) caught and released by fly fishermen in Deer Creek, Maryland. Maryland Dept. Nat. Res., Technical Publication 19.

Plosila, D. S. 1961. Lower Susuehann Rivers port fishery survey, 1985- 1960. In the Susquehanna Fishery Study, 1957-1960. A report of a study on the desirability and feasibility of passing fish at Conowingo Dam. The Susquehanna Electic Company, Conowingo, Maryland.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Table 1. Gear types used to sample Upper Chesapeake Bay American shad, 1980-1987.

Year	Gear Types									
	Pound Net Number[1]								Anchor Gill	Hook & Line
	1	2	3	4	5	6	7	8		
1980				X	X	X	X		X	
1981				X		X			X	
1982				X		X			X	X
1983									X	X
1984									X	X
1985				X					X	X
1986									X	X
1987									X	X
1988	X	X		X						X
1989		X	X	X						X
1990		X		X						X
1991		X		X				X		X
1992		X						X		X
1993		X			X					X
1994		X			X					X
1995		X	X	X						X
1996		X		X		X				X
1997		X		X						X

1. For pound net names, please refer to Figure 1.

Table 2. Data utilized in calculating the emigration factor for the Upper Chesapeake Bay American shad estimate, 1980-1997.

Year	Number of pre-spawned fish tagged from pound nets and recapture outside the upper Bay (A)	Total number of pound net-marked fish later recaptured, regardless gear type (B)	Total number of fish marked from pound nets. (C)	Emmigration factor (EF)
1980	02	09	89	20
1981	01	05	65	13
1982	01	07	76	11
1983[2]	??	??	??	??
1984	??	??	??	??
1985	??	??	30	??
1986	??	??	??	??
1987	??	??	??	??
1988	03	07	136	58
1989	01	16	298	19
1990	02	19	286	30
1991	08	78	641	66
1992	01	09	114	13
1993	??	19	159	??
1994	01	09	197	22
1995	04	56	552	39
1996	??	26	956	??
1997	01	17	464	27

2. Pound nets were not fished from 1983-84 and 1986-87.

Table 3. The number of American shad caught, marked and recaptured from the Conowingo Dam tailrace and the resultant population estimate, 1982-1997.

Year	Number of Fish Caught (C)	Number of Fish Marked (M)[3]	Number of Fish Recaptured (R)	Tailrace Population Estimate
1982	1,846	79	4	29,552
1984	289	96	7	3,516
1985	1,709	151	32	7,876
1986	5,432	256	76	18,134
1987	6,887	319	100	21,823
1988	4,526	221	34	28,714
1989	8,076	253	46	43,650
1990	11,179	286	53	59,420
1991	26,927	377	120	84,122
1992	25,697	342	101	86,416
1993	13,090	245	98	32,529
1994	31,736	429	143	94,770
1995	55,943	556	147	210,546
1996	36,561	398	129	112,217
1997	99,156	554	129	423,324

3. M was adjusted for 3% tag loss.

Table 4. The number of American shad caught, marked and recaptured from the Upper Chesapeake Bay and the resultant population estimate, 1980-1997.

Year	Number of Fish Caught (C)	Number of Fish Marked (M)[4]	Number of Fish Recaptured (R)	Upper Bay Population Estimate
1980	379	130	8	5,531
1981	604	231	14	9,357
1982	2,413	335	17	45,061
1983	576	208	9	12,059
1984	414	213	10	8,074
1985	1,836	310	39	14,283
1986	5,532	326	78	22,902
1987	8,019	381	111	27,354
1988	5,585	297	38	42,683
1989	8,953	524	61	75,820
1990	16,664	534	71	123,830
1991	27,991	674	156	121,119
1992	26,253	440	109	105,255
1993	13,995	400	117	47,563
1994	33,072	598	152	129,482
1995	63,356	1,053	199	333,891
1996	38,838	810	154	203,216
1997	105,678	978	145	708,628

4. M was adjusted for emigration and 3% tag loss.

Table 5. Pearson Product Moment Correlation (rp) for the annual Upper Chesapeake Bay population estimate, annual geometric mean CPUEs for 3 gear types (1980-1996), annual Conowingo tailrace estimate and annual geometric mean CPUEs for 2 gear types (1984-1996) that capture American shad in the Upper Chesapeake Bay (N = number of

		Upper Ches. Bay population estimate	Conowingo Dam tailrace estimate
Pound Net	rp	0.86	
	N	13	
	P	0.0002	
Hook&Line	rp	0.58	0.56
	N	13	13
	P	0.0378	0.0456
Fish Lifts	rp	0.81	0.77
	N	16	13
	P	0.0002	0.0022

Table 6. Pound net CPUE, hook & line CPUE, Conowingo Dam trap CPUE, total catch at Conowingo Dam,1991-1997.

Year	Pound Net GM CPUE	Hook & Line GM CPUE	Conowingo Trap GM CPUE	Total Catch Conowingo Dam
1991	5.31	5.29	2.57	26,927
1992	0.97	5.05	2.49	25,721
1993	1.86	4.49	2.19	13,736
1994	2.7	5.13	2.87	31,736
1995	6.53	7.1	2.96	55,943
1996	4.29	9.39	3.26	37,513
1997	10.6	11.86	11.28	103,945

years).

Table 7. Regression equations and predicted population estimate for the four variables used to back-calculate the population.

Conowingo Dam Tailrace

Variable	Regression Equation	1997 Value	Calculated Tailrace Population Estimate (confidence intervals)
Pound Net GM CPUE	Ln Pop. Est. = 10.6 + (0.233 x Pound Net GM CPUE)	10.60	474,397 (491,906-576,357)
Hook & Line GM CPUE	Ln Pop. Est. = 9.88 + (0.255 x Hook & Line GM CPUE)	11.86	402,037 (394,099-410,136)
Conowingo GM CPUE	Ln Pop. Est. = 10.6 + (0.292 x Lift GM CPUE)	11.28	1,081,392 (1,033,375-1,131,641)
Total Trap Catch	Ln Pop. Est. = -1.21 + (1.23 x Ln Total Catch)	11.42	375,720 (225,240-626,736)

Upper Bay

Variable	Regression Equation	1997 Value	Calculated Upper Bay Population Estimate (confidence intervals)
Pound Net GM CPUE	Ln Pop. Est. = 10.9 + (0.242 x Pound Net GM CPUE)	10.60	704,469 (674,759-735,488)
Hook & Line GM CPUE	Ln Pop. Est. = 10.3 + (0.246 x Hook & Line GM CPUE)	11.86	549,938 (539,465-560,613)
Conowingo GM CPUE	Ln Pop. Est. = 7.94 + (1.42 x Lift GM CPUE)	11.28	25,389,461,000 (20,357,707,000-31,664,899,000)
Total Trap Catch	Ln Pop. Est. = 1.37 + (1.06 x Ln Total Catch)	11.42	711,549 (455,887-1,110,588)

Figure 1. Pound net, anchor gillnet and Conowingo Dam tailrace sites in the Upper Chesapeake Bay.

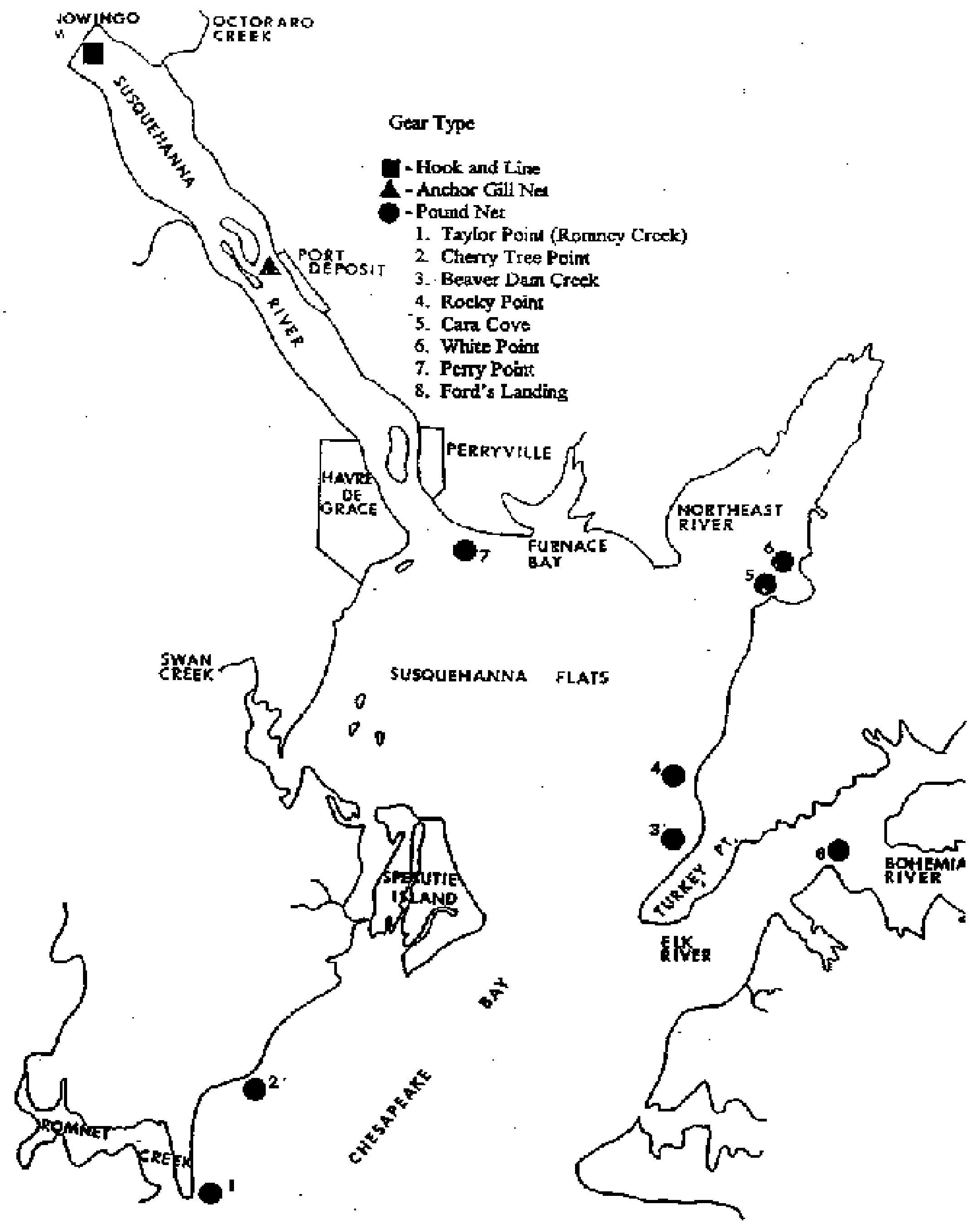


Figure 2. Conowingo Dam tailrace Petersen population estimates of American shad, 1984-1997. Bars indicate 95% confidence ranges and numbers above indicate the yearly population estimates.

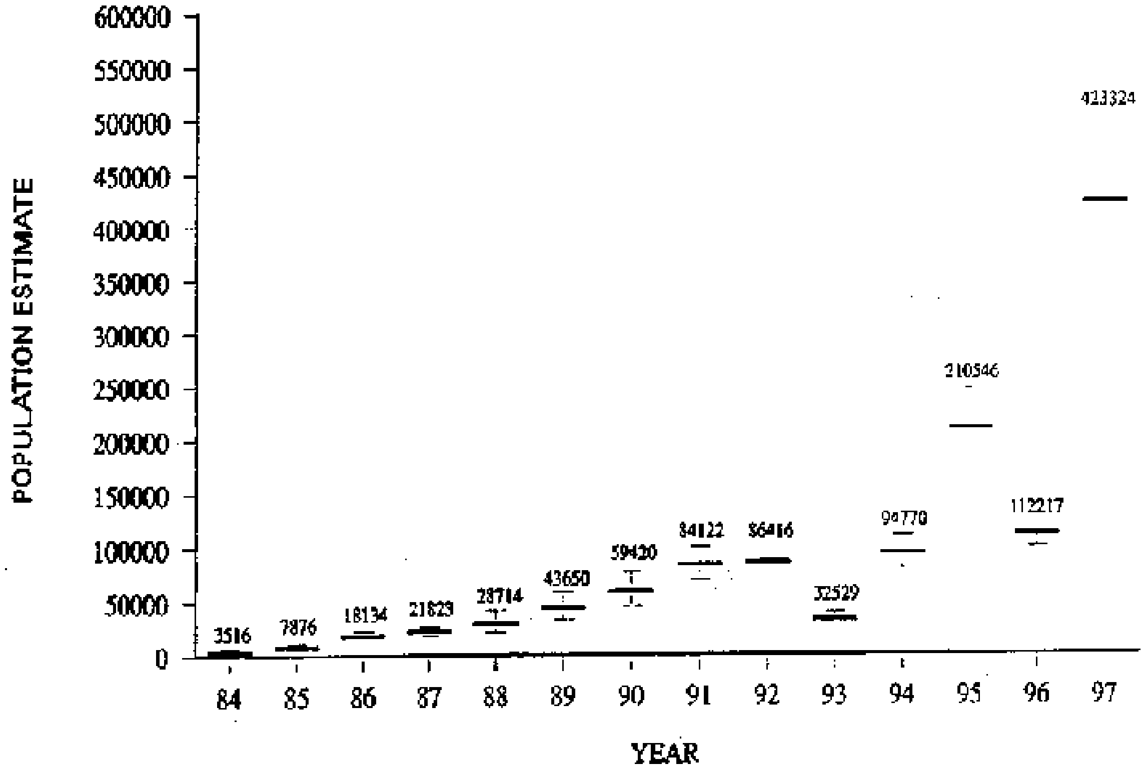


Figure 3. Upper Chesapeake Bay population estimates of American shad, 1980-1997. Bars indicate 95% confidence ranges and numbers above indicate the yearly population estimate.

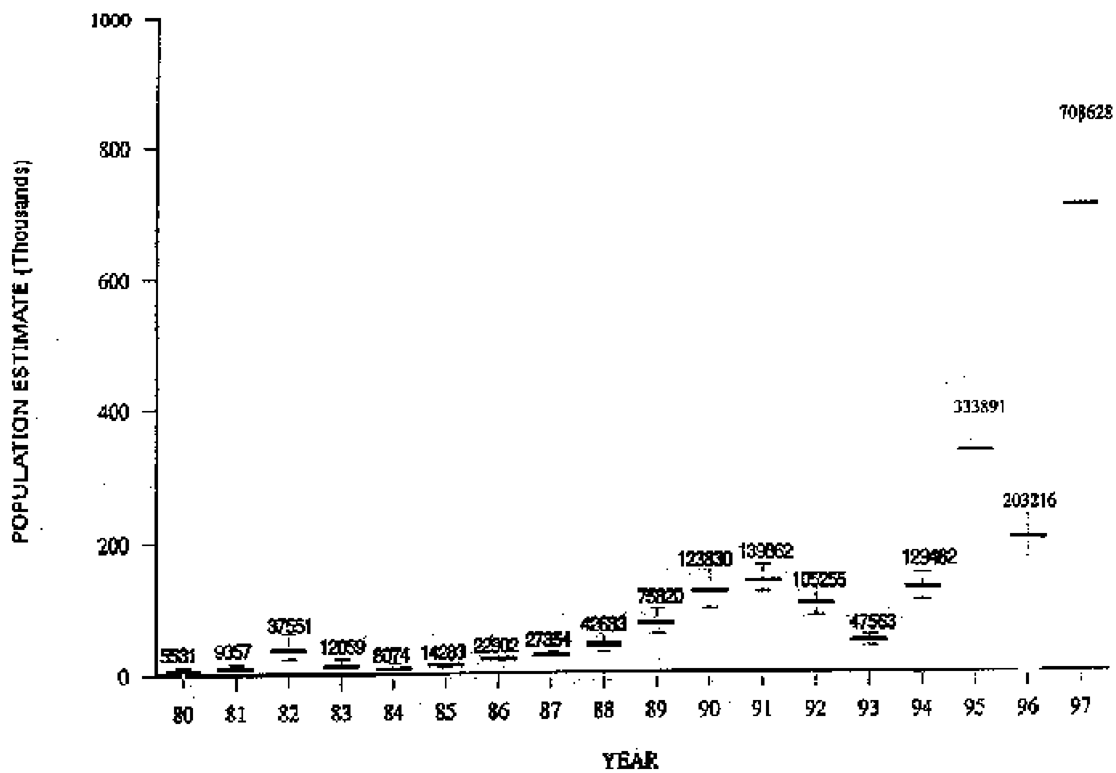


Figure 4. Cumulative total catch and number of recapture from Conowingo Dam versus Julian Day, 1995-1997.

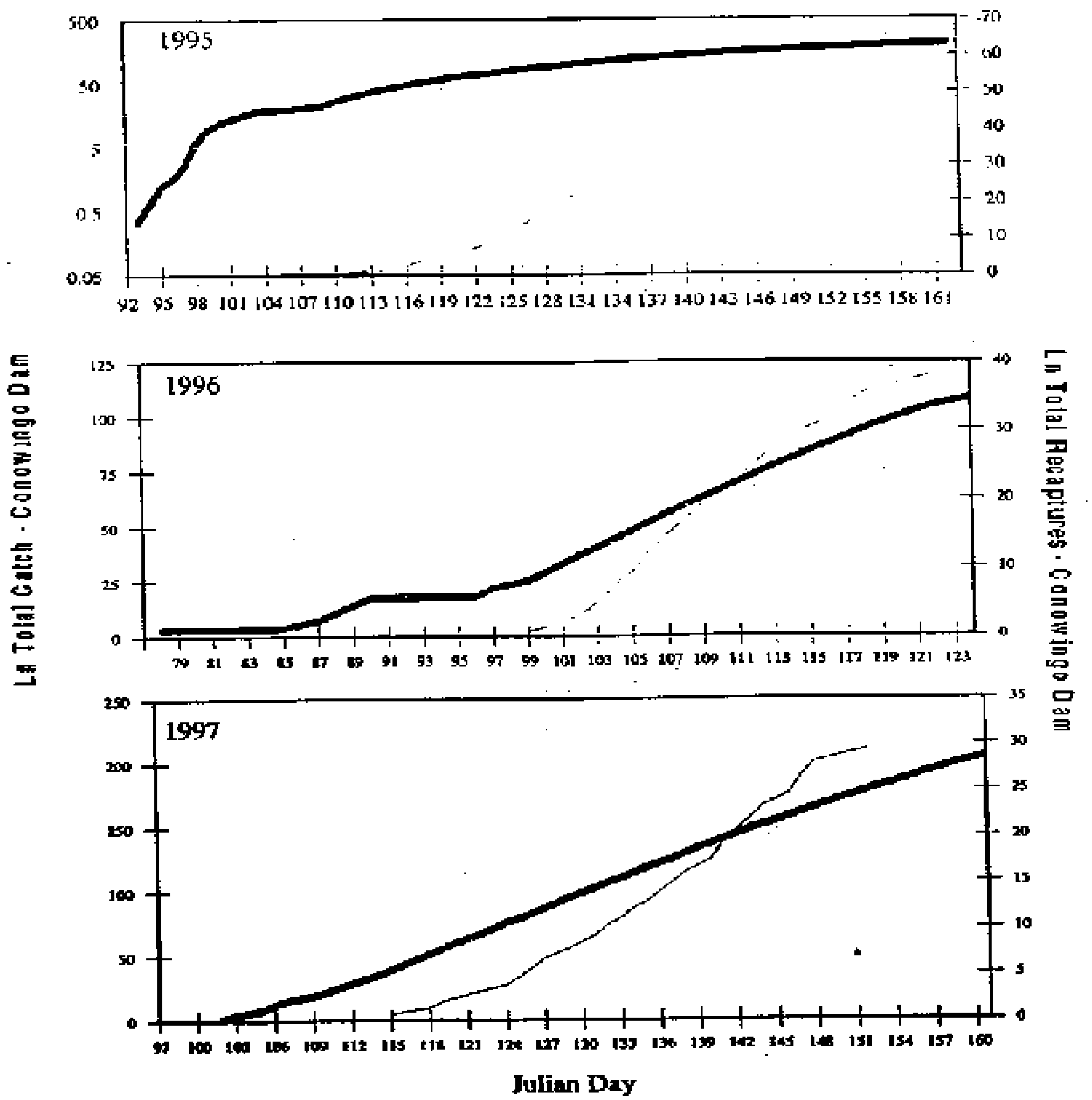


Figure 5. Regression analysis of geometric mean catch-per-unit-effort (CPUE) of American shad sampled by pound net, hook and line and Conowingo fish lifts in the Upper Chesapeake Bay, 1980-1997.

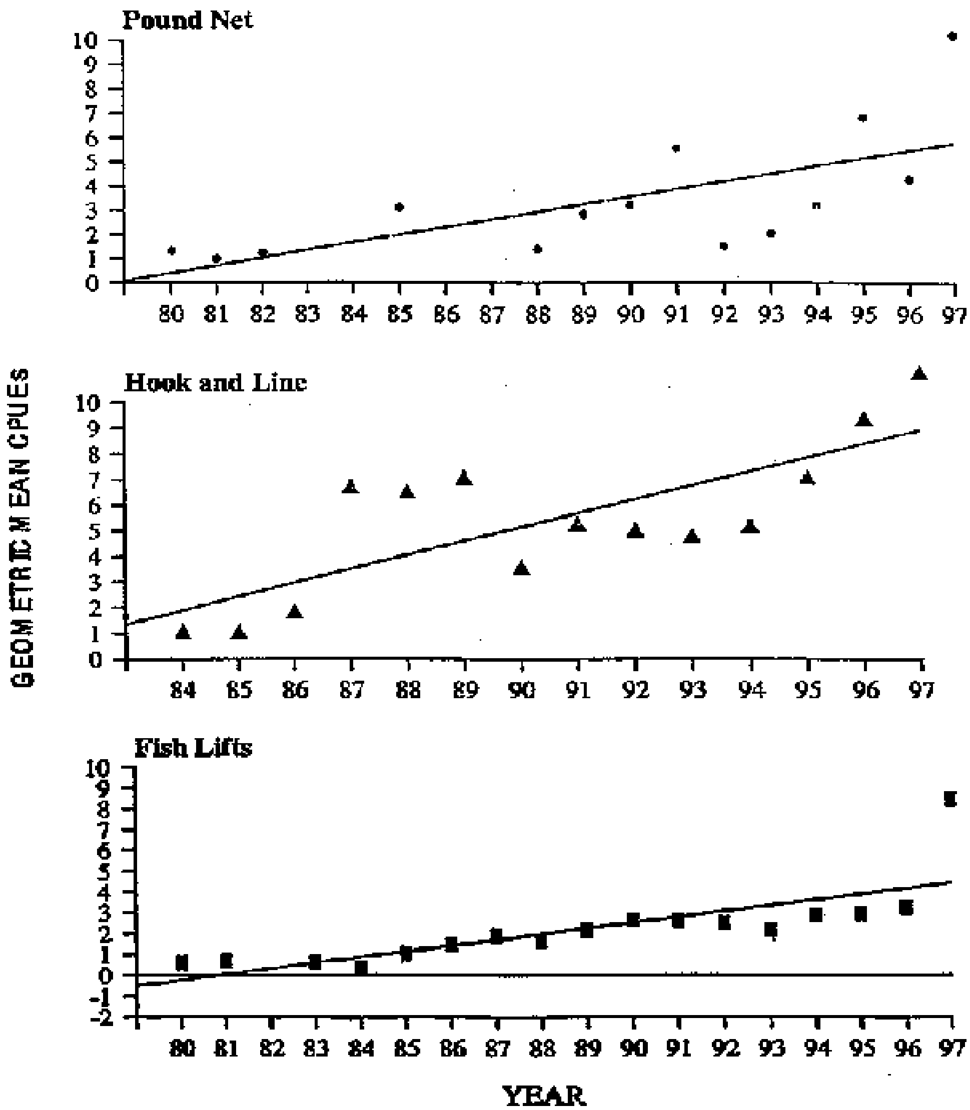


Figure 6. Pound net, hook and line, and Conowingo fish lift geometric mean catch-per-unit-effort (CPUE) versus Conowingo Dam tailrace population estimates of American shad, 1980-1996.

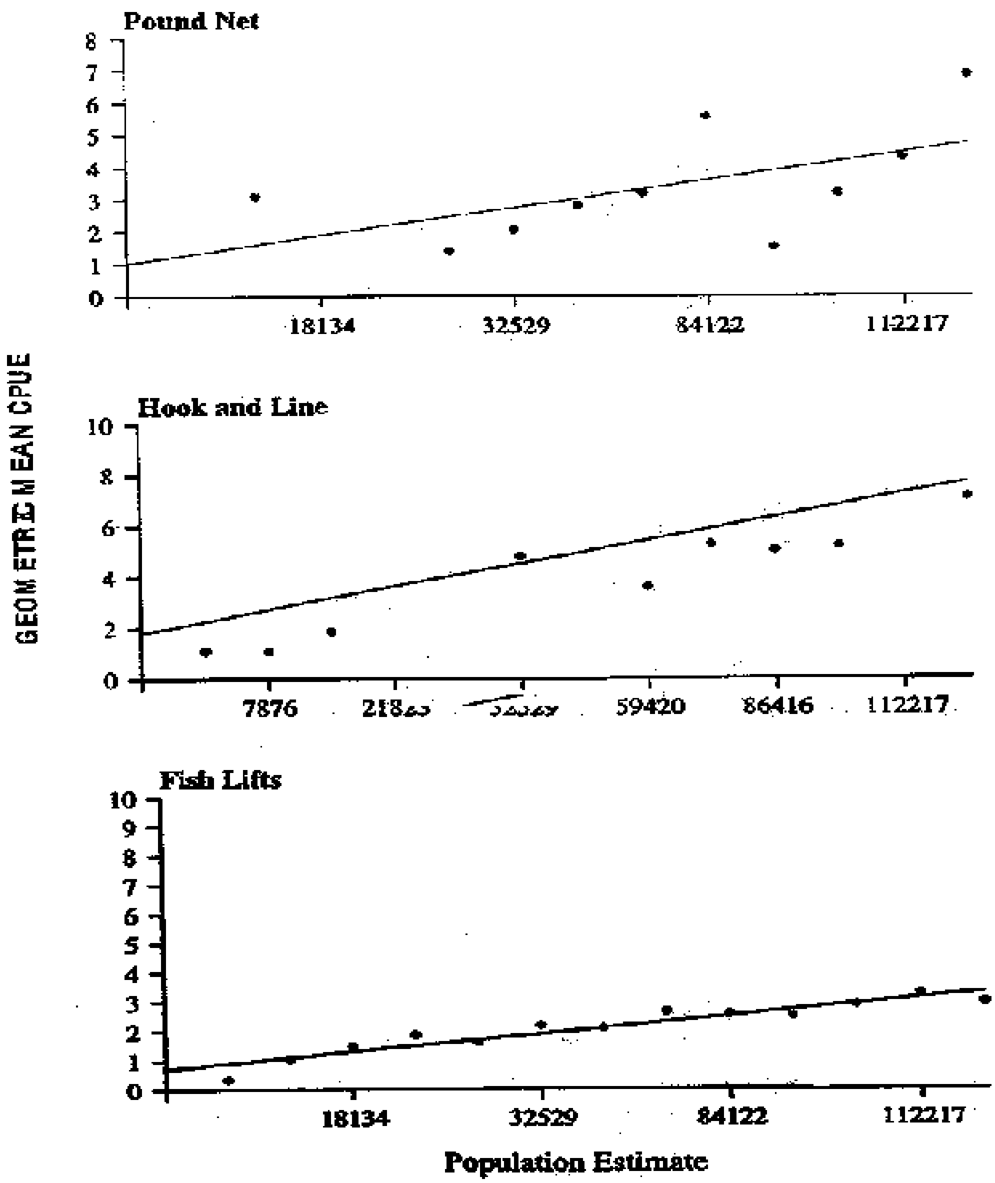


Figure 7. Pound net, hook and line, and Conowingo fish lift geometric mean catch-per-effort (CPUE) versus Upper Chesapeake Bay population estimates of American, 1980-1996.

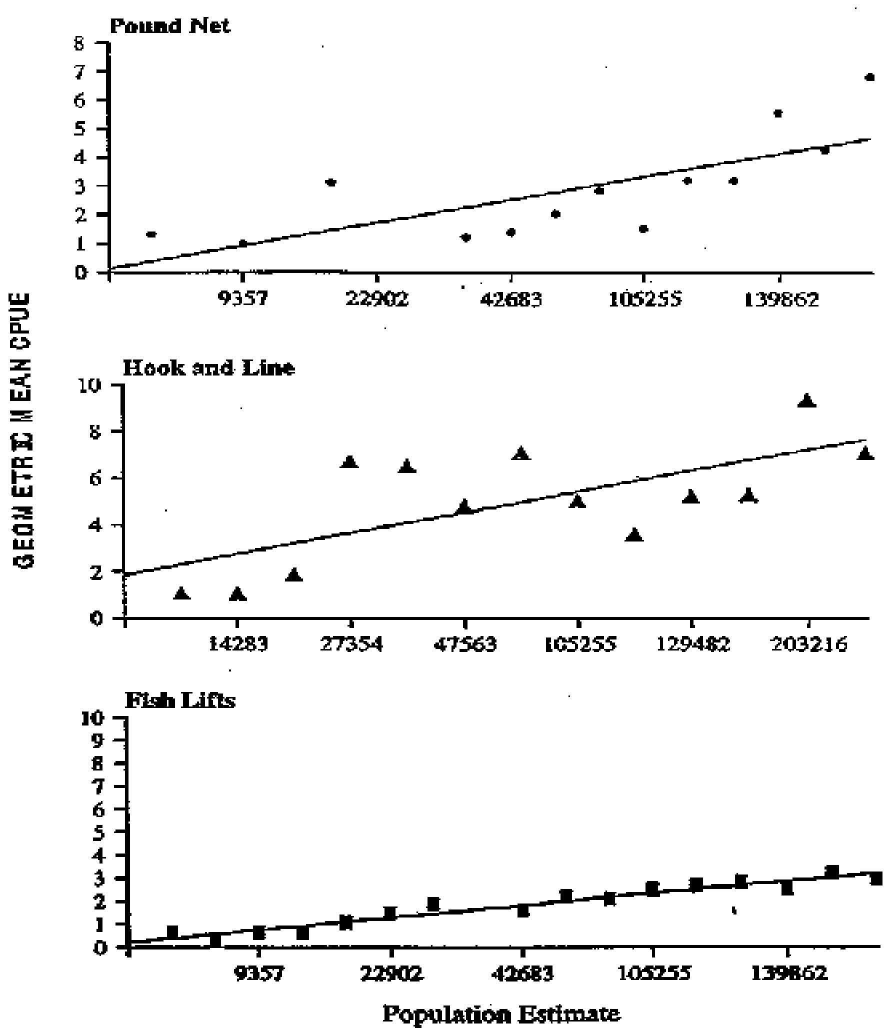


Figure 8. Conowingo Dam tailrace Schaefer population estimates of American shad, 1988-1996. Bars indicate 95% confidence ranges and numbers above indicate the yearly population estimates.

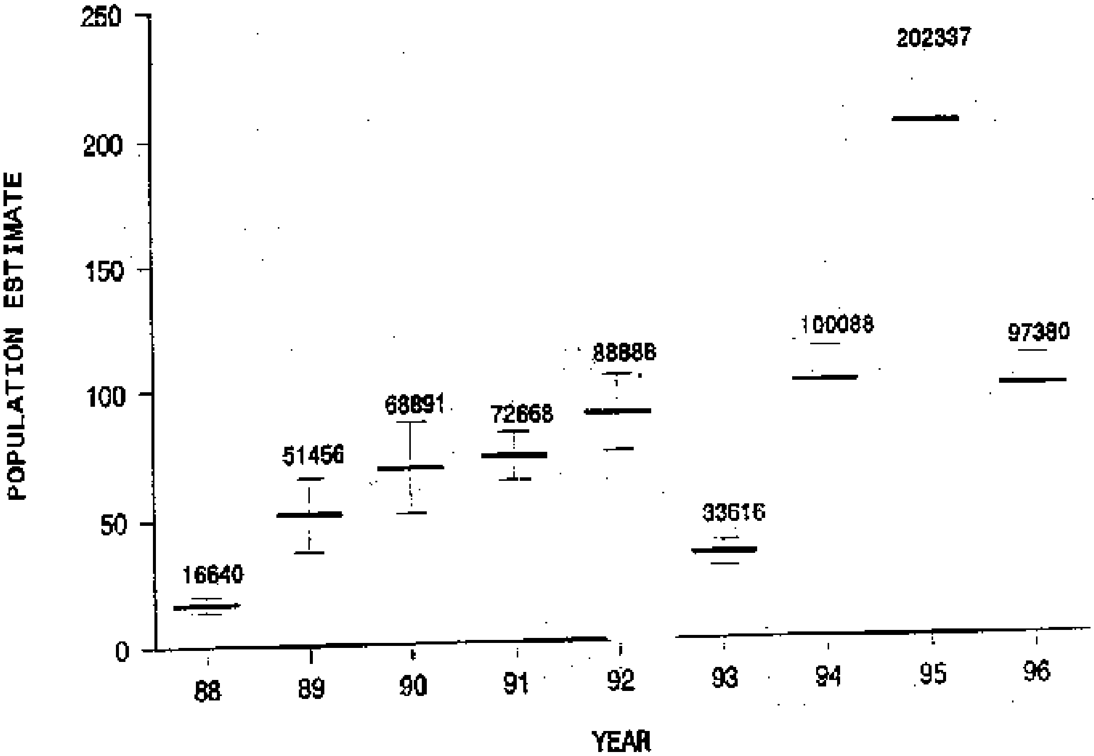
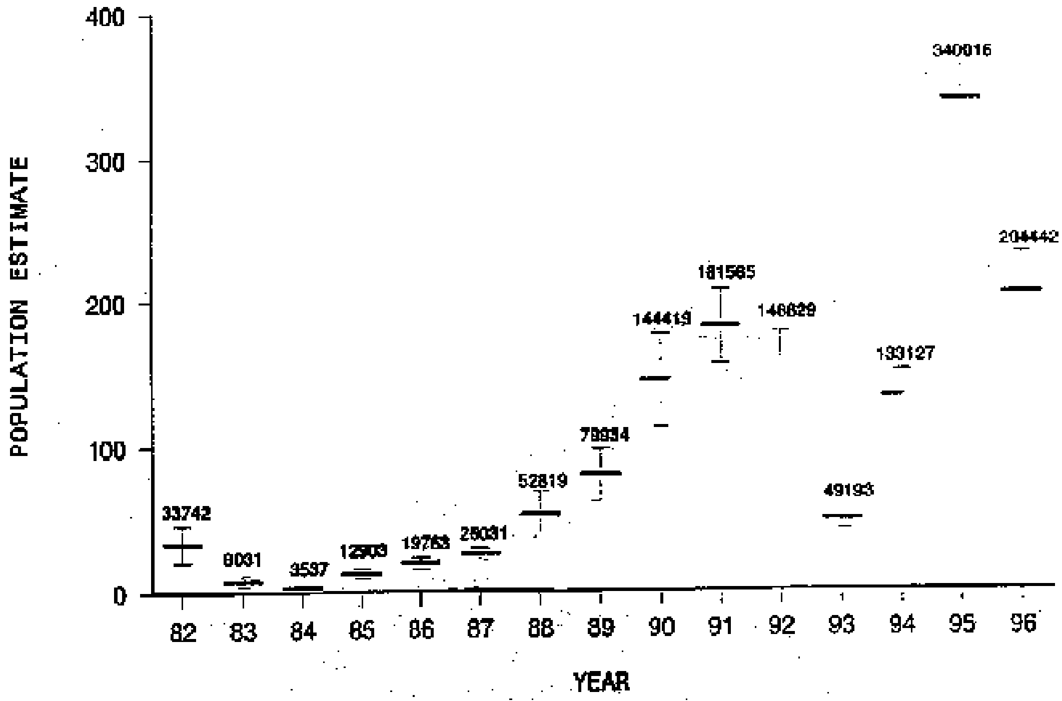


Figure 9. Upper Chesapeake Bay Schaefer population estimates of American shad, 1982-1996. Bars indicate 95% confidence ranges and numbers above indicate the yearly population estimate.



Attachment C: Stock Status and Definition of Over-Fishing Rate for American shad of the Hudson River Estuary

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INTRODUCTION

American shad has waned in its importance as a food fish since the turn of the century, when it was among the top three species harvested on the Atlantic coast (Winslow 1907, US Commission of Fish and Fisheries 1884-1905). Following WWII, most of the major east coast stocks collapsed, faulted primarily to overfishing during the war and the seven to ten year period that followed (Talbot 1954, Figure 1). Other factors contributing to declines were habitat destruction in the form of major dams constructed on spawning rivers with little or no passage, and water quality problems associated with pollution, primarily blocks of low oxygen (Rulifson 1994).

Commercial harvest of American shad continues. However, the once traditional inriver spring fisheries for roe (the eggs are considered a delicacy) have expanded in recent years, to include late winter / early spring fisheries in ocean waters and large coastal bay waters. These fisheries exploit the pre-spawning migration of American shad. These fisheries are relatively small compared to the magnitude of past fisheries, but are an important economic input during a time of continuing restrictions on other, more lucrative, species. More important to note, however, is that these fisheries continue to operate on a much smaller size of stocks present 40 or even 15 years ago.

The last coastwide stock assessment for American shad was completed in 1988 (Gibson et al. 1988). They indicated that even then many stocks were either in depressed or poor condition. Only a few major stocks -- the Hudson, Delaware and Connecticut stocks -- retained some viable status. Since then, the Hudson and Connecticut stocks have experienced noted declines (Hattala 1995, Crecco 1995). The Delaware stock appears to be stable, yet is beginning to show subtle changes (smaller fish size, lack of bigger, older fish) (R. Snyder, personal communication). These changes are similar to those exhibited by the Hudson stock in the mid 1980's.

Much discussion has occurred in recent years debating the cause of declines in the Hudson and other systems. The need for an updated assessment is evident. However, the debate now centers on inputs, methods and assumptions to be used. At the forefront of the debate is the appropriate level of natural mortality (M) to use for American shad. Both age invariant and age specific rates have been used in recent assessments (Crecco 1997, Deriso 1995, and Gibson et al. 1988).

In this paper, we present an assessment of status of the Hudson River stock of American shad, a sensitivity analysis and discussion of natural mortality rates, and definition of overfishing.

OBJECTIVES

The objectives of this paper are:

- a thorough assessment of the current condition of the Hudson River American shad stock, and

- selection of a fishing rate for use as an overfishing definition.

STOCK STATUS

Study Area

The Hudson River is a tidal estuary which extends 246 km north of the Battery in New York City to the Federal Dam at Troy (Figure 2). The shoals and shallow water areas in the upper half of the estuary above Kingston (km 144) are used as spawning habitat. The nursery area encompasses this area extending south to Newburgh Bay (km 90).

History of the Hudson River American shad stock

Landings of Hudson River shad suggest that the stock has undergone two dramatic declines in the past 100 years (Figure 3, Table B1). Both declines are attributed to overfishing. The first event occurred at the turn of the century, the second after World War II. Walters (1995) suggested that the population has not fully recovered from the second event. Recent landings of American shad are at an all time low.

During the years following WWII, pollution, primarily in the form of sewage, became a common occurrence. Inadequate oxygen (oxygen blocks) occurred in some sections of the river. The best known block was present in the Albany pool, located in the northern section of shad spawning and nursery habitat. Much spawning and nursery habitat was also lost in the upper half of the tidal Hudson due to dredge and fill operations to maintain the river's shipping channel to Albany. Recent work is in progress to attempt to quantify the amount of habitat loss that occurred (C. Needer and J. Ladd, Hudson River National Estuarine Research Reserve, personal communication). Preliminary estimates are that approximately one third of the shallow water habitat north of Hudson (km 190) was lost to filling.

Fishing effort in the Hudson River, in number of licenses and amount of licensed net sold, grew through the early 1980's, peaking in 1984. Effort declined after that but remained relatively stable from 1985 through 1990 (Figure 4, Table B2). Since then, effort has started to decline as fish become increasingly scarce and fishing becomes a non-profitable venture. Concern for status of the stock by Hudson River Valley commercial fishermen is noticeably high.

Stock Characteristics

The Hudson River Fisheries Unit conducts annual programs to assess the status of the Hudson River American shad stock. Fishery dependent and independent programs sample biological characteristics of mature fish returning to spawn. Relative abundance of shad is tracked through the catch/effort (c/f) statistics of fish taken during the commercial gillnet fishery in the Estuary. The spawning stock (mature fish) that escapes this fishery is sampled for age, length, weight and sex composition. Mortality rates are calculated for this portion of the stock. The success of the spawn is measured by abundance data for age zero fish.

Fishery Dependent Programs

The current commercial fishery for American shad in New York State occurs in the Hudson River Estuary and in marine waters around Long Island. A recreational fishery occurs in the upper half of the estuary, but the magnitude is unknown. A preliminary creel survey conducted this spring (1997) may provide insight on the recreational fishery. Commercial and recreational fishing restrictions are listed in Appendix A.

Commercial Landings and License Reporting

The National Marine Fisheries Service (NMFS) reported landings annually for the Hudson River up until 1993. Landings from 1994 to the present are from mandatory state catch reports for Hudson River commercial fishing licensee's. Recording of effort data was phased in on reporting forms beginning in 1991. Full compliance for reporting of fishing effort was implemented in 1997. The commercial monitoring data (see next section) is used to verify and adjust reporting rate for the mandatory reports.

Commercial Monitoring Program

Relative abundance of shad is tracked through catch/effort (c/f) statistics of fish taken during the commercial gillnet fishery in the Estuary.

The commercial gillnet fishery exploits the spawning migration of American shad in the Hudson River Estuary. The fishery targets female shad for their roe, however most captured males are kept for fillets and/or smoking. Fishing usually begins in early April and, continues until May when fish come into full spawning condition. Fishing activity in New York waters of the Hudson occurs by fixed gear from km 40 to km 70 (Piermont to Peekskill) and drifted gear from km 98 to km 182 (Newburgh Bay to Catskill). One small stake gill net operation exists in the New Jersey portion of the Hudson River near km 19 (George Washington Bridge).

We have monitored the commercial fishery annually since 1980. Information is obtained by direct observation. Data are recorded on numbers of fish caught, gear type and size, fishing time and location. Scale samples, lengths and weights are taken from a subsample of the fishermen's catch. C/f is calculated as the number of fish collected per yd^2 x hrs x 10^{-3} of net fished. C/f data is summarized as an annual sum of weekly c/f. Run size is determined by number (density) of spawners each week as well as duration (number of weeks) of the run. Scales from 1988 through 1997 (except 1991) have not been aged, but should be available some time in 1998.

C/f for female American shad was low in the early 1980's increased to a high in 1986, declined through 1993 then varied through 1997 (Figure 5, Table B3). It is unclear how the increase in the 1994 and 1996 indices relates to low landings during this period (Figure 2). Perhaps catchability increased as stock size declined (Crecco and Savoy 1985). If landings reasonably represent stock size, this may be what occurred in these years. C/f data from 1993 through 1996 should be interpreted with caution as sample size was lower than in previous years. Male c/f followed the same pattern as females, however, after 1990 it has remained extremely low.

Mean fork length (FL) and weight of female American shad declined over the period 1987 to 1992 and has remained low since then. The current average size of females is the smallest observed since 1980 (Figure 6, Table B4). A similar pattern occurred for males.

Fishery Independent

Spawning Stock Survey

The fish sampled in this program represents the spawning stock, or production, portion of the population that has escaped the commercial fishery. Mortality rates are calculated for this portion of the stock.

The spawning stock has been sampled annually since 1983. Sampling occurs within the spawning reach (km 145-232) from late April through early June, concentrated from km 146 to km 182. Fish are collected by a 183 m or 304 m haul seine, selected because of its relative low size selectivity. Sampling efforts in 1983 and 1984 were very limited. The most useful age data are from 1985 to the present. All shad collected are identified by sex, weighed, measured, and sampled for scales. Scales from 1988 through 1997 (except 1991) have not been aged, but should be available some time in 1998.

Mean fork length and weight for both sexes remained steady until 1988 but have slowly declined since then. The smallest fish were observed in 1994 when sizes of both sexes were at the lowest level observed since the program began (Figure 7, Table B4). Mean fork length and weight increased slightly in 1995 and 1996.

Age structure of the spawning stock remained stable in the 1980's (Table 1). The most recent data in 1991 indicated a change to younger fish. Incidence of repeat spawning also dropped in 1991 to 28% from an average of 56% for females and to 21% from 46% for males (Table 1).

We investigated the influence of year-class strength and its effect on mean age since the decline in mean age could have been caused by strong year classes of young fish in 1991. Effects of year class strength were removed from age structure by dividing catch at age by year class strength of the same cohort. Adjusted mean age declined in 1991 (Figure 8, Table 1). This indicates that the change to younger fish in 1991 was caused by a loss of older fish rather than an influx of younger fish.

Mortality Estimates

Total instantaneous mortality (Z) is calculated using within-year catch curve on ages and number of repeat spawners (Crecco and Gibson 1988). The most recent estimates of total instantaneous mortality (Z) calculated from 1991 spawning stock age data were Z_{AGE}=0.98 and Z_{SM}=0.99 (SM=spawning marks) for males and Z_{AGE}=0.97 and Z_{SM}=0.74 for females (Table 2) . This is an increase from the Z's calculated for 1985-1987 when Z_{AGE}=0.69 and Z_{SM}=0.56 for males and Z_{AGE}=0.57 and Z_{SM}=0.50 for females.

Young-of-the-Year Abundance

A measure of relative abundance of young-of-the-year (YOY) American shad has been obtained annually in the Hudson River Estuary since 1980. Sampling is concentrated in the middle and upper portions of the Estuary (km 88-225), the major nursery area for young alosids. Sampling is conducted biweekly from mid-June through late October each year. Gear is a 100 ft. beach seine, sampled during the day at approximately 30 standard sites.

Catch / effort is expressed as an annual geometric mean: number of fish per seine haul for weeks 26 through 42 (July through October). C/f indices were low through the early 1980's then increased greatly in 1986 (Figure 9, Table B5). Annual measures have been extremely variable but follow a declining trend until 1995. It is not clear why the index in 1996 was so high.

In addition to the young-of-the-year index, additional data on year class abundance data are available. These data are abundance of post-yolk-sac larval shad (PYSL), collected by Hudson River valley utility companies Long River Survey (LRS). The LRS samples ichthyoplankton river-wide from the G. Washington Bridge (km 19) to Troy (km 246) following a stratified random design (CONED 1997). Ichthyoplankton is sampled from all strata (shore, shoals, bottom and channel). Gears used are a 1-m epibenthic sled or a 1-m Tucker trawl. The PYSL index is the density of fish collected per 1000m^3 of water sampled.

The two indices, YOY and PYSL, correlate well (R^2=0.8). The PYSL index has a longer time series back to 1974. The indices in 1974 through 1979 were much lower than that measured after 1980. Since 1980, trends in the two indices track well for all years except 1996. The 1996 indices are still preliminary and the relationship between the two indices may change once the data are finalized.

OVERFISHING DEFINITION

We decided to use an F_{30} as the overfishing definition for the Hudson River American shad stock. F_{30} is defined as the fishing rate that would generate stock size of 30% of the unfished (virgin) stock. This is the same criterion used by Crecco (1997) and as selected by the Shad Stock Assessment Subcommittee of the Atlantic States Marine Fisheries Commission.

Methods

Model inputs by age are listed in Table 3 and Figure 10. All data are specific to the Hudson River stock.

Our analyses augment a basic yield and biomass-per-recruit (BPR) model for females with estimates of egg production for information on egg-per-recruit (EPR). Our model starts with recruits at age one. These recruits are decremented annually by natural mortality until they reach harvestable ages. They are then decremented by natural and fishing mortality through age 12. As survivors mature, the fraction of females of each age that is mature is multiplied by fecundity at that age. Resulting egg production and biomass by age is summed for all ages. In the final step, total egg production and total biomass are each divided by the number of initial recruits for an estimate of EPR and BPR. The model was run for a range of fishing rates (F) from zero to 0.7. Formulae used in model calculations are summarized in Appendix C.

Selection of Instantaneous Rate of Natural Mortality

The appropriate level of natural mortality (M) for American shad remains unresolved. Crecco (1997) used several values for M , based on age groups. These values are M=0.3 for ages 1-3 (all stocks), M=2.5 for ages 4-10 in southern rivers and M=1.5 for ages 4-10 in most northern rivers. The exception for northern rivers was the Hudson, where a value of 0.6 for ages 4-10 was used. Gibson et al. (1988) used age invariant (constant), river-specific M's, calculated using a variety of methods (Hoenig 1983, Pauly 1980 or Leggett 1976). Deriso et al. (1995) used a age invariant rate of 0.3 for Hudson River American shad. The value of 0.35 was estimated using Hoenig (1983) from the most commonly observed maximum age of 12 years for the Hudson stock.

Given that immature American shad and other herring are forage for many fish predators, it is likely that M is not age invariant and is higher at young ages. We used a method by Boudreau and Dickie (1989) and Dickie (1987) to estimate M at age for Hudson River shad. These methods relate M to a specific rate of production (biomass) for each size group (age) in a population. The curve generated over all size (age) groups is an indication of the natural mortality pattern of a stock (Table 3).

Since M remains unknown, we also included a sensitivity analysis of M. The model was run using a variety of M's: constant, age-invariant values from 0.2 to 1.4 and age dependent values which increased or decreased with age.

Given the stress of spawning experienced by American shad (movement from fresh to saltwater, no food consumption while spawning) and the lengthy exposure to a fishery (late February to May),we used a Type II fishery where both natural and fishing mortality are occurring simultaneously.

Results

Overfishing Rate

The response of EPR and BPR to changes in F varied with type and level of M that was input to the model. Highest values were produced by lowest values of age invariant M (Figure 11) and age specific M that decreased with age (Figure 12).

For a constant, age-invariant M, the F_{30} increased with increasing M (Table 4). Values ranged from F_{30} = 0.22 (EPR) when M = 0.2, and F_{30} = 0.65 for M =1.4. Estimates of F_{30} , based on BPR, were similar and ranged from 0.24 for M = 0.2 and 0.69 for M = 1.4.

For age-specific M, where M declined with age, F_{30} =0.23 (EPR) and F_{30} = 0.25 (BPR) (Table 4). Where M was higher for mature fish (>3 age group), F_{30} = 0.38 (BPR) for M = 0.6 and F_{30} = 0.68 (BPR) for M = 1.5 (Table 4).

For the purposes of this assessment we recommend that either an age invariant M of 0.3 or an age specific M which decreased with age should be used. These result in estimates of an overfishing rate of F = 0.23 to F = 0.27 (Table 4).

Current F

Deriso (1995) found fishing mortality rates (F) for older shad of 0.4 to 0.5 for the period 1974 to 1992, with rates higher for female shad and than for males. Average exploitation was 0.33 (F = 0.4) for the same period.

Given that Z = M + F, estimates of Z (Section 3.3.2) and assumed values of M can be used to generate estimates of F. Using the age invariant estimate of M = 0.30, estimates of mean F for females in 1985 to 1987 were 0.25 using age data and 0.20 using spawning marks. The 1991 estimates were 0.67 and 0.44 respectively. Using a mean M for the mature ages (0.20) for the age specific M, estimates of mean F for females in 1985 to 1987 were 0.35 and 0.30. The 1991 estimates were 0.77 and 0.54.

Estimates of F reported by Deriso (1995) and those generated from recent estimates of Z above exceed all estimates of overfishing calculated in this analyses (Figure 13) .

Estimates of F also could be generated from reported harvest and estimates of population. We are currently analyzing tag release and recapture data for 1995 through 1997 with the intent of generating inriver estimates of spawning stock size. Estimates of u and then F will be generated when the population estimates are complete. However, it is very important to note that estimates of harvest rate using reported harvest is very much affected by the assumed reporting rate. A doubling of reported harvest doubles any estimate of u.

Discussion

Models and analyses presented in this paper were developed to provide New York with an approach to assessing status of American shad of the Hudson River Estuary. We used the simple EPR and BPR approach for identifying overfishing levels of F because we felt that data were not adequate for including any stock recruit relationship (S/R). We explored data on relative abundance of stock and recruits for 1974 through 1996 provided by Crecco (1997 January stock assessment draft). However, the fit was poor and estimates describing density dependence were unrealistically high, b > 4.0. Moreover, we were reluctant to use such a short time series of data into a S/R function - especially since the 20 year time series essentially spans a period of low stock size.

The choice of a value for M is very important to all modeling work on American shad. Mortality rates of fishes, as well as all animals, are inversely related to longevity. American shad, with no repeat spawning, such as southern stocks clearly have a higher natural mortality rate than those that repeat. Most southern stocks seldom exceed a maximum age of 7. In most northern stocks, in NC and north, with repeat spawning, maximum age falls within the range of 8 to 11 (Markham 1997, O'Reilly 1997, Winslow 1997) with the exception of the Hudson River. Model runs, with selected M, that generate the virgin stock size benchmark, should, at minimum, approximate ages observed in the wild populations. If they do not, then virgin stock size can be underestimated (no egg production or biomass at older ages) as older ages that should be there, are not present.

Maximum age of Hudson shad most often equals 12, but a few fish have been observed at age 13. These older ages in the Hudson stock suggest M should be fairly low to reflect the stock's longevity. It is not clear how old shad can get since current data, collected within the last 15 years, reflect conditions present in shad populations at low stock size and the effects of F.

For comparative value, many other fish stocks have similar natural mortality rates. Age invariant M has been the choice of most assessments. For top end predators, natural mortality is fairly low: striped bass, M=0.2; weakfish, M=0.3 (ASMFC). Shad, however, fall into the prey species category at younger ages until they grow large enough to avoid being food. For a similar prey-type, though non-anadromous, clupeid species, Atlantic herring, the value selected for M is 0.2 (SAW 1996). For another anadromous species, Atlantic salmon, the value of M=0.12 is used (Freidland et al. 1996).

We feel that changes observed in the Hudson River American shad stock are a result of overfishing. We base our conclusion on observed changes in size and age structure and on recent rates of mortality relative to acceptable levels.

Size and mean age decreased in 1991 relative to that in 1984-1987. These changes could be caused by changes in year class production resulting in more young fish or in decreased survival of older fish. Increased fishing is the logical cause of any increase in mortality. We tested effects of year class fluctuation on age structure by normalizing catch at age data by relative abundance of the same cohort at age zero. Resulting mean age (Table 1) continued to be lower in the most recent data suggesting that change was caused by actual losses of older fish rather than on year class fluctuation.

The most recent estimate of Z (1991) is higher than those observed in 1985-1987 and result in F values that exceed our overfishing definition at most reasonable values of M. The possible weakness in our Z estimates is that estimates are based on age composition generated from scale samples. Aging of scales remains an art and estimates have not been verified by known age fish. However, the same staff and methods have been used to age shad for the entire time period. Thus any bias should be consistent. The reduction in average age lead to increased mortality estimates regardless of size of bias. Our estimates of current Z and F are close to those generated by Deriso. (1995) by a stock reconstruction analyses.

LITERATURE CITED

Boudreau, P. R. and L. M. Dickie. 1989. Biological modeling of fisheries production based on physiology and ecological scalings of body size. Can. J. Fish. Aquat. Sci. 46: 614-623.

CONED (Consolidated Edison) 1997. Year Class Report for the Hudson River Estuary Monitoring Program 1997. New York, NY USA.

Crecco, V. 1995. Status of American shad in the Connecticut River, 1970-1995. Report to the shad and river herring Technical Committee of the Atlantic States Marine Fisheries Commission, Washington, D.C. USA.

Crecco, V. 1997. DRAFT Stock assessment of American shad from selected Atlantic coast rivers. Report to the American shad stock assessment Subcommittee of the Atlantic States Marine Fisheries Commission. Washington, D.C. USA.

Crecco, V. and M. Gibson. 1988. Methods of estimating fishing mortality rates on American shad stocks. In 1988 Supplement to the American shad and river herring Management Plan, Fisheries Management Report No. 12 of the Atlantic States Marine Fisheries Commission, Washington, D.C. USA.

Crecco, V. and T. Savoy. 1985. Density dependent catchability and its potential causes and consequences on Connecticut River shad, *Alosa sapidissima*. Can. J. Fish. Aquat. Sci. 42(10):1649-1657.

Dickie, L. M., S. R. Kerr, and P. Scwinghamer. 1987. An ecological approach to fisheries assessment. Can J. Fish. Aquat. Sci. 44(Suppl. 2) 68-74

Deriso, R. (with assistance from K. Hattala and A. Kahnle). 1995. Hudson River assessment and equilibrium calculations: extension of assessment to include repeat spawning information and sex specific attributes. ESSA Technologies, Ltd. for the NY State Dept. of Environmental Conservation. Canada. (Unpublished).

Freidland, K. D., R. E. Haas and T. F. Sheehan. 1996. Comparative post smolt growth, maturation and survival in two stocks of Atlantic salmon. Fishery Bulletin 94:654-6663.

Gibson, M., V. Crecco and D. Stang. 1988. Stock assessment of American shad from selected Atlantic coast rivers. Special report #15 of the Atlantic States Marine Fisheries Commission, Washington, D. C. USA.

Hattala, K. 1995. Stock status of American shad in the Hudson River Estuary. Report to the shad and river herring Technical Committee of the Atlantic states Marine Fisheries Commission, Washington, D. C. USA.

Hoenig, J. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82(1):898-903.

Leggett, W. C. 1976. The American shad. *Alosa sapidissima*, with special reference to its migrations and population dynamics in the Connecticut River. In Merrriman and Thorpe, editors, The Connecticut River Ecological Study: The impact of a nuclear power plant. American Fisheries Soc. Monograph 1.

Lehman, B. 1953. Fecundity of Hudson River shad. US Fish and Wildlife Service, research report 33.

Markham, C. 1997. Memo to Atlantic States Marine Fisheries Commission shad and river herring Technical and stock assessment committees on age structure and estimates of Z for the Upper Chesapeake Bay.

O'Reilly, R. 1997. Memo to Atlantic States Marine Fisheries Commission shad and river herring stock assessment committees on harvest and age structure for some Virginia Rivers.

Pauley, D. 1980. On the inter-relationship between natural mortality, growth parameters , and mean environmental temperature in 175 fish stocks. J. Cons. Explor. Mer. 39:175-192.

Rulfson, R. 1994. Status of anadromous Alsosa along the east coast of North American Anadromous Alsoa Symposium, 1994, pp. 134-158.

SAW 1996. 21st Northeast Regional stock assessment workshop, Northeast Fisheries Science Center Reference document 96-05d.

Talbot, G. 1954. Factors associated with fluctuations in abundance of Hudson River shad. US Fishery Bulletin 101.

Walters, C. 1995. Estimation of historical stock size and recruitment anomalies from relative abundance time series. Can. J. Fish. Aquat. Sci. 52:1523-1534.

Winslow 1997. US Bureau of Fisheries. 1907. Statistics of the fisheries of the Middle Atlantic States for 1904. Report of Comm. of Fisheries for 1905. Appendix (Doc. 609).

US Commission of Fish and Fisheries. 1884-1905. Reports of the Commissioner, 1882-1905.

Figure 1. Total commercial fishery landings of American shad for all Atlantic coast states: ME to FL, 1880-1995.

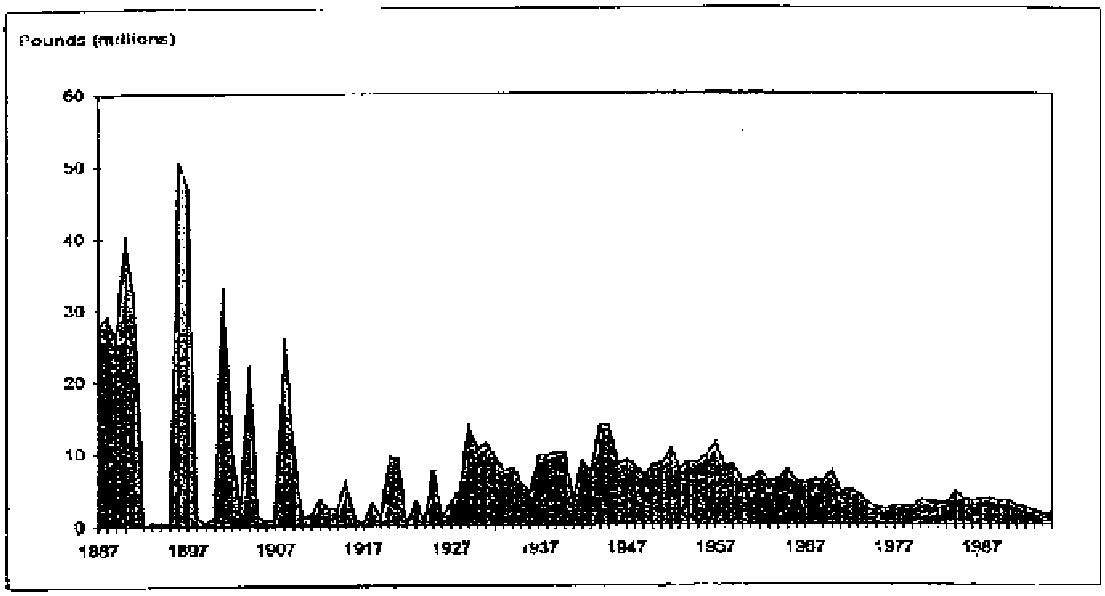


Figure 2. The Hudson River Estuary.

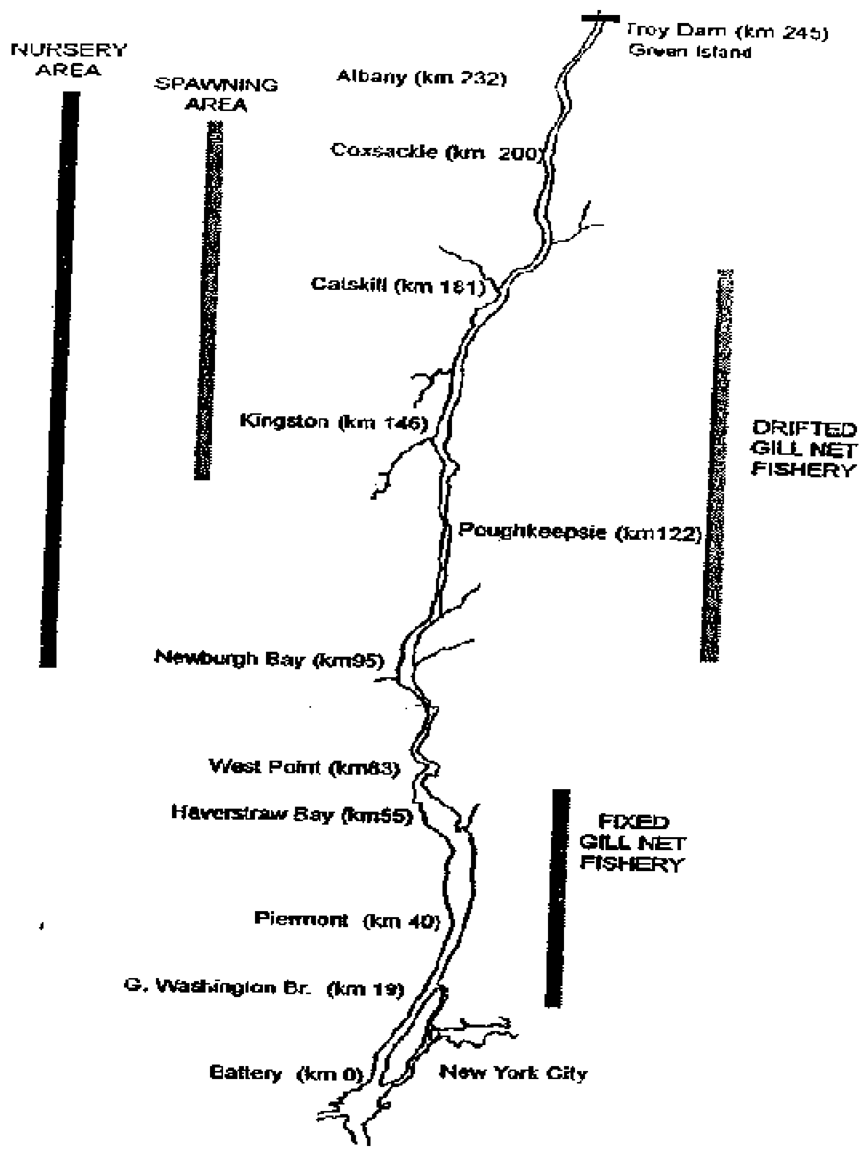


Figure 3. Historic commercial fishery landings of American shad in the Hudson River Estuary, 1880-1996.

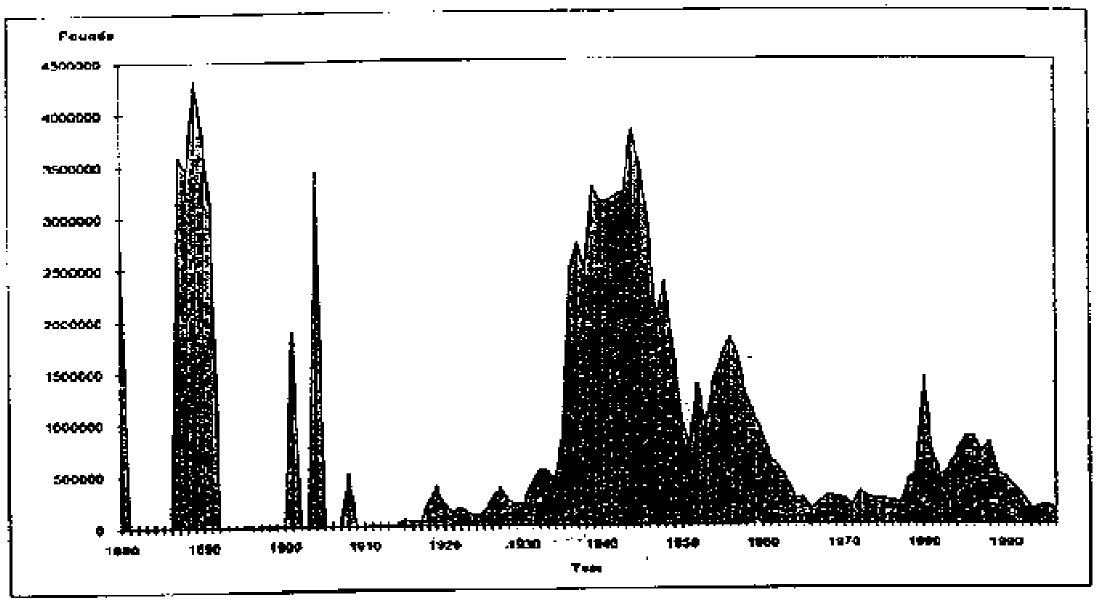


Figure 4. Number of shad licenses and amount (ft) of licensed gillnet sold for the Hudson River, 1976-1996.

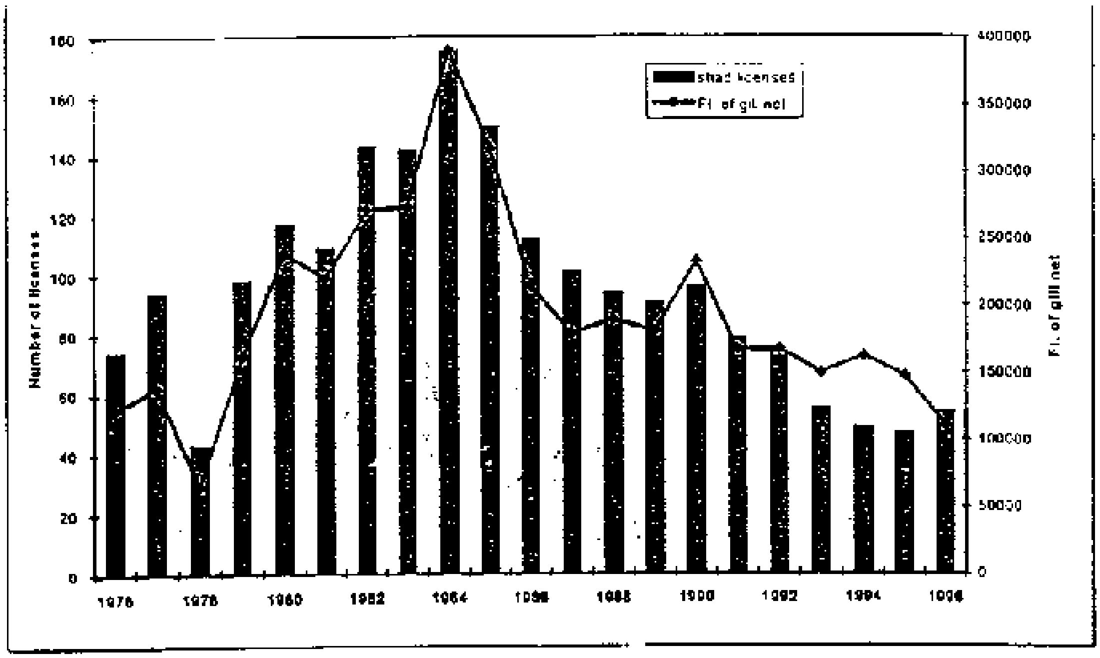


Figure 5. Weekly sum of c/f of American shad caught in fixed gillnets in the commercial gillnet fishery in the Hudson River Estuary, 1980-1997.

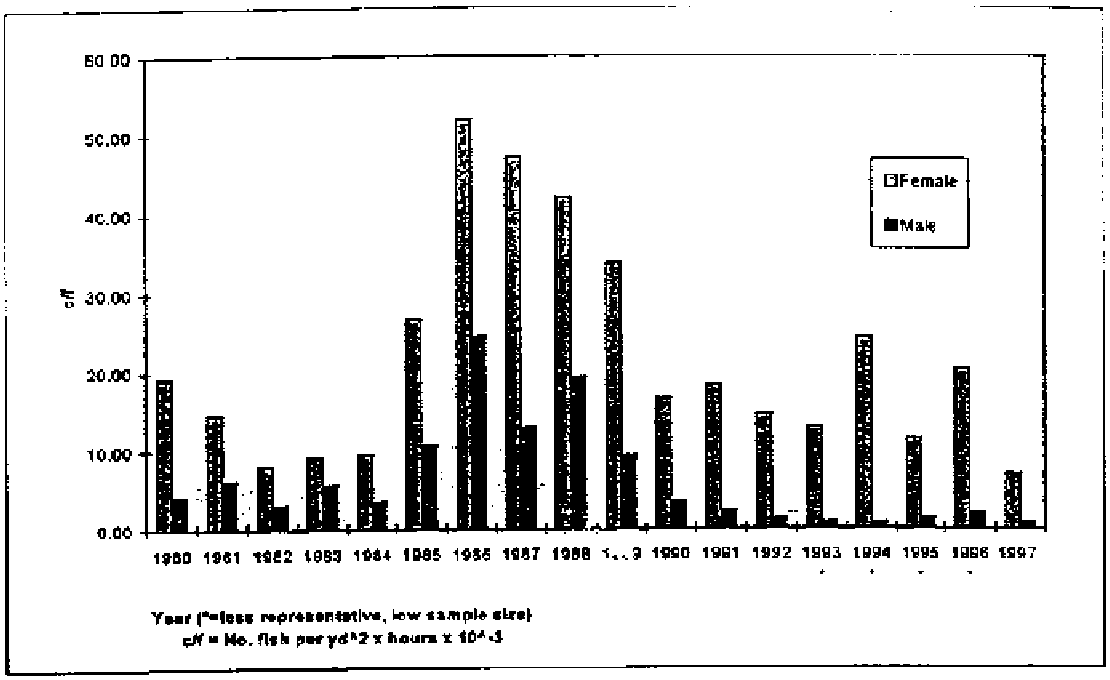


Figure 6. Mean fork length and weight of American shad caught in the commercial gillnet fishery in the Hudson River Estuary.

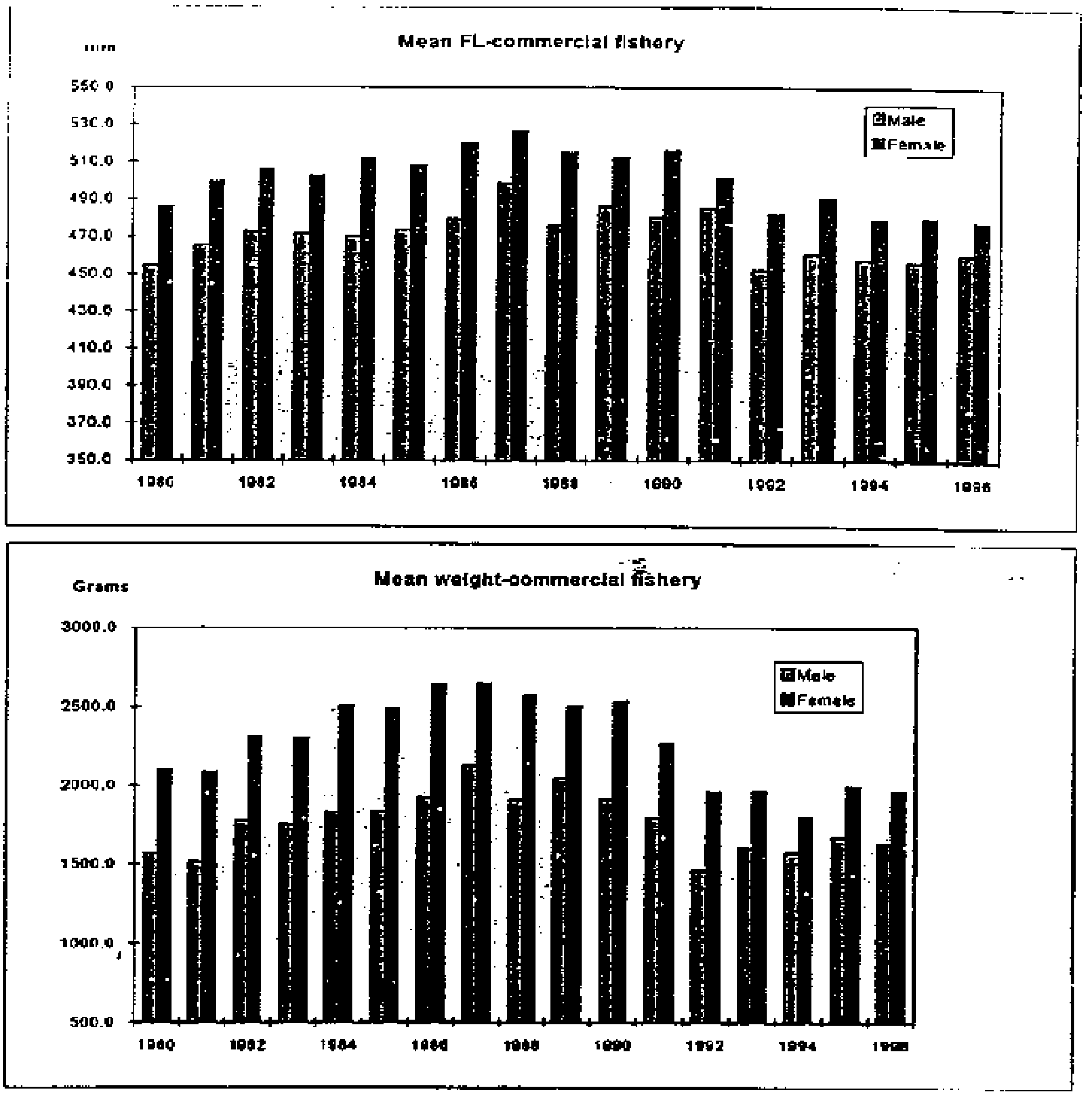
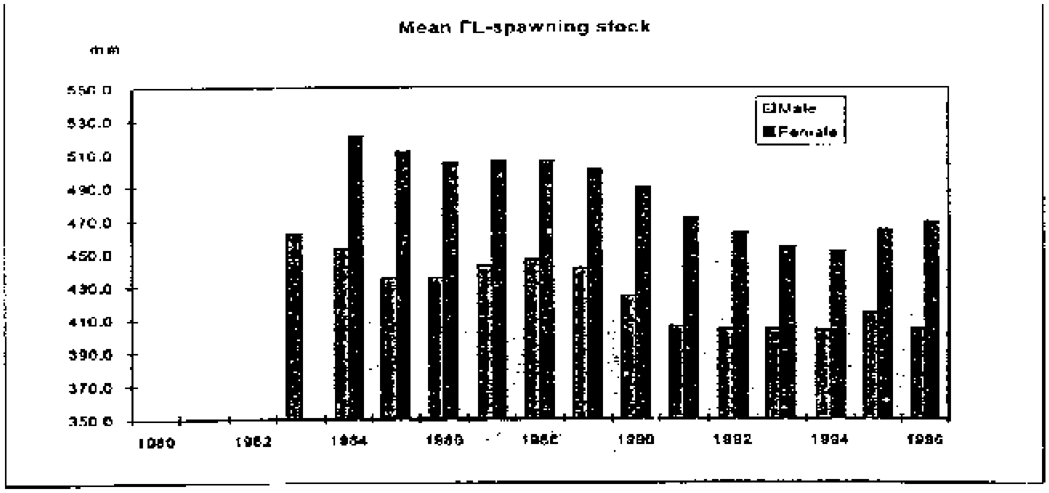


Figure 7. Mean fork length and weight of American shad collected in the spawning stock survey in the Hudson River Estuary.



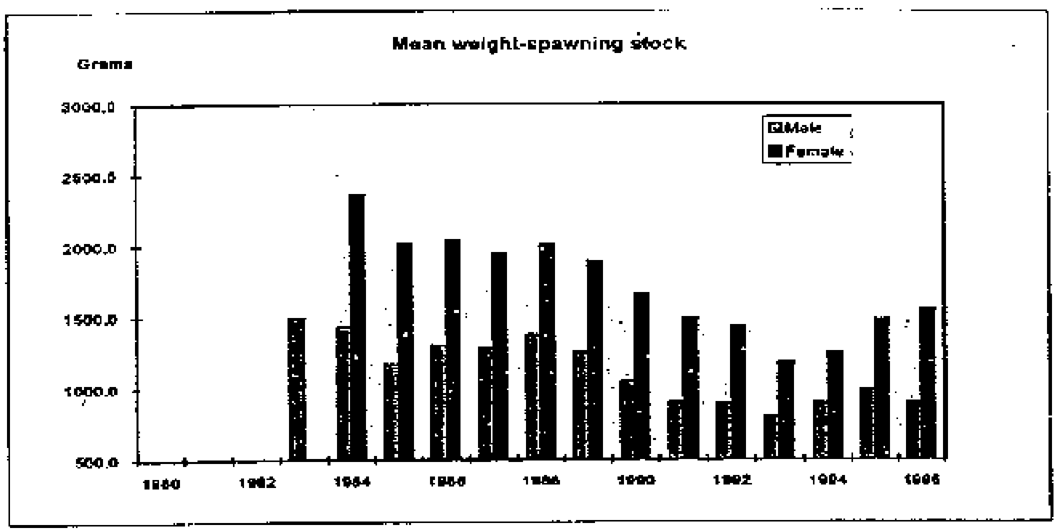


Figure 8. Mean age and mean adjusted age of American shad collected in the spawning stock survey in the Hudson River Estuary.

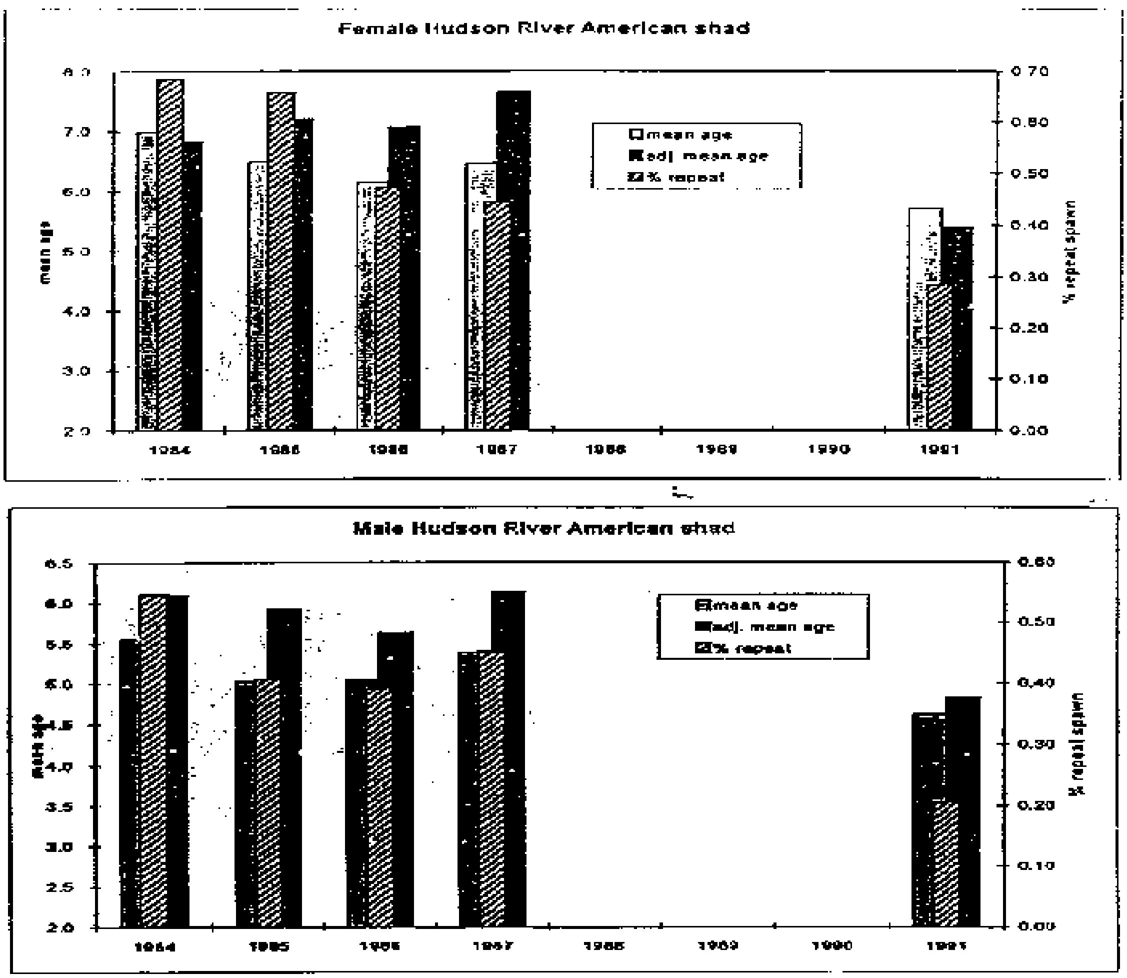


Figure 9. Young-of-the-year and post-yolk-sac indices of abundance for American shad collected in the Hudson River Estuary.
***1996 estimates are PRELIMINARY

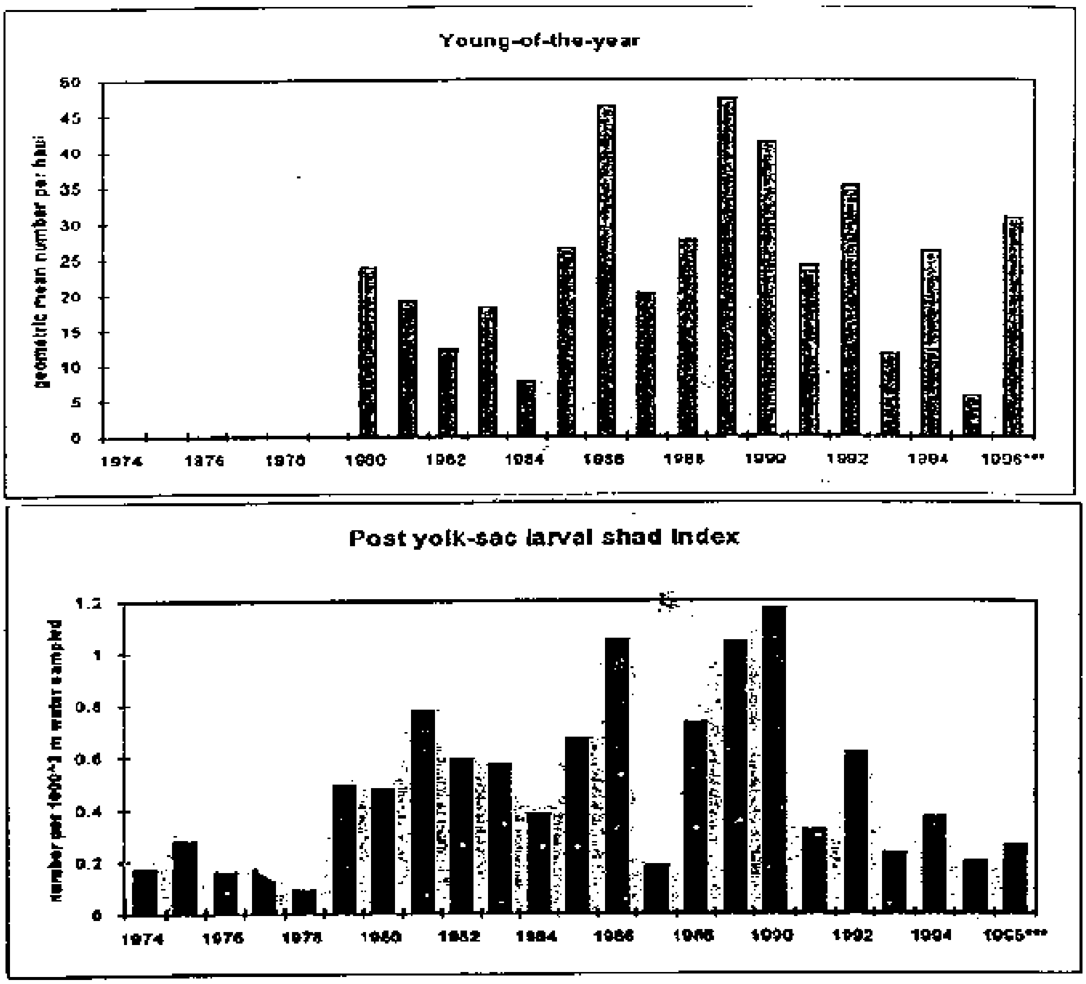


Figure 10. Observed weight at age for Hudson River American shad.

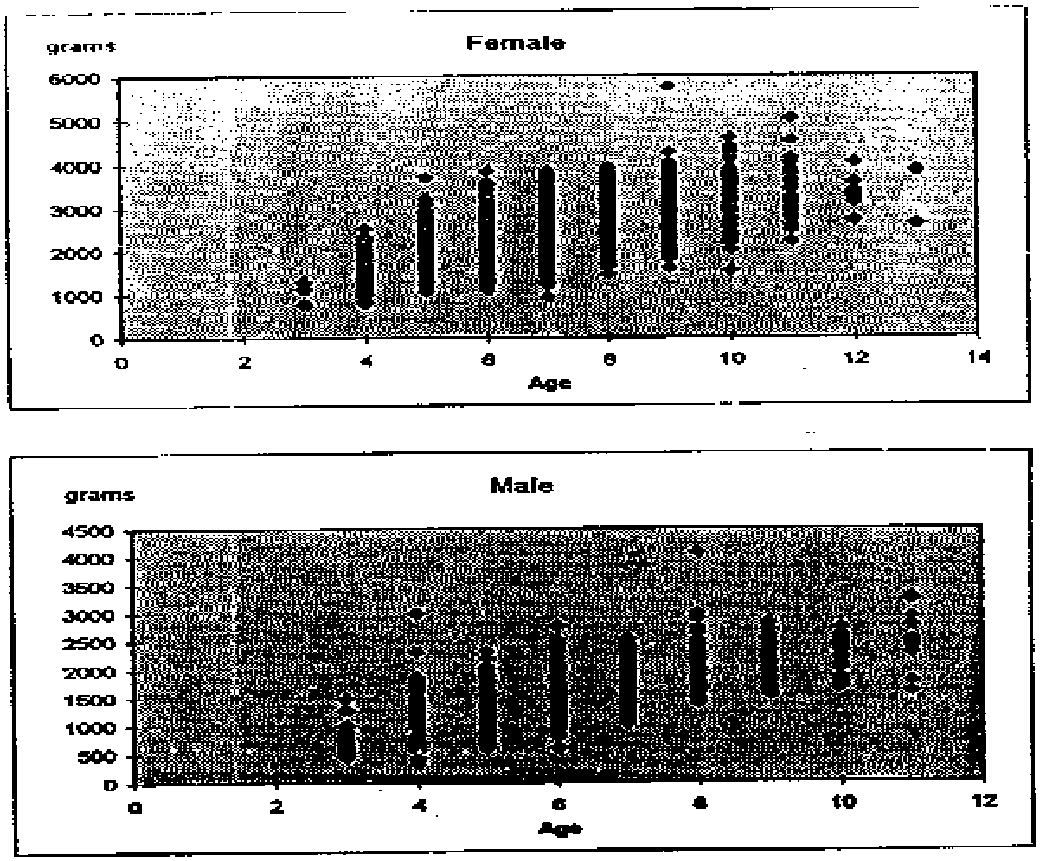


Figure 11. Comparison of model results of EPR and BPR run at various levels of age invariant M.200

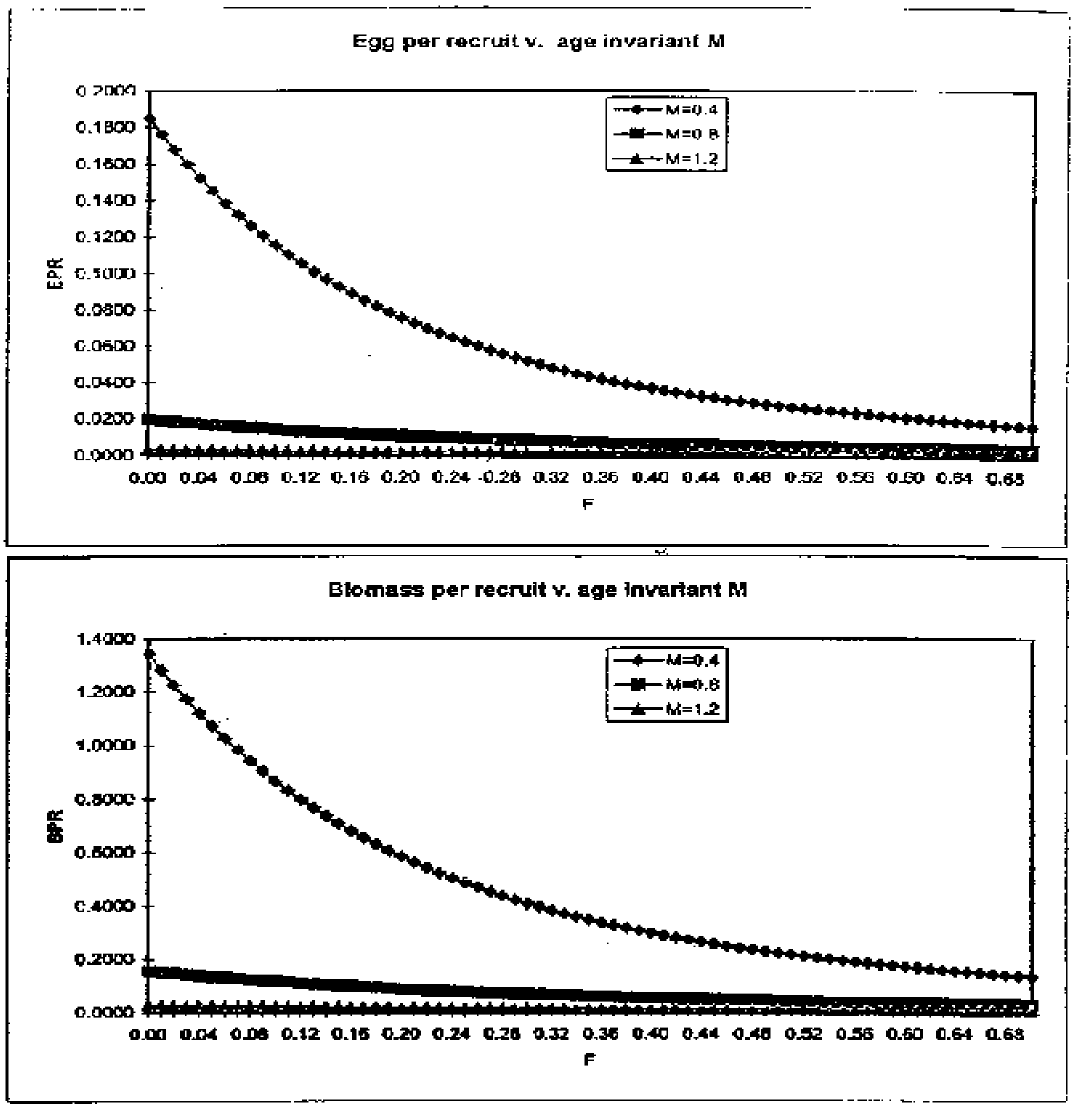
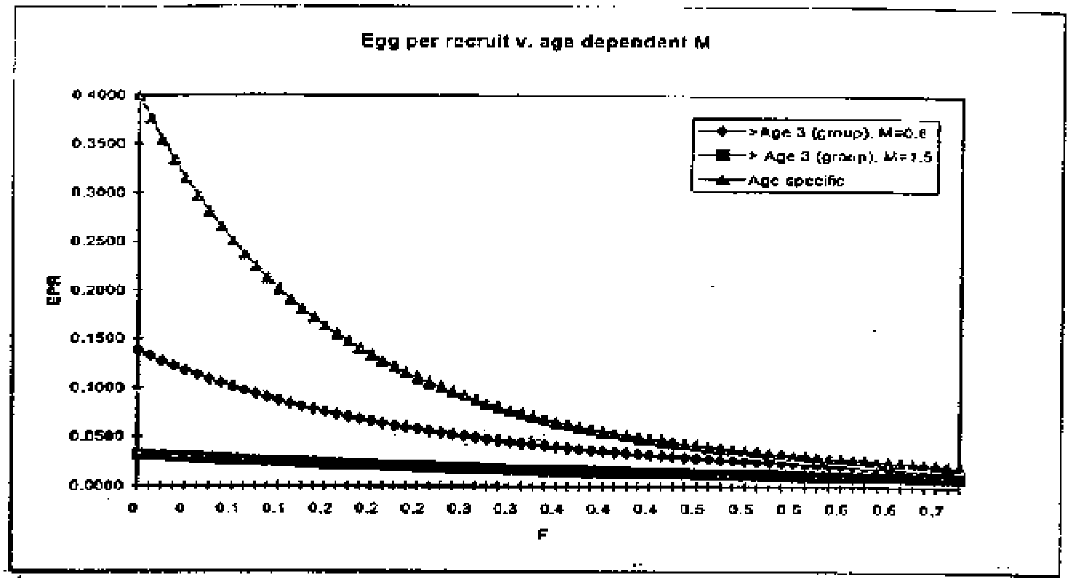


Figure 12. Comparison of model results of EPR and BPR run using age dependent M (See Table 3).



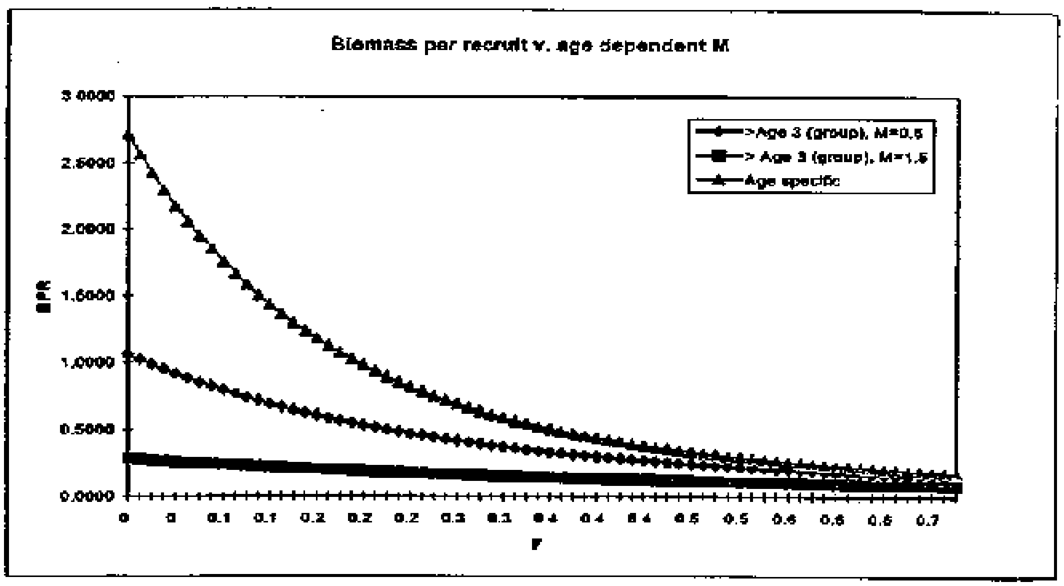


Figure 13. Comparison of observed fishing mortality rates v. selected overfishing rates.

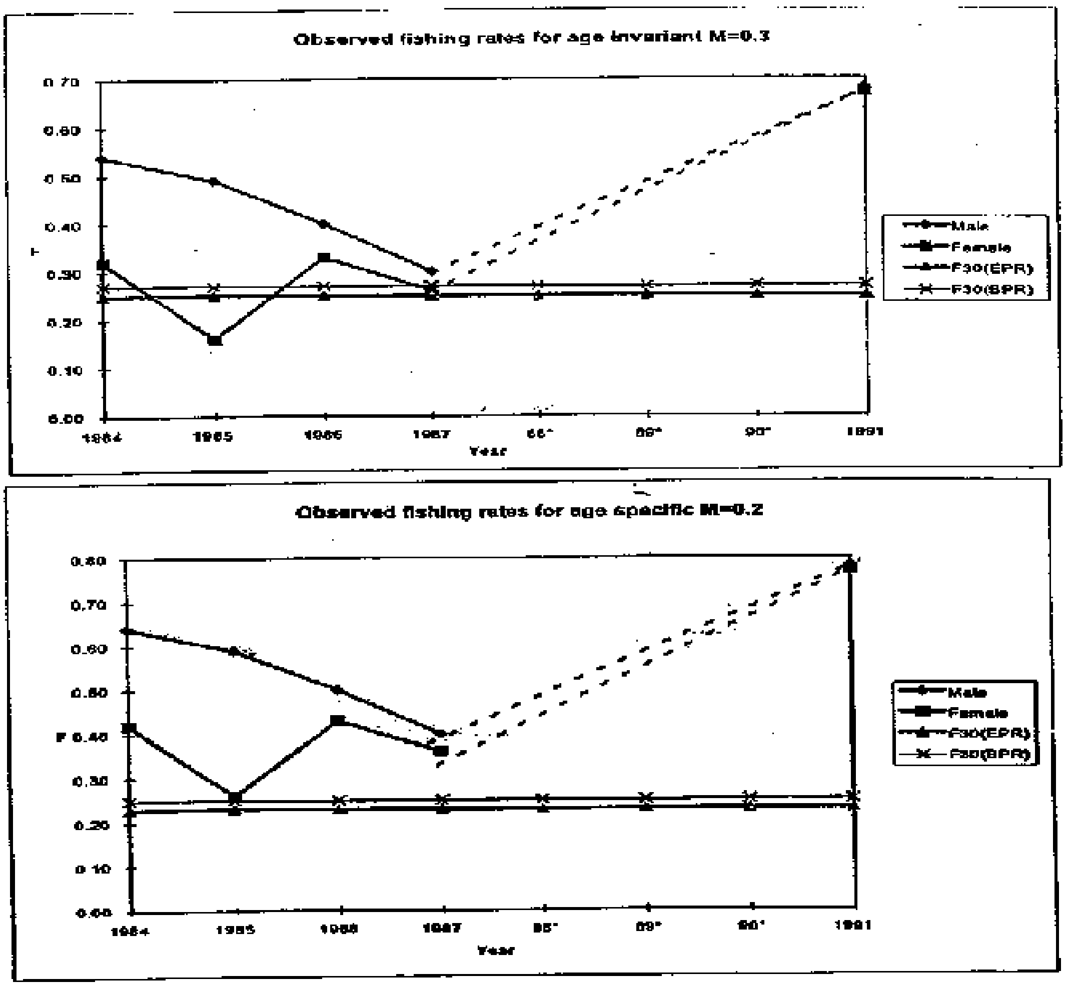


Table 1. Age structure, mean age and adjusted age of American shad collected in the spawning stock survey in the Hudson River Estuary.

	Observed age structure								Adjusted age structure							
	Year															
Age	84	85	86	87	88	89	90	91	84	85	86	87	88	89	90	91
Female																
3		1						1								1
4	1	10	17	13				10	2	13	29	23				14
5	7	16	56	61				31	14	33	72	103				172
6	15	27	65	46				34	167	55	135	59				32
7	14	17	26	25				14	82	109	53	52				21
8	8	11	17	20				3	50	65	189	41				8
9	5	5	10	14				1	18	31	59	156				2
10	3	4	2	6				1	18	14	13	35				2
11	1	3	4	1						18	14	6				
12				2								7				
13				1								6				
Total	54	94	197	188				95	351	416	564	475				252
Mean age	7.0	6.5	6.1	6.5				5.7	6.8	7.2	7.1	7.7				5.4
Mean Repeat spawn	1.9	1.5	1.1	0.9				0.5								
% virgin	0.31	0.34	0.53	0.55				0.72								
%repeat	0.69	0.66	0.47	0.45				0.28								
Male																
3	3	13	9	5				12	4	22	16	13				12
4	18	64	77	51				46	38	69	131	89				63
5	23	53	72	59				33	47	110	92	100				183
6	22	24	39	31				16	244	49	81	40				15
7	9	12	15	17				4	53	133	31	36				6
8	7	8	6	6				1	44	47	67	12				3
9	1	2	3	5					4	13	18	67				0
10	1	1		2					6	4	0	12				0
11			1	2							4	13				
12																
13																
Total	84	157	222	179				112	439	447	438	381				282
Mean age	5.5	5.0	5.0	5.4				4.6	6.1	5.9	5.6	6.1				4.8
Mean Repeat spawn	1.1	0.8	0.7	1.0				0.3								
% virgin	0.45	0.59	0.61	0.55				0.79								
%repeat	0.55	0.41	0.39	0.45				0.21								

Table 2. Estimates of total instantaneous mortality (Z) and annual survival of American shad collected in the spawning stock survey in the Hudson River Estuary.

	Catch curve - age					Catch curve-Spawning marks				
Year	Ages	Z	SE	R^2	S	Spawning Marks	Z	SE	R^2	S
Spawning Stock - Males										
1985	5-10	0.79	0.06	0.98	0.45	1-5	0.62	0.05	0.97	0.54
1986	4-9	0.70	0.07	0.96	0.50	1-4	0.49	0.14	0.86	0.61
1987	5-11	0.60	0.05	0.96	0.55	1-6	0.56	0.06	0.95	0.57
avg:85-87		0.70					0.56			
1991	4-8	0.98	0.14	0.94	0.38	1-4	0.99	0.25	0.88	0.37
Spawning Stock - Females										
1985	6-11	0.46	0.04	0.97	0.63	1-5	0.36	0.09	0.83	0.70
1986	6-11	0.63	0.12	0.86	0.53	1-7	0.63	0.10	0.89	0.53
1987	5-13	0.56	0.06	0.92	0.57	1-7	0.51	0.06	0.92	0.60
avg:85-87		0.55					0.50			
1991	6-10	0.97	0.15	0.93	0.38	1-5	0.74	0.10	0.94	0.48
Spawning stock - all										
1985	5-11	0.55	0.03	0.98	0.58	1-5	0.47	0.08	0.92	0.63
1986	6-11	0.67	0.10	0.89	0.51	1-7	0.79	0.10	0.91	0.45
1987	5-13	0.61	0.03	0.99	0.54	1-7	0.59	0.04	0.98	0.55
avg:85-87		0.61					0.62			
1991	6-10	0.98	0.11	0.95	0.38	1-5	0.87	0.52	0.98	0.42

Table 3. Inputs to the yield model for Hudson River American shad

M - Natural mortality	age invariant (constant), range of:	0.2-1.4
	age specific	table below
	age groups ages 1-3	0.3
	ages >3	0.6 and 1.5
F - Fishing mortality	range of:	0.0-0.7

				Gompertz Growth Function (b)		
				WO 3.77588		
				G 0.24223		
				g -1.55407		
				3		
Age	Natural Mortality M(a)	Maturity (a)	Fecundity (c)	kg	lbs	Vulnerability to Fishery (b)
1	0.885	0.000		0.371	0.818	0.000
2	0.474	0.000		0.726	1.601	0.000
3	0.348	0.007	95491	1.126	2.484	0.141
4	0.287	0.165	157637	1.527	3.368	0.173
5	0.252	0.708	219783	1.901	4.193	0.401
6	0.230	0.970	281929	2.234	4.927	0.700
7	0.216	1.000	344075	2.522	5.560	0.865
8	0.205	1.000	406221	2.763	6.093	0.952
9	0.198	1.000	468367	2.964	6.535	1.000
10	0.192	1.000	530513	3.127	6.896	1.000
11	0.188	1.000	592650	3.260	7.188	1.000
12	0.185	1.000	654805	3.367	7.424	1.000
Average M for age 1-12	0.296					

(a) estimated using Boudreau and Dickie 1989, Dickie et al. 1987
(b) estimated from observed Hudson River data
(c) Lehman 1953

Table 4. Sensitivity of F_{30} to changes in M, based on Egg (EPR) or Biomass (BPR) per recruit.

Type of model run	M	F30 EPR	F30 BPR
Age invariant			
	0.2	0.22	0.24
	0.3	0.25	0.27
	0.4	0.28	0.30
	0.6	0.35	0.38
	0.8	0.42	0.45
	1.0	0.49	0.53
	1.2	0.57	0.60
	1.4	0.65	0.69
Age specific	(See Table1)	0.23	0.25
Age groups			
Ages 1-3	0.3	0.35	0.38
Ages >3	0.6		
Ages 1-3	0.3	0.65	0.68
Ages >3	1.5		

Appendix A

Fishery Restrictions for American shad in New York waters

Commercial Harvest:

Hudson River Estuary*: G. Washington Bridge north to Troy Dam (Rivermile 12-152)

- season: 15 March through 15 June
- 36 hour escapement period
- net size restriction: limit of 1200 ft ; mesh size restriction: mesh > than 5 in stretch mesh)
- net deployment restrictions (distance between fishing gear > 1500 ft)
- area restrictions (drifted gears allowed in certain portions of the river)
- area closures (no fishing in a portion of the spawning area)

Marine Waters: G. Washington Bridge south, including waters around Long Island

- none

Delaware River: NY portion, north of Port Jervis

- no commercial fishery exists in this portion; no rules prohibiting it

Recreational Harvest:

- statewide for Inland waters: bag limit of 6 fish per day
- NO season

Appendix B

Hudson River American shad data tables

Table B1. Historic commercial fishery landings of American shad in the Hudson River Estuary.

1915-1949: Talbot, G.A. Factors associated with fluctuations in abundance
of Hudson River Shad. Fish. Bull. 101(58):373-413. (data from USFWS)
1950-1993: annual report from NMFS
1994-present: NY landings: NYSDEC State reports & NJ landings from NMFS

Year	Total	Year	Total	Year	Total
1880	2734000	1931	414611	1982	452200
1881		1932	529754	1983	520800
1882		1933	518850	1984	678300
1883		1934	438000	1985	627264
1884		1935	847400	1986	849168
1885		1936	2487900	1987	682182
1886		1937	2732200	1988	706132
1887	3588000	1938	2467000	1989	483300
1888	3448000	1939	3270700	1990	449338
1889	4332000	1940	3114400	1991	345328
1890	3777000	1941	3133500	1992	284564
1891	3045000	1942	3185900	1993	142898
1892		1943	3225350	1994	157872
1893		1944	3809400	1995	190607
1894		1945	3477200	1996	135829
1895		1946	2972143		
1896		1947	1981792	1996 =PRELIMINARY	
1897		1948	2354400		
1898		1949	1727370		
1899		1950	1008900		
1900		1951	764100		
1901	1884000	1952	1362800		
1902		1953	964900		
1903		1954	1371400		
1904	3432000	1955	1621600		
1905		1956	1805100		
1906		1957	1655500		
1907		1958	1256800		
1908	498000	1959	1050900		
1909		1960	887200		
1910		1961	628200		
1911		1962	552000		
1912		1963	414400		
1913		1964	244700		
1914		1965	251000		
1915	68668	1966	129000		
1916	40173	1967	213900		
1917	43384	1968	267000		
1918	234602	1969	256800		
1919	374974	1970	241400		
1920	199844	1971	173900		
1921	130803	1972	311800		
1922	175186	1973	255000		
1923	121728	1974	231900		
1924	94369	1975	233600		
1925	124334	1976	214900		
1926	265420	1977	185400		
1927	358065	1978	419400		
1928	246231	1979	498200		
1929	196745	1980	1420800		
1930	208504	1981	673600		

Table B2. Number of shad licenses and amount (ft) of licensed gillnet sold for the Hudson River, 1976-1996.

Year	Number of shad licenses sold	Amount of gill net licensed (ft)
1976	74	121700
1977	94	138300
1978	43	65350
1979	98	160933
1980	117	238479
1981	109	219840
1982	143	270740
1983	142	272990
1984	175	389960
1985	150	316800
1986	112	214120
1987	101	179000
1988	94	189400
1989	91	180280
1990	96	232200
1991	79	166290
1992	74	166988
1993	55	149150
1994	49	161900
1995	47	146695
1996	54	111000

Table B3. Annual summary of observed catch-per-unit-effort of American shad in the commercial gill fishery in the Hudson River Estuary.

Males Year	Total number of trips	Annual weekly c/f - FIXED GEAR Week of Year 13	14	15	16	17	18	19	20	21	22	23	SUM
1980	26			1.20	2.17	0.47	0.13	0.07	0.14	0.10			4.28
1981	24		0.64	3.62	0.87	0.56	0.07	0.08	0.47	0.06			6.16
1982	37		-	0.26	1.45	0.85	0.41		0.07				3.03
1983	38			1.79	0.46	2.21	0.59	0.48					5.66
1984	57		0.00	0.00	0.24	1.40	1.64	0.08	0.06				3.43
1985	54		2.14	5.35	1.44	0.77		0.17	0.79				10.66
1986	49	8.88	5.30	7.37	1.73	0.41	0.05	0.57	0.23				24.53
1987	49		4.62	3.98	3.24	0.56	0.27	0.33					13.00
1988	38		3.23	8.14	4.11	2.57	0.80	0.55					19.41
1989*	30		1.05	1.25	3.39	2.61	1.10						9.30
1990	23		1.37	1.50	0.26	0.40							3.63
1991	22		0.90	0.77	0.50	0.06	0.09						2.33
1992	33		0.13	0.41	0.27	0.39	0.12						1.31
1993*	8				0.73	0.18							0.92
1994*	9				0.65	0.13	0.07						0.86
1995*	10			0.61	0.66	0.13							1.40
1996*	19			0.38	1.02	0.58	0.18	0.15					2.18
1997	26			0.20	0.31	0.30	0.10						0.91

Females Year	Total number of trips	Annual weekly c/f - FIXED GEAR Week of Year 13	14	15	16	17	18	19	20	21	22	23	SUM
1980	26			3.38	8.90	4.28	1.27	0.35	0.83				19.11
1981	24		0.62	3.56	2.09	6.45	0.99	1.03	0.71				14.46
1982	37			0.41	2.04	2.37	3.04		0.16				8.01
1983	36			1.18	0.81	2.67	1.93	2.57					9.16
1984	57		0.00	0.02	0.52	3.19	4.65	0.72	0.19				9.49
1985	54		2.28	6.91	4.82	6.39		1.22	4.87	0.06			26.65
1986	49	7.62	7.63	8.63	7.63	7.66	2.56	8.50	1.61				52.09
1987	49		11.81	8.90	14.97	5.91	3.92	3.83					47.33
1988	38		3.74	11.59	6.77	16.36	5.77	3.99					42.20
1989*	30		0.83	1.39	7.61	11.84	12.22						33.79
1990	23		2.68	4.56	3.98	4.89							16.62
1991	22		6.66	4.14	4.61	1.53	1.17						18.31
1992	33		1.10	2.76	2.69	6.59	1.50						14.60
1993*	6				8.55	4.47							13.02
1994*	9				10.66	3.88	9.04	0.84					24.35
1995*	10			4.85	4.19	2.36							11.40
1996*	19			2.19	5.21	5.38	4.43	3.04					20.26
1997	26			1.99	2.43	1.91	0.78						7.10

a. Yd^2 x Hr x 10^-3
b. Catch per unit effort
* Total catch and c/f are sample size

Table B4. Mean fork length and weight of American shad collected in the Hudson River Estuary.

	Commercial fishery						Spawning stock					
	Fork length (mm)			Weight (g)			Fork length (mm)			Weight (g)		
Year	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
MALES												
1980	109	454.6	24.0	110	1672.6	266.0						
1981	225	455.3	23.4	225	1517.8	234.4						
1982	165	472.3	20.4	172	1778.3	296.7						
1983	153	474.8	30.0	152	1754.7	345.1	20	461.9	29.4	20	1493.0	290.4
1984	139	470.2	33.1	139	1631.9	408.2	87	452.7	40.5	86	1429.7	250.1
1985	117	473.6	28.3	115	1835.8	335.6	184	435.1	43.0	167	1179.3	430.2
1986	154	479.7	30.6	153	1919.0	413.4	416	435.2	41.2	353	1299.1	366.7
1987	71	498.4	25.2	71	2124.5	332.5	279	442.5	41.4	278	1286.9	366.4
1988	110	476.2	24.2	148	1908.2	365.0	227	446.1	34.8	219	1379.6	369.6
1989	132	496.2	24.9	174	2042.5	373.7	162	440.4	44.3	162	1245.9	410.6
1990	40	480.8	37.3	40	1909.3	492.1	39	424.1	43.1	36	1047.1	367.6
1991	29	486.4	35.5	27	1792.2	402.0	119	405.6	32.3	117	894.8	221.6
1992	143	457.3	35.0	136	1458.6	365.9	591	403.9	26.4	548	884.0	235.6
1993	35	460.7	27.4	35	1601.1	296.3	320	405.7	24.3	316	799.0	188.2
1994	15	457.7	17.4	8	1572.5	213.5	93	402.9	27.1	87	890.1	202.7
1995	113	456.3	20.0	78	1670.6	188.0	287	413.7	31.1	280	889.0	249.1
1996	63	480.4	20.8	63.0	1627.4	274.8	295	403.8	32.6	252	890.8	436.5
FEMALES												
1980	271	496.1	23.3	272	2101.5	337.6						
1981	579	493.5	26.9	578	2088.4	396.7						
1982	414	505.9	30.1	420	2307.4	454.1						
1983	307	502.2	33.8	366	2300.1	506.1						
1984	452	511.5	32.1	411	2507.0	513.9	61	520.3	35.4	51	2361.4	541.0
1985	474	508.1	36.3	473	2489.2	598.0	105	511.1	41.7	78	2024.6	629.1
1986	478	519.9	34.2	476	2635.2	572.0	287	504.2	39.5	277	2040.1	542.4
1987	470	520.5	35.2	469	2647.4	650.7	283	505.5	40.7	277	1946.4	564.0
1988	254	515.0	36.3	253	2571.2	575.0	316	505.4	38.1	308	2008.4	525.0
1989	332	512.4	28.6	300	2502.6	458.7	188	500.3	36.2	187	1891.2	541.6
1990	223	515.9	36.7	223	2530.7	552.6	48	498.5	40.8	48	1850.7	440.6
1991	223	501.6	34.3	220	2265.6	459.4	101	471.8	35.1	100	1483.1	335.3
1992	364	483.2	29.7	361	1857.1	402.4	445	482.5	30.4	438	1429.7	320.1
1993	73	480.4	31.2	73	1962.5	336.9	144	453.8	27.3	139	1173.8	261.0
1994	114	478.3	24.4	104	1798.5	307.2	89	451.6	23.6	83	1244.0	240.3
1995	149	480.2	28.0	107	1999.9	275.8	460	464.0	23.4	451	1476.2	308.7
1996	366	478.4	26.1	355	1959.2	347.5	131	468.4	37.4	126	1547.1	605.3
ALL FISH												
1980	380	477.1	27.6	342	1940.1	398.5						
1981	804	489.7	30.1	804	1920.9	446.1						
1982	579	496.3	33.2	592	2153.6	476.9						
1983	549	493.8	35.6	546	2140.8	526.9	20	461.9	29.8	20	1493.0	290.4
1984	551	501.2	37.0	569	2295.3	579.6	148	480.6	52.1	146	1816.6	632.3
1985	592	501.2	37.4	589	2308.8	613.4	290	482.7	56.1	225	1468.8	645.7
1986	641	509.5	37.8	637	2451.9	631.1	703	469.3	52.9	670	1605.6	685.1
1987	541	522.8	35.4	540	2570.8	655.8	564	474.1	51.7	555	1615.4	560.8
1988	372	502.7	37.5	371	2300.6	602.3	543	480.6	45.8	528	1742.7	562.1
1989	525	502.4	30.0	475	2331.2	482.3	371	472.8	49.3	370	1501.9	471.4
1990	263	510.5	30.8	263	2496.2	617.3	88	450.0	52.7	88	1388.5	512.8
1991	252	499.3	34.4	247	2213.9	484.8	225	435.6	46.2	222	1164.6	402.7
1992	509	473.8	34.0	501	1818.2	464.5	1437	422.1	38.8	1288	1070.5	387.2
1993	108	480.6	33.0	108	1845.4	403.4	467	418.4	34.2	460	813.9	273.7
1994	129	476.7	24.6	112	1782.3	308.3	184	428.5	34.8	172	1064.2	287.5
1995	287	480.9	23.7	185	1857.1	288.8	762	444.8	38.1	748	1270.2	388.0
1996	418	475.4	28.1	416	1903.2	357.6	431	423.6	45.3	423	1084.8	547.4

Table B5. Young of the year indices of Hudson River American shad.

Year	Number of hauls	YOY* Number	Geometric Mean	SD	SE	Zero hauls	PYSL** Utilities (density)
1974							0.17
1975							0.28
1976							0.16
1977							0.17
1978							0.09
1979							0.49
1980	20	1071	23.9	2.6	0.34	0	0.48
1981	21	1098	19.1	4.5	0.45	3	0.78
1982	23	583	12.2	3.3	0.35	3	0.59
1983	133	5289	18.2	2.8	0.12	4	0.57
1984	124	2039	7.8	2.5	0.12	13	0.36
1985	177	10578	26.5	3.0	0.11	10	0.67
1986	186	14321	46.3	2.2	0.09	4	1.05
1987	95	3622	20.2	2.5	0.14	7	0.16
1988	192	14099	27.6	3.6	0.12	10	0.73
1989	212	19601	47.3	2.4	0.09	3	1.04
1990	202	16501	41.2	2.5	0.09	7	1.17
1991	240	15051	24.1	3.8	0.11	17	0.32
1992	245	18408	35.2	3.2	0.10	14	0.62
1993	205	5107	11.6	2.8	0.10	21	0.23
1994	217	9363	26.1	2.0	0.08	1	0.37
1995	238	3884	6.7	3.1	0.10	56	0.20
1996***	189	14594	30.9	2.8		9	0.26

* YOY = geometric mean: number per haul, weeks 26-42.
** PYSL = density: number per 1000^3
*** 1996 estimates are PRELIMINARY

Table B6. Weight at age for Hudson River American shad estimated using Gompertz Growth Function.

females		(WO*(EXP(G*(1-(EXP(-sg*t))))))			males			
		0.2144	WO				0.1587	WO
		2.647	G				2.912	G
		0.2868	sg				0.2552	sg
AGE	observed g	observed kg	predicted kg	predicted lbs	observed g	observed kg	predicted kg	predicted lbs
0								
1			0.44	0.96			0.31	0.67
2			0.74	1.64			0.51	1.12
3	1023	1.02	1.11	2.44	742	0.74	0.75	1.66
4	1621	1.62	1.50	3.30	1011	1.01	1.02	2.25
5	1903	1.90	1.87	4.13	1341	1.34	1.29	2.86
6	2180	2.18	2.22	4.90	1593	1.59	1.55	3.43
7	2491	2.49	2.52	5.56	1789	1.79	1.79	3.95
8	2718	2.72	2.77	6.12	2010	2.01	2.00	4.41
9	2997	3.00	2.98	6.57	2148	2.15	2.18	4.80
10	3166	3.17	3.14	6.93	2259	2.26	2.33	5.13
11	3328	3.33	3.27	7.22	2516	2.52	2.45	5.40
12	3335	3.34	3.37	7.44			2.55	5.62
13	3420	3.42	3.45	7.61			2.63	5.79

Table B7a. Results of yield model runs with various inputs of M.

	M varies by age groups (Grecco 1997)				Age specific M		Constant Natural Mortality			
	3	0.3		0.3			0.2		0.3	
	>4	0.6		1.5						
F30	0.35	0.38	0.65	0.85	0.23	0.25	0.22	0.24	0.25	0.27
30%	0.04154	0.31911	0.00967	0.06533	0.11994	0.814128	0.21722	1.47265	0.10718	0.76398
	EPR		EPR		EPR					
F	>Age 3 for BPR		> Age 3 for BPR		Age specif BPR		EPR	BPR	EPR	BPR
0	0.1385	1.0627	0.0327	0.2844	0.3688	2.7136	0.7241	4.9068	0.3573	2.5103
0.01	0.1329	1.0240	0.0320	0.2786	0.3763	2.5648	0.6816	4.6383	0.3382	2.3850
0.02	0.1277	0.9862	0.0313	0.2728	0.3565	2.4254	0.6416	4.3852	0.3203	2.2672
0.03	0.1227	0.9502	0.0307	0.2673	0.3341	2.2960	0.6047	4.1464	0.3035	2.1564
0.04	0.1180	0.9158	0.0300	0.2618	0.3150	2.1729	0.5702	3.9267	0.2877	2.0522
0.05	0.1135	0.8830	0.0294	0.2565	0.2973	2.0585	0.5379	3.7169	0.2730	1.9540
0.06	0.1092	0.8516	0.0288	0.2514	0.2807	1.9513	0.5078	3.5242	0.2591	1.8615
0.07	0.1051	0.8217	0.0282	0.2464	0.2651	1.8509	0.4796	3.3416	0.2461	1.7744
0.08	0.1012	0.7931	0.0276	0.2415	0.2506	1.7564	0.4533	3.1703	0.2339	1.6922
0.09	0.0974	0.7657	0.0270	0.2367	0.2371	1.6679	0.4286	3.0095	0.2224	1.6147
0.1	0.0939	0.7395	0.0265	0.2320	0.2244	1.5847	0.4055	2.8585	0.2116	1.5415
0.11	0.0905	0.7145	0.0260	0.2275	0.2125	1.5066	0.3840	2.7166	0.2014	1.4724
0.12	0.0873	0.6905	0.0254	0.2231	0.2013	1.4331	0.3637	2.5832	0.1918	1.4071
0.13	0.0842	0.6676	0.0249	0.2188	0.1909	1.3640	0.3448	2.4577	0.1827	1.3454
0.14	0.0812	0.6456	0.0244	0.2146	0.1811	1.2989	0.3270	2.3396	0.1742	1.2870
0.15	0.0784	0.6245	0.0239	0.2104	0.1719	1.2377	0.3103	2.2284	0.1662	1.2317
0.16	0.0757	0.6043	0.0234	0.2064	0.1633	1.1800	0.2946	2.1236	0.1586	1.1794
0.17	0.0731	0.5850	0.0230	0.2025	0.1552	1.1255	0.2799	2.0248	0.1514	1.1298
0.18	0.0707	0.5664	0.0225	0.1987	0.1476	1.0742	0.2660	1.9317	0.1447	1.0829
0.19	0.0683	0.5486	0.0221	0.1950	0.1404	1.0258	0.2530	1.8438	0.1383	1.0383
0.2	0.0660	0.5315	0.0216	0.1913	0.1337	0.9801	0.2408	1.7608	0.1322	0.9961
0.21	0.0639	0.5151	0.0212	0.1878	0.1273	0.9369	0.2293	1.6825	0.1265	0.9560
0.22	0.0618	0.4993	0.0208	0.1843	0.1213	0.8961	0.2184	1.6084	0.1211	0.9180
0.23	0.0598	0.4841	0.0204	0.1809	0.1157	0.8576	0.2082	1.5384	0.1160	0.8818
0.24	0.0579	0.4695	0.0200	0.1776	0.1104	0.8210	0.1986	1.4722	0.1111	0.8474
0.25	0.0561	0.4555	0.0197	0.1744	0.1054	0.7864	0.1895	1.4095	0.1065	0.8146
0.26	0.0543	0.4420	0.0193	0.1712	0.1007	0.7536	0.1809	1.3502	0.1022	0.7837
0.27	0.0526	0.4291	0.0189	0.1681	0.0962	0.7226	0.1728	1.2940	0.0980	0.7541
0.28	0.0510	0.4166	0.0186	0.1651	0.0920	0.6932	0.1651	1.2407	0.0941	0.7259
0.29	0.0494	0.4046	0.0182	0.1622	0.0880	0.6653	0.1579	1.1901	0.0904	0.6991
0.3	0.0479	0.3930	0.0179	0.1593	0.0842	0.6388	0.1511	1.1422	0.0868	0.6735
0.31	0.0465	0.3818	0.0176	0.1565	0.0806	0.6137	0.1446	1.0967	0.0835	0.6491
0.32	0.0451	0.3711	0.0172	0.1537	0.0773	0.5898	0.1385	1.0534	0.0803	0.6258
0.33	0.0438	0.3607	0.0169	0.1510	0.0741	0.5671	0.1327	1.0123	0.0772	0.6036
0.34	0.0425	0.3506	0.0166	0.1484	0.0710	0.5455	0.1272	0.9733	0.0743	0.5824
0.35	0.0413	0.3411	0.0163	0.1458	0.0682	0.5250	0.1220	0.9362	0.0716	0.5622
0.36	0.0401	0.3318	0.0160	0.1433	0.0654	0.5054	0.1170	0.9009	0.0689	0.5428
0.37	0.0389	0.3229	0.0157	0.1409	0.0628	0.4869	0.1123	0.8672	0.0664	0.5244
0.38	0.0378	0.3142	0.0155	0.1385	0.0604	0.4691	0.1079	0.8351	0.0640	0.5067
0.39	0.0368	0.3058	0.0152	0.1361	0.0580	0.4522	0.1036	0.8046	0.0617	0.4898
0.4	0.0357	0.2978	0.0149	0.1338	0.0558	0.4361	0.0996	0.7755	0.0595	0.4736
0.41	0.0347	0.2900	0.0147	0.1316	0.0537	0.4207	0.0958	0.7477	0.0575	0.4581
0.42	0.0338	0.2824	0.0144	0.1293	0.0517	0.4060	0.0922	0.7213	0.0555	0.4432
0.43	0.0329	0.2752	0.0141	0.1272	0.0498	0.3920	0.0887	0.6960	0.0536	0.4290
0.44	0.0320	0.2681	0.0139	0.1251	0.0479	0.3786	0.0854	0.6719	0.0518	0.4153
0.45	0.0311	0.2613	0.0137	0.1230	0.0462	0.3658	0.0823	0.6488	0.0500	0.4022
0.46	0.0303	0.2547	0.0134	0.1210	0.0446	0.3536	0.0793	0.6267	0.0484	0.3897
0.47	0.0295	0.2483	0.0132	0.1190	0.0430	0.3419	0.0764	0.6056	0.0468	0.3777
0.48	0.0287	0.2422	0.0130	0.1171	0.0415	0.3307	0.0737	0.5855	0.0452	0.3661
0.49	0.0280	0.2362	0.0128	0.1152	0.0400	0.3199	0.0711	0.5662	0.0438	0.3550
0.5	0.0273	0.2304	0.0125	0.1133	0.0386	0.3097	0.0686	0.5477	0.0424	0.3443
0.51	0.0266	0.2248	0.0123	0.1115	0.0373	0.2998	0.0663	0.5300	0.0410	0.3341
0.52	0.0259	0.2194	0.0121	0.1097	0.0361	0.2904	0.0640	0.5130	0.0397	0.3242
0.53	0.0252	0.2142	0.0119	0.1079	0.0349	0.2813	0.0618	0.4968	0.0385	0.3147
0.54	0.0246	0.2091	0.0117	0.1062	0.0337	0.2727	0.0598	0.4812	0.0373	0.3056
0.55	0.0240	0.2041	0.0115	0.1045	0.0326	0.2643	0.0578	0.4662	0.0362	0.2968
0.56	0.0234	0.1993	0.0113	0.1029	0.0316	0.2564	0.0559	0.4519	0.0351	0.2884
0.57	0.0228	0.1947	0.0112	0.1013	0.0306	0.2487	0.0541	0.4381	0.0344	0.2802
0.58	0.0223	0.1902	0.0110	0.0997	0.0296	0.2413	0.0523	0.4249	0.0334	0.2724
0.59	0.0217	0.1858	0.0108	0.0982	0.0287	0.2342	0.0507	0.4122	0.0321	0.2649
0.6	0.0212	0.1816	0.0106	0.0966	0.0278	0.2274	0.0491	0.4000	0.0311	0.2578
0.61	0.0207	0.1775	0.0105	0.0951	0.0269	0.2208	0.0476	0.3882	0.0302	0.2506
0.62	0.0202	0.1735	0.0103	0.0937	0.0261	0.2145	0.0461	0.3769	0.0294	0.2438
0.63	0.0197	0.1696	0.0101	0.0923	0.0253	0.2085	0.0448	0.3661	0.0285	0.2373
0.64	0.0193	0.1659	0.0100	0.0909	0.0246	0.2026	0.0433	0.3556	0.0277	0.2310
0.65	0.0188	0.1622	0.0098	0.0895	0.0238	0.1970	0.0420	0.3455	0.0269	0.2249
0.66	0.0184	0.1587	0.0097	0.0881	0.0231	0.1916	0.0407	0.3358	0.0262	0.2190
0.67	0.0180	0.1552	0.0095	0.0868	0.0225	0.1863	0.0395	0.3265	0.0255	0.2133
0.68	0.0176	0.1519	0.0094	0.0855	0.0218	0.1813	0.0384	0.3175	0.0248	0.2078
0.69	0.0172	0.1486	0.0092	0.0842	0.0212	0.1764	0.0373	0.3088	0.0241	0.2025
0.7	0.0168	0.1454	0.0091	0.0830	0.0206	0.1716	0.0362	0.3005	0.0235	0.1974

Table B7b.

	0.4		0.6		0.8		1		1.2		1.4	
F30	0.28	0.3	0.35	0.38	0.42	0.45	0.49	0.53	0.57	0.6	0.65	0.69
30%	0.05940	0.40315	0.0189	0.12995	0.0059	0.0479	0.00297	0.0188	0.00094	0.00790	0.00041	0.00366
F	EPR	BPR	EPR	BPR	EPR	BPR	EPR	BPR	EPR	BPR	EPR	BPR
0	0.1850	1.3430	0.0563	0.4335	0.0197	0.1577	0.0076	0.0627	0.0031	0.0266	0.0014	0.0119
0.01	0.1780	1.2832	0.0541	0.4170	0.0190	0.1527	0.0074	0.0610	0.0031	0.0260	0.0013	0.0116
0.02	0.1678	1.2269	0.0520	0.4016	0.0184	0.1480	0.0071	0.0593	0.0030	0.0253	0.0013	0.0114
0.03	0.1596	1.1717	0.0499	0.3870	0.0178	0.1434	0.0069	0.0574	0.0029	0.0248	0.0013	0.0111
0.04	0.1521	1.1205	0.0480	0.3730	0.0172	0.1390	0.0067	0.0562	0.0028	0.0242	0.0013	0.0109
0.05	0.1451	1.0720	0.0462	0.3596	0.0166	0.1348	0.0066	0.0548	0.0028	0.0236	0.0012	0.0107
0.06	0.1384	1.0261	0.0444	0.3469	0.0161	0.1308	0.0064	0.0533	0.0027	0.0231	0.0012	0.0105
0.07	0.1321	0.9827	0.0428	0.3347	0.0156	0.1269	0.0062	0.0520	0.0026	0.0226	0.0012	0.0103
0.08	0.1262	0.9415	0.0412	0.3231	0.0151	0.1231	0.0060	0.0506	0.0026	0.0220	0.0011	0.0100
0.09	0.1206	0.9025	0.0397	0.3119	0.0146	0.1195	0.0059	0.0493	0.0025	0.0215	0.0011	0.0098
0.1	0.1153	0.8655	0.0382	0.3013	0.0142	0.1160	0.0057	0.0481	0.0024	0.0211	0.0011	0.0096
0.11	0.1103	0.8303	0.0368	0.2911	0.0138	0.1127	0.0056	0.0469	0.0024	0.0206	0.0011	0.0095
0.12	0.1055	0.7970	0.0355	0.2814	0.0133	0.1095	0.0054	0.0457	0.0023	0.0201	0.0011	0.0093
0.13	0.1010	0.7653	0.0343	0.2721	0.0129	0.1064	0.0053	0.0446	0.0023	0.0197	0.0010	0.0091
0.14	0.0967	0.7352	0.0331	0.2631	0.0126	0.1034	0.0051	0.0435	0.0022	0.0193	0.0010	0.0089
0.15	0.0927	0.7066	0.0319	0.2546	0.0122	0.1005	0.0050	0.0424	0.0022	0.0189	0.0010	0.0087
0.16	0.0889	0.6794	0.0308	0.2463	0.0118	0.0977	0.0049	0.0414	0.0021	0.0185	0.0010	0.0086
0.17	0.0852	0.6535	0.0298	0.2385	0.0115	0.0950	0.0048	0.0404	0.0021	0.0181	0.0010	0.0084
0.18	0.0818	0.6288	0.0288	0.2309	0.0112	0.0924	0.0046	0.0394	0.0020	0.0177	0.0009	0.0083
0.19	0.0785	0.6054	0.0278	0.2237	0.0108	0.0899	0.0045	0.0385	0.0020	0.0173	0.0009	0.0081
0.2	0.0754	0.5830	0.0269	0.2167	0.0105	0.0875	0.0044	0.0376	0.0019	0.0169	0.0009	0.0079
0.21	0.0725	0.5618	0.0260	0.2100	0.0102	0.0852	0.0043	0.0367	0.0019	0.0166	0.0009	0.0078
0.22	0.0697	0.5415	0.0252	0.2036	0.0100	0.0830	0.0042	0.0359	0.0019	0.0162	0.0009	0.0077
0.23	0.0670	0.5219	0.0244	0.1975	0.0097	0.0808	0.0041	0.0350	0.0018	0.0159	0.0008	0.0075
0.24	0.0644	0.5034	0.0236	0.1915	0.0094	0.0787	0.0040	0.0342	0.0018	0.0156	0.0008	0.0074
0.25	0.0620	0.4857	0.0228	0.1858	0.0092	0.0767	0.0039	0.0335	0.0017	0.0153	0.0008	0.0072
0.26	0.0597	0.4688	0.0221	0.1804	0.0089	0.0747	0.0038	0.0327	0.0017	0.0150	0.0008	0.0071
0.27	0.0575	0.4526	0.0214	0.1751	0.0087	0.0728	0.0037	0.0320	0.0017	0.0147	0.0008	0.0070
0.28	0.0554	0.4372	0.0208	0.1700	0.0084	0.0710	0.0036	0.0313	0.0016	0.0144	0.0008	0.0068
0.29	0.0534	0.4224	0.0201	0.1651	0.0082	0.0692	0.0035	0.0306	0.0016	0.0141	0.0008	0.0067
0.3	0.0515	0.4082	0.0195	0.1604	0.0080	0.0675	0.0035	0.0299	0.0016	0.0138	0.0007	0.0066
0.31	0.0497	0.3946	0.0190	0.1559	0.0078	0.0658	0.0034	0.0292	0.0016	0.0135	0.0007	0.0065
0.32	0.0480	0.3816	0.0184	0.1515	0.0076	0.0642	0.0033	0.0286	0.0015	0.0133	0.0007	0.0064
0.33	0.0463	0.3694	0.0179	0.1473	0.0074	0.0626	0.0032	0.0280	0.0015	0.0130	0.0007	0.0063
0.34	0.0447	0.3573	0.0173	0.1432	0.0072	0.0611	0.0032	0.0274	0.0014	0.0128	0.0007	0.0062
0.35	0.0432	0.3461	0.0168	0.1393	0.0070	0.0597	0.0031	0.0268	0.0014	0.0125	0.0007	0.0061
0.36	0.0417	0.3352	0.0163	0.1355	0.0068	0.0583	0.0030	0.0263	0.0014	0.0123	0.0007	0.0060
0.37	0.0403	0.3247	0.0159	0.1318	0.0067	0.0569	0.0030	0.0257	0.0014	0.0121	0.0006	0.0059
0.38	0.0390	0.3147	0.0154	0.1284	0.0065	0.0556	0.0029	0.0252	0.0013	0.0118	0.0006	0.0058
0.39	0.0377	0.3050	0.0150	0.1250	0.0064	0.0543	0.0028	0.0246	0.0013	0.0116	0.0006	0.0057
0.4	0.0365	0.2957	0.0146	0.1217	0.0062	0.0530	0.0028	0.0241	0.0013	0.0114	0.0006	0.0056
0.41	0.0353	0.2868	0.0142	0.1186	0.0061	0.0518	0.0027	0.0236	0.0013	0.0112	0.0006	0.0055
0.42	0.0342	0.2782	0.0138	0.1156	0.0059	0.0506	0.0026	0.0232	0.0012	0.0110	0.0006	0.0054
0.43	0.0331	0.2700	0.0134	0.1126	0.0058	0.0495	0.0026	0.0227	0.0012	0.0108	0.0006	0.0053
0.44	0.0321	0.2621	0.0131	0.1098	0.0056	0.0484	0.0025	0.0222	0.0012	0.0106	0.0006	0.0052
0.45	0.0311	0.2544	0.0127	0.1069	0.0055	0.0473	0.0025	0.0218	0.0012	0.0104	0.0006	0.0051
0.46	0.0302	0.2471	0.0124	0.1042	0.0054	0.0462	0.0024	0.0214	0.0011	0.0102	0.0005	0.0050
0.47	0.0292	0.2400	0.0120	0.1016	0.0052	0.0452	0.0024	0.0209	0.0011	0.0100	0.0005	0.0050
0.48	0.0284	0.2332	0.0117	0.0991	0.0051	0.0442	0.0023	0.0205	0.0011	0.0099	0.0005	0.0049
0.49	0.0275	0.2267	0.0114	0.0967	0.0050	0.0433	0.0023	0.0201	0.0011	0.0097	0.0005	0.0048
0.5	0.0267	0.2204	0.0111	0.0943	0.0049	0.0423	0.0022	0.0198	0.0011	0.0095	0.0005	0.0047
0.51	0.0259	0.2143	0.0109	0.0920	0.0048	0.0414	0.0022	0.0194	0.0010	0.0094	0.0005	0.0047
0.52	0.0252	0.2084	0.0106	0.0898	0.0047	0.0405	0.0022	0.0190	0.0010	0.0092	0.0005	0.0046
0.53	0.0244	0.2027	0.0103	0.0877	0.0046	0.0397	0.0021	0.0186	0.0010	0.0090	0.0005	0.0045
0.54	0.0237	0.1973	0.0101	0.0856	0.0045	0.0389	0.0021	0.0183	0.0010	0.0089	0.0005	0.0045
0.55	0.0231	0.1920	0.0098	0.0836	0.0044	0.0380	0.0020	0.0180	0.0010	0.0087	0.0005	0.0044
0.56	0.0224	0.1869	0.0096	0.0817	0.0043	0.0373	0.0020	0.0176	0.0010	0.0086	0.0005	0.0043
0.57	0.0218	0.1820	0.0093	0.0798	0.0042	0.0365	0.0019	0.0173	0.0009	0.0085	0.0005	0.0043
0.58	0.0212	0.1773	0.0091	0.0780	0.0041	0.0357	0.0019	0.0170	0.0009	0.0083	0.0005	0.0042
0.59	0.0206	0.1727	0.0089	0.0762	0.0040	0.0350	0.0019	0.0167	0.0009	0.0082	0.0004	0.0041
0.6	0.0201	0.1683	0.0087	0.0745	0.0039	0.0343	0.0018	0.0164	0.0009	0.0080	0.0004	0.0041
0.61	0.0195	0.1640	0.0085	0.0728	0.0038	0.0336	0.0018	0.0161	0.0009	0.0079	0.0004	0.0040
0.62	0.0190	0.1599	0.0083	0.0712	0.0038	0.0330	0.0018	0.0158	0.0009	0.0078	0.0004	0.0039
0.63	0.0185	0.1559	0.0081	0.0696	0.0037	0.0323	0.0017	0.0155	0.0008	0.0077	0.0004	0.0039
0.64	0.0180	0.1520	0.0079	0.0681	0.0036	0.0317	0.0017	0.0152	0.0008	0.0075	0.0004	0.0038
0.65	0.0175	0.1482	0.0077	0.0666	0.0035	0.0310	0.0017	0.0150	0.0008	0.0074	0.0004	0.0038
0.66	0.0171	0.1446	0.0076	0.0651	0.0035	0.0304	0.0016	0.0147	0.0008	0.0073	0.0004	0.0037
0.67	0.0167	0.1411	0.0074	0.0637	0.0034	0.0298	0.0016	0.0144	0.0008	0.0072	0.0004	0.0037
0.68	0.0162	0.1377	0.0072	0.0624	0.0033	0.0293	0.0016	0.0142	0.0008	0.0071	0.0004	0.0036
0.69	0.0158	0.1344	0.0070	0.0610	0.0033	0.0287	0.0016	0.0139	0.0008	0.0070	0.0004	0.0036
0.7	0.0154	0.1312	0.0068	0.0598	0.0032	0.0282	0.0015	0.0137	0.0008	0.0069	0.0004	0.0035

Appendix C

Formulae used in Yield Model Analyses of Hudson River American shad

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Yield per recruit (YPR) was calculated as follows:

$$YPR = \frac{\sum_{j=t}^{n} N_j \times \mu \times W_j}{R} \qquad (1)$$

Where:

YPR	= lifetime yield (lbs) per recruit
n	= Maximum age in the population (12)
t	= Age of first recruitment (age 3 for females)
N_j	= Number of individuals at the start of year j
W_j	= Mean weight (lbs) of individuals at the start of year j
u	= Exploitation rate
R	= Number of recruits at age one

Mortality was modeled using the negative exponential model:

$$N_{j+1} = N_j \times \exp(-F_j + M_j) \qquad (2)$$

Where:

N_{j+1}	= Number of fish alive at age j+1
N_j	= Number alive at age j
F_j	= Fishing mortality rate from j to j+1
M_j	= Natural mortality rate from j to j+1

Vulnerability to the fishery was age based, calculated from observed data obtained from monitoring of commercial fishing operations in the Hudson River (Deriso et al. 1996).

Natural mortality was considered age invariant and assigned a value of M = 0. 35 It was obtained from the formula from Hoenig (1973):

$$Log_e\, M = 1.46 - 1.01 * Log_e\,(T_{MAX}) \qquad (3)$$

Where:

M	= instantaneous rate of natural mortality
T_{MAX}	= maximum age of the fished stock (12)

Natural mortality at age was calculated from observed weight at age data for the Hudson using methods of Boudreau and Dickie 1989, Dickie 1987. Weight (in lbs) at age was converted to kcal by multiplying by 592.

$$M = 2.88 * (weight\text{-}kcal\ at\ age)\ \hat{}\ 0.33 \qquad (4)$$

The model was run at fishing rates (F_j) of zero to 0.7 in 0.02 increments

Exploitation was calculated as follows:

$$E_j = (F_j * A_j) / Z_j \qquad (5)$$

Where:
- E_j = Exploitation rate from j to j+1
- F_j = Fishing mortality rate from j to j+1
- A_j = Total mortality rate from j to j+1, calculated as 1-S, where S = exp(-Z_j), $Z_j = F_j + M_j$

Number harvested at age was converted to weight by multiplying numbers by weight at age. **Weight at age** was estimated using the Gompertz Growth function.

$$W_t = W_0 * exp\{G * [1-exp(-g*t)]\} \qquad (6)$$

Where:
- W_t = Weight at age t
- W_0 = Weight at time t_0
- G = Instantaneous growth rate at time t_0
- g = rate of decrease of G

Data for parameters estimates were calculated from observed length at age data collected by the Hudson River Fisheries Unit (unpublished).

Egg per recruit (EPR) was calculated as:

$$EPR = \left(\frac{\sum_{j=t}^{n} N_j \times P_j \times p_j \times G_j}{R} \right) \times 10^{-6} \qquad (7)$$

Where:	EPR	= Lifetime egg deposition per recruit
	n	= Maximum age in the population (12)
	t	= Age of first maturity in females
	N_j	= Number of females at age j
	P_j	= Proportion of females mature at age j
	Gj	= Mean fecundity of age j females
	R	= Number of recruits at age one

Biomass per recruit (BPR) was calculated as:

$$BPR = \left(\frac{\sum_{j=t}^{n} N_j \times P_j \times W_j \times G_j}{R} \right) \times 10^{-6} \qquad (8)$$

Where:	BPR	= Lifetime biomass of spawning stock per recruit
	n	= Maximum age in the population (12)
	t	= Age of first maturity in females
	N_j	= Number of females at age j
	P_j	= Proportion of females mature at age j
	W_j	= Mean weight (kg) of individuals at age
	R	= Number of recruits at age one

Maturity schedule for female American shad were calculated from observed age and repeat spawning data, to estimate proportion mature at age (Hudson River Fisheries Unit data, unpublished). Fecundity at age from Lehman (1953).